Abstracts

New Mexico Geological Society spring meeting

The New Mexico Geological Society annual spring meeting was held on April 5, 2002, at New Mexico Institute of Mining and Technology, Socorro. Following are the abstracts from all sessions given at that meeting.

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SESSION 1—GEOLOGY OF WASTE DISPOSAL

DEEP GEOLOGIC ISOLATION IN NEW MEXICO IN INTERNATIONAL PERSPECTIVE, by *Norbert T. Rempe*, norbert.rempe@wipp.carlsbad.nm.us, 1403 N. Country Club Circle, Carlsbad, NM 88220

The United States hosts the first fully licensed, operating deep geologic repository in salt for intermediate-level radioactive and mixed waste from defense programs: the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. But other countries contributed to the scientific and technical foundations for isolating various categories of waste in the earth's crust. Germany places chemotoxic wastes into salt and potash mines. Sweden and Finland dispose of low-level civilian radioactive waste in basement rocks. Belgium and France operate underground research laboratories to examine the viability of high-level radioactive waste disposal in argillaceous rocks. Germany had come closest to the disposal of high-level radioactive waste in salt by 1998, when an anti-nuclear coalition took office and progress ceased.

The WIPP compares very well with foreign analogues. Geological evidence indicates host formation stability for longer than 250 million years. Seventy years of local potash mining experience enhance our confidence that the creeping, impermeable salt will encapsulate anything placed inside. Three decades of research, site characterization, and in situ experiments make the WIPP one of the most intensively investigated pieces of real estate in the world.

Independent scientists and engineers worldwide agree on the advantages of deep geologic isolation for waste with the potential for long-term harm. With increasing globalization, no country can manage its waste in "splendid isolation." Continued growth of information exchange and cooperation between deep geologic disposal efforts in New Mexico and abroad benefit safety and the environment everywhere.

UNSAFE RADWASTE DISPOSAL AT WIPP, by *David T. Snow*, 9813 W 83rd Ave., Arvada, CO 80005

At WIPP, radioactive waste is being disposed of permanently in drums and boxes placed in rooms excavated in the Salado salt beds. Like all other excavations below the water table, the repository will saturate, and dissolved radioactivity can ultimately escape via boreholes, shafts, or fractures to the overlying Rustler evaporites. The most evident aquifer in the Rustler, the Culebra Dolomite, is claimed by DOE to provide such slow transport that the Rustler can be considered an adequate barrier. But performance assessment modeling based on insufficient exploration data, unsupportable deductions, and faulty assumptions led to that claim. This paper asserts that the Rustler Formation overlying and down-gradient of the WIPP repository will not provide the claimed geologic containment because karst conduits are present that will facilitate rapid, ephemeral flow. If disposal is not halted and timely rectified, escaping radioactivity may reach Nash Draw within a thousand years, contaminating the Pecos River and Rio Grande. Until a suitable disposal site or method is engineered, a monitored retrievable storage facility may offer the only alternative.

PHYTOREMEDIATION POTENTIAL IN SEMI-ARID SOILS—NEW MEXICAN URANIUM-ACCUMULATING PLANTS, by *Joy Rosen, Dana Ulmer-Scholle*, and *Bruce J. Harrison*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Phytoremediation of U-contaminated soils has been explored extensively in Ohio and other temperate U.S. areas. These studies have used soil amendments such as EDTA or citric acid to stimulate plant U hyperaccumulation. Arid and semi-arid soils, however, are significantly different from temperate U.S. soils as they generally have a higher pH, higher calcium carbonate content, and less organic carbon. As pH increases, oxidized U (VI) becomes less soluble and adsorbs to the Fe and Mn oxyhydroxides. These soil treatments become less effective and cost-effective in areas with diffuse contamination and alkaline soils.

For phytoremediation to work, it is important to find U-accumulating plants that can grow well in the local environment. Uranium geobotanical studies of the Four Corners area have found preliminary evidence of native plant accumulation of uranium. These studies documented a wide variety of plant species under varying site conditions. The response of multiple plant species involves a more detailed analysis of site conditions.

Two unremediated mine sites (with U to 10^{-4} Rem levels) and a uranium-bearing surface outcrop were evaluated for plant concentrations of uranium and for the soil availability of uranium. Initial results indicate that the winter annual *Descurainia obtusa* and the grass *Oryzopsis hymenoides* may be natural U accumulators. The end goal is identifying semi-arid plant species that will naturally accumulate uranium. Natural accumulators will then be further investigated through greenhouse and field application studies to identify the most useful U phytoremediation species in semi-arid soil.

SESSION 2—CERRO GRANDE FIRE

BENEATH THE BURN—A PHOTOGEOLOGIC TOUR OF THE CERRO GRANDE FIRE, by *Kirt A. Kempter*, 2365 Camino Pintores, Santa Fe, NM 87505

Geologic mapping of the 7.5-min Guaje Mountain quadrangle is nearing completion. Approximately two-thirds of the area within the quadrangle was burned during the Cerro Grande fire of May 2000, extending from Pajarito Mountain in the southwest to Santa Clara Canyon in the north. The fire, which burned over 47,000 total acres over a period of two weeks, denuded much of the pine forest and piñon-juniper ecosystems in the quadrangle, greatly enhancing rock exposures and surface expressions of geologic features. Particularly well exposed is the intricate, valley-fill contact between the Bandelier Tuff and the Tschicoma-lava highlands that form the eastern rim of the Valles caldera. In areas of high-intensity burn, post-fire erosion effects are clearly related to the underlying rock type. Some units, such as the highly porphyritic Tschicoma Rendija lavas, weathered extensively as a result of the fire, resulting in local stream bed aggradation due to the large influx of sand to gravel-sized rock fragments. More fire-resistant units, however, have contributed far less sediment to their drainage systems, resulting in post-fire stream bed incision. Numerous faults (related to the Pajarito fault zone) are more evident since the fire, particularly in south-facing canyon walls where offset of volcanic/sedimentary strata is displayed.

GEOMORPHIC RESPONSE OF PUEBLO CANYON, LOS ALAMOS, NEW MEXICO, TO FLOODING AFTER THE CERRO GRANDE FIRE, by *Jared Lyman*, *S. Reneau*, Los Alamos National Laboratory, Los Alamos, NM 87545; *D. Malmon*, Balance Hydrologics, Berkeley, CA 94787; *A. Lavine,* Los Alamos National Laboratory, Los Alamos, NM 87545; *H. E. Canfield*, USDA Agricultural Research Center, Tucson, AZ 85719; and *D. Katzman,* Los Alamos National Laboratory, Los Alamos, NM 87545

The Cerro Grande fire (May 2000) burned approximately 174 km^2 of forest in and around Los Alamos, New Mexico. Post-fire runoff was greatly enhanced due to the loss of forest litter and the development of hydrophobic soils. The upper 4.9 km^2 of the 21.7 km^2 drainage basin of Pueblo Canyon had high severity burn with 100% tree mortality. Pueblo Canyon has subsequently experienced multiple post-fire floods, the largest of which occurred on 2 July 2001 with an estimated peak discharge of 40 m^3/s. Re-surveying of 41 cross sections established between

November 1996 and June 2000 along 10 km of canyon downstream of the burn area allows quantification of the geomorphic response to these floods. Channel response varied greatly, ranging from net incision of 0.75 m to net aggradation of 1.1 m. Channel widening was also documented at some sections. Extrapolation between sections yields an estimated net deposition of approximately 6,000 m^3 of sediment along the 10 km of channel. The predominant result of overbank flooding was net deposition on the floodplains, although local scour also occurred. Up to 0.45 m of deposition was measured with an estimated total floodplain deposition in the study area of 6,500–8,000 m^3. Available data suggest that the net deposition following the fire may not be significantly different from pre-fire flood deposition. Data from the cross sections are being used to test and refine a sediment transport model, which will be used to estimate the effects of continued post-fire flooding in Pueblo Canyon and other canyons affected by the Cerro Grande fire.

SESSION 3—STRATIGRAPHY

LOWER PERMIAN MARINE STRATA IN THE ABO FORMATION OF THE DERRY HILLS AND SOUTHERN CABALLO MOUNTAINS, SOUTH-CENTRAL NEW MEXICO, by *Spencer G. Lucas,* New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; *K. Krainer*, Institute for Geology and Paleontology, University of Innsbruck, Innran 52, A-6020 Innsbruck, Austria; and *D. Chaney*, Department of Paleobiology, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560

Geologists have long believed that Lower Permian nonmarine red beds of the Abo Formation in the Caballo Mountains are laterally equivalent, at least in part, to a mixed nonmarine (Abo) and marine (Hueco) stratigraphic interval 50 or more km to the south in the Doña Ana and Robledo Mountains. Stated another way, current data suggest that in the Rio Grande valley, the northernmost outcrops of marine strata of the Hueco Group are in the Doña Ana Mountains. Our recent fieldwork, however, documents outcrops of marine and estuarine equivalents of the Hueco Group in the Abo Formation of the Derry Hills and southern Caballo Mountains.

The outcrops are: (1) in the Derry Hills near Garfield (sec. 33 T17S R4W), ~ 30 m above the Abo base is a 4.5-m thick interval of pink shale and marine limestone (contains phylloid algae and marine gastropods) that is a tongue of the Hueco; (2) in the southern Caballos, at Red Hill Tank (sec. 15 T17S R4W), ~ 40 m above the Abo base is an 8-m thick interval of green shale with marine bivalves (myalinids and pectinaceans), the brachiopod *Lingula*, palaeoniscoid fish and fossil plants; (3) at McLeod Draw (sec. 22 T17S R3W), a similar shale bed in the Abo yields myalinid bivalves and fossil plants; and (4) in the McLeod Hills, as far north as sec. 3 T17S R3W, we traced two intervals of green shale, limestone, and limestone-pebble conglomerate that yield fossil plants and myalinid bivalves. One interval is ~ 87 m and the other is ~ 112 m above the Abo base, and the northern limit of these beds has not been established. Bivalves and brachiopods from these Abo shale beds in the Caballo Mountains indicate brackish to marine water, and the paleoflora from Red Hill Tank includes two forms of walchian conifer, the walchian cone scale *Gomphostrobus*, two types of pteridophylls and a variety of seeds. We interpret these shales as estuarine deposits based on their stratigraphic architecture (shales and intercalated thin sandstones with current ripples represent deposits of a tidal flat, the thicker, cross-bedded sandstones and conglomerates, frequently displaying an erosive base, are tidal bars and estuarine channel fills) and the association of terrestrial plants with marine bivalves.

Clearly, a tongue of the Hueco Group is present in the Derry Hills, and estuarine deposits that formed marginal to the Hueco seaway are complexly interbedded with the Abo Formation in the southern Caballo Mountains. These recently identified outcrops thus force us to redraw the Early Permian paleogeography of the Orogrande Basin in south-central New Mexico to extend the Hueco shoreline at least 50 km northward.

SESSION 4—GROUND WATER AND GEOMORPHOLOGY

A REASSESSMENT OF NEW MEXICO GEOTHERMAL SYSTEMS, by *David I. Norman*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

New Mexico geothermal systems, with the exception of that in the Valles caldera, are considered by many to be small in size and advective. New Mexico warm springs do not resemble circum-Pacific, volcanic-rock-hosted geothermal systems in discharge temperatures, in association with large, low-conductivity anomalies, nor in a temporal association with volcanism. However, quartz and cation geothermometry indicates subsurface water temperatures well above 100°C, and in some cases > 200°C, for a large number of thermal springs that discharge 30°–60°C waters. Examples are the Gila Springs, Grant County; Hillsboro Warm Springs, Sierra County; Bosque del Apache well #13, Socorro County; and Ojo Caliente, Taos County.

There is a remarkable similarity between New Mexico warm-spring gas chemistry and New Mexico fluorite-Pb-barite-Mn-W mineral-deposit fluid-inclusion gas chemistry. Fluid inclusion microthermometry studies of the mineral deposits commonly indicate maximum temperatures > 150°C. The few detailed isotopic studies performed on these deposits show no evidence for a magmatic contribution to the ore solutions. Evidence of fluid boiling and stratigraphic reconstruction constrain mineralization depths to less than 1.5 km. Hence, the paleo record tells us that non-magmatic, 150+°C geothermal fluids were present at depths of 1.5 km or less throughout portions of the state affected by basin and range tectonics. Warm-spring gas chemistry and chemical geothermometry suggest that the springs may represent surface expressions of fluids systems similar to those that formed mineral deposits in the past. If this is true, there are several implications from our knowledge of past geothermal systems. Fluid migration is structurally controlled, fluids have little H_2S, alteration is minimal, and the size may be large. The size of the mineralized districts, like those at Luis Lopez and Hansonburg, suggest the volume of hot waters could be equal to that of the largest volcanic-hosted geothermal systems. Hot waters at depth may remain hidden because the lack of clay-mineral alteration does not allow detection by electrical methods; mixing with near-surface waters limits the thermal anomaly; and the solutions do not have driving force characteristic of volcanic-hosted geothermal systems that have near 300°C temperatures and high gas contents. Mechanisms for amagmatic geothermal fluid-flow are not clear. Some proposed mechanisms for mineralizing fluids in other states and countries call on tectonic forces, other differential heat flow between basins and basin margins, both of which are compatible with basin and range tectonics and geology.

New Mexico geothermal fluids may be a much more significant resource than here-to-fore considered.

GROUND-WATER GEOLOGY OF WESTERN TAOS COUNTY, by *Tony Benson,* Anthony Benson@msn.com, *Elsbeth Atencio, Susan Meyers,* and *Tom Carrow*, University of New Mexico (Taos), P.O. Box 2848, Taos, NM 87571

A study for the Taos Soil and Water Conservation District has plotted most of the water wells in Taos County, north and west of the town of Taos. Accurate on-the-ground locations of over 300 water wells, using a GPS receiver, have provided more precise surface locations and topographic map elevations. State Engineer Office static water level data and landowner information were used to calculate a more accurate ground-water table elevation. Arc-View mapping programs were used to plot data and provide a medium for continued updates.

A contoured map of water table elevation west of the Rio Grande Gorge shows southeast dip of about 50 ft/mi of the ground-water table from the Colorado border to the south edge of Taos County with discharge tied to the river water level in the Rio Grande Gorge.

Detailed mapping in the Carson area shows water-producing zones in the lower Servilleta basalt, in clastic interbeds within the lower Servilleta, and in the underlying Santa Fe Group. The water table is controlled by the depth of the nearby Petaca Canyon where springs and riparian vegetation tie to nearby well water levels. Sapping by ground-water seepage is probably causing erosion of this enlarged "dry" canyon.

The water table east of the gorge dips southwest and west toward the river level at about 50 ft/mi with minor flexures along the Arroyo Seco drainageway through Las Colonias and along the Rio Pueblo. Down-to-the-west faulting at Los Cordovas and the town of Taos landfill appears to drop the water table down quickly across this fault.

Cross sections made using drillers' logs show clear correlations between basalt layers (and clastic interbeds) and allow faults to be recognized. A major structural feature is the Gorge arch trending northeast-southwest, with a width in excess of 5 mi and a structural uplift in excess of 200 ft. This arch has uplifted in Quaternary time and is probably rising today. This feature is possibly a result of rifting and wrench-related tectonism.

GEOCHEMISTRY OF WATER AND STREAM SEDIMENTS IN THE UPPER RED RIVER, TAOS COUNTY, NEW MEXICO, by *Meghan L. Jackson*, Department of Earth and Environmental Science, New Mexico Institute of Min-

ing and Technology, Socorro, NM 87801; *Virginia T. McLemore*, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *B. M. Walker*, Molycorp, Inc., P.O. Box 469, Questa, NM 87556

The Red River drainage in Taos County, northern New Mexico, contains a wide range of rock types, from Precambrian schists through Tertiary volcanic rocks that host deposits of volcanic-epithermal Au-Ag-Cu vein and porphyry molybdenum deposits. This geological setting affects the stream water and sediment geochemistry in a number of ways. In this study, water chemistry and trace element data of stream sediments are combined to determine which elements are being carried in solution and which elements are being transported as components of specific minerals. There is a distinct change in water chemistry at the town of Red River, downstream of the Mallette Creek drainage, notably as increased concentrations of Mg, Si, F, SO_4, and Na. Mg increases from <5 to >7 ppm, Si increases from below detection limits (<10 ppm) to >13 ppm, F increases from below detection limits to >0.22 ppm, SO_4 increases from approximately 15 ppm to 55–90 ppm, and Na increases from 1.5–4.5 ppm to 5.5–9.5 ppm. This same break point marks an increase in non-carbonate hardness, conductivity, and total dissolved solids.

Sediment samples were divided into two fractions, a large fraction (2 mm–63 µ), similar to the probable bed load of the stream, and a fine fraction (<63 µ), approximately equivalent to the suspended load. In general, sediment geochemistry does not show a correspondingly distinct change in composition as the water samples, but S concentrations in the sediments increased downstream of the Bitter Creek drainage. Pearson correlations between As and S (>0.80) seem to indicate that As is present in the large sediment fraction as a sulfide, probably as arsenopyrite. Strong Pearson correlation coefficients exist between Fe, Ti, and V (>0.85) in both the fine fraction and the coarse fraction, while strong Pearson correlation coefficients between Zn, Cu, Pb, Rb, Mo, and Ba (>0.75) exist in the large fraction but not in the fine fraction, probably due to variable adsorption onto clays in the fine fraction. Cl concentrations in water samples increased downstream, but remained uniformly low (<500 ppm) in the sediments. A sample of the scoria mixture used to prevent icing on the roads (primarily NM–38), contained high Cl concentration (7,000 ppm), indicating that this treatment was probably adding Cl, and possibly Na and K, to the stream.

The Red River has been the subject of extensive research in the areas of stream water chemistry, sediment geochemistry, and associated geological studies, but none of this research has addressed the exact forms in which various elements are being transported within the stream environment. The final goal of this study is to characterize element mobility in this geologically complex watershed, providing a more comprehensive model of water and sediment conditions upstream of the town of Red River, and between the town of Red River and the Molycorp Questa molybdenum mine property.

SESSION 5—TECTONICS, STRUCTURE, AND PETROLOGY

MONAZITE GEOCHRONOLOGY OF THE PROTEROZOIC ORTEGA QUARTZITE—DOCUMENTING THE EXTENT OF 1.4 GA TECTONISM IN THE TUSAS RANGE AND BEYOND, by *Joseph P. Kopera*, jkopera@geo.umass.edu, *Michael L. Williams*, and *Michael J. Jercinovic*, Department of Geosciences, University of Massachusetts, 611 North Pleasant St., Amherst, MA 01003

Preliminary results of in situ microprobe dating of monazite from the Ortega quartzite suggest an increasing influence of 1.4 Ga tectonism from north to south in the Tusas Mountains of northern New Mexico. Monazite from the Jawbone syncline within the northernmost part of the range consistently yields ages of 1.75–1.72 Ga. These monazite grains are interpreted to be mostly detrital in origin, with REE and age zoning reflecting the history of the source terranes. Monazite from an anticline immediately to the south has 1.72–1.75 Ga detrital cores with 1.67–1.68 Ga rims, implying that initial fold formation occurred during the ~1.67–1.65 Ga Mazatzal orogeny. Monazite from the middle and southern Tusas Mountains is predominantly 1.4 Ga in age. This suggests that a previously documented gradient in deformation and metamorphism from north to south may reflect a multistage tectonic history for the range, with an increasingly intense overprint of 1.4 Ga tectonism to the south.

The discovery of abundant monazite in regionally extensive, 1–2-km thick quartzites found throughout the Proterozoic orogenic belt of the southwestern United States may provide important new constraints on the region's tectonic history, specifically, the extent and influence of 1.4 Ga tectonism on the formation and modification of fundamental large-scale structures. These quartzites define the present regional geometry of exposed rocks within the Proterozoic Mazatzal Province and are believed to strongly influence local structure. In addition to northern New Mexico, monazite has also been found in several Proterozoic quartzites in Colorado, allowing the possibility to compare and correlate deformation and metamorphism across the region. Monazite dating in thick quartzites represents a powerful tool by which we can better understand the evolution and stabilization of Proterozoic crust in the southwestern United States and may be an important new technique in explaining the tectonic histories of other orogenic belts.

LOWER PALEOZOIC ISOPACH MAPS OF SOUTHERN NEW MEXICO AND THEIR IMPLICATIONS FOR LARAMIDE AND ANCESTRAL ROCKY MOUNTAIN TECTONISM, by *Steven M. Cather*, steve@gis.nmt.edu New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Compilation of new isopach maps in southern New Mexico for four lower Paleozoic sedimentary successions (Bliss–El Paso, Montoya, Fusselman, and Devonian strata) indicates the presence of pronounced dextral deflections in the isopach patterns for these strata, particularly in data-rich areas near their northern pinchouts. These deflections occur across fault systems of known or suspected Laramide and, in the east, Ancestral Rocky Mountain ancestry. The magnitude and interpreted origin of the best-defined of these dextral deflections are: Hot Springs fault system near Truth or Consequences (~26 km, mostly Laramide); Engle Basin (32–36 km, mostly Laramide, includes ~26 km value for Hot Springs fault system); Palomas Basin (57–70 km, ~26 km of which is attributable to Laramide slip on the Hot Springs fault system—the remainder is of unknown origin; Tularosa Basin (~40 km, largely tectonic in origin but the relative contributions of Laramide and Ancestral Rocky Mountain slip are unknown). Additional deflections may exist across the Pedernal uplift but are in need of further study.

The cumulative dextral deflection of lower Paleozoic isopachs in southern New Mexico is ~100–110 km, not counting possible additional deflections associated with the Pedernal uplift. This is approximately equivalent to the magnitude of dextral separation of Proterozoic rocks and basement aeromagnetic anomalies in northern New Mexico, which suggests that the Proterozoic offsets may be entirely Phanerozoic in origin.

EOCENE MAGMAS OF THE SACRAMENTO MOUNTAINS, NM—SUBDUCTION OR RIFTING?, by *C. E. Dowe, N. J. McMillan*, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003; *Virginia T. McLemore*, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *A. Hutt*, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003

A series of Eocene intrusions in the Sacramento Mountains of south-central New Mexico were emplaced as the tectonic regime of western North America shifted from Laramide subduction to Rio Grande rift/Basin and Range extension. The suite contains dioritic sills and a cogenetic northeast-trending dike swarm. $^{40}Ar/^{39}Ar$ age determinations for three sets of sills suggest that intrusion occurred over at least an 8 million year period (sills at Oliver Lee State Park: 44.01 ± 0.15 Ma; McLemore [1998]; sill at Ortega Peak: 41.13 ± 0.42 Ma; and sill at Three Rivers Petroglyph site: 36.32 ± 0.35 and 36.11 ± 0.32 Ma). Fresh material from dikes has yet to be retrieved for radiometric dating.

The Eocene Sacramento Intrusions (ESI) have the following unusual geochemical signature: 1) high alkalis; 2) nepheline-normative compositions; 3) low concentrations of high field strength elements (HFSE, Nb, Ti, Zr); and 4) K_2O < Na_2O. These characteristics preclude an arc origin for the ESI, because arc magmas are rarely, if ever, silica-undersaturated. Although the paleogeographic position of the ESI is consistent with a back-arc, or shoshonitic model, the ESI lack key characteristics of shoshonites (Druelle, 1981): K_2O > Na_2O, silica-oversaturation, and high HFSE concentrations. A model that is consistent with all of the data is that the ESI are the easternmost early rift magmas, produced from the subcontinental lithosphere as asthenosphere migrated into the space previously occupied by the subducted Farallon Plate. ESI compositions are similar to early-rift magmas erupted in south-central New Mexico that have been interpreted as partial melts of subduction-modified lithospheric mantle.

~35 MA VOLCANIC AND PLUTONIC ACTIVITY IN SOUTHWESTERN NEW MEXICO, by *Virginia T. McLemore*, ginger@ gis.nmt.edu, *William C. McIntosh, Richard P. Esser*, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *O. Tapani Rämö*, Geology Department, P.O. Box 64, FIN-00014 Univ. Helsinki, Finland

New ^{40}Ar/^{39}Ar dates show previously unrecognized Mogollon–Datil age (~35 Ma) plutonic activity in southwestern New Mexico (Table) that was related to the early phases of mid-Tertiary subduction-to-extension transition along the western coast of North America. Within the time framework of the large-volume silicic magmatism in New Mexico and Colorado (Bootheel, Mogollon–Datil, central Colorado/San Juan volcanic fields), all of these plutons are in the same age range as the older, 37–32 Ma, "subduction-related" pulse of caldera activity (Steins, Muir, Juniper, Animas Peak, Tullous, Geronimo Trail, Socorro, Twin Sisters, Emory, Organ, Schoolhouse Mountain), and none fall within the later 29–24 Ma "subduction-to-extension transition" caldera pulse. All but two of the plutons (Organ, Animas) are not associated with calderas. The Organ pluton is 3 m.y. younger than caldera collapse, which does not fit classic caldera development models, where intracaldera sequences are intruded within a few hundred thousand years after collapse. The most mafic of the plutons is a diorite from the Prospect Hills, the other plutons are granodiorite to granite to quartz monzonite. The granites from the western Burro Mountains and Little Hatchet Mountains have epsilon-Nd (at 0 Ma) values of – 7.3 and – 6.5, respectively. They thus contain slightly more radiogenic Nd than the Precambrian granites from the Burro and Little Hatchet Mountains, indicating a significant Precambrian crustal source component. This is similar to epsilon-Nd (at 0 Ma) values of – 7.3 of ignimbrites that erupted from the calderas in Hidalgo County (Bryan, 1995). Tungsten-molybdenum skarns are found adjacent to the Victorio, Granite Gap, Granite Pass, and Eureka stocks, and tungsten and molybdenum have been reported from near the Organ and Tres Hermanas plutons. Collectively, the geochemical and isotopic data, and metal association suggest that source magmas were mixtures of mantle-derived mafic magmas and Proterozoic crust. Compositional differences between the various rhyolitic and granitic rocks are probably a result of fractional crystallization.

Pluton/Dome	^{40}Ar/^{39}Ar age(Ma ± 2σ error)
Camel Mountain–Eagle Nest, diorite, Prospect Hills	36.8 ± 4.7 (hornblende)
Fluorite Ridge granodiorite	38.82 ± 0.57 (biotite)
Tres Hermanas, quartz monzonite	34.65 ± 0.28 (hornblende)
Victorio Granite, Victorio Mountains	35.09 ± 0.08, 35.27 ± 0.41 (biotite)
Red Mountain rhyolite, Deming	35.92 ± 0.24 (groundmass)
Granite Pass granite, Little Hatchet Mountains	32.32 ± 0.17 (biotite, K-feldspar)
Eureka , Little Hatchet Mountains	35.5 ± 1.7 (groundmass)
Granite Gap granite, Peloncillo Mountains	33.20 ± 0.20 Ma (biotite)
Animas quartz monzonite	33.6 ± 0.1 (biotite)
Organ quartz monzonite	33.1 ± 0.1 (biotite)
Burro Mountains granite	33.4 ± 0.4 (biotite)

GEOLOGY OF TRIGO CANYON, VALENCIA COUNTY, NEW MEXICO—UPLIFT CONSTRAINTS FOR THE SOUTHERN MANZANO MOUNTAINS, by *Sean D. Connell*, connell@gis.nmt.edu, New Mexico Bureau of Geology and Mineral Resources—Albuquerque office, New Mexico Institute of Mining and Technology, 2808 Central Ave. SE, Albuquerque, NM 87106; *William C. McIntosh*, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *S. Rogers*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Uplift of the Manzano Mountains is constrained by stratigraphic studies and ^{40}Ar/^{39}Ar dating, allowing partial reconstruction of the tectonic history of a part of the eastern margin of the Albuquerque Basin. Proterozoic schist, quartzite, and granite and Pennsylvanian conglomerate and limestone are exposed along the rugged footwall escarpment. The eastern dip slope exposes reddish-brown Permian sandstone. A 12°–37° west-dipping succession of volcanic-bearing sandstone and conglomerate near Trigo Canyon, ~0.75 km west of the frontal fault, was previously correlated to the pre-rift Datil Formation and early rift Popotosa Formation (Santa Fe Group). Groundmass concentrate from an interbedded basalt flow in this succession yielded a whole-rock plateau age of 26.20 ± 0.18 Ma (NMGRL#51633). A fluvially recycled tuff cobble, stratigraphically below the basalt, yielded a laser-fusion age on sanidine of 27.83 ± 0.27 Ma (NMGRL#51625). This cobble is similar in age and composition to the pre-rift Lemitar Tuff, found 30–60 km to the south. These ages and a potential southern detrital source suggest correlation to the Mogollon–Datil Groups.

The 504-m deep Aguayo–Comanche #1 well (sec. 31 T6N R5E), drilled 3.4 km north-northeast of Trigo Canyon and < 1.5 km west of the mountain front, encountered 158 m of schist-bearing detritus derived from the Manzano Mountains, herein assigned to the Santa Fe Group. The lower 115 m of this upper interval contains sparse volcanic detritus. At least 346 m of volcanic-bearing lithic arkose and feldspathic litharenite, herein assigned to the Mogollon–Datil Groups, underlie this upper interval. The proximity of thick volcanic-bearing deposits in this well relative to the mountain front suggests that these recycled volcanic-sourced deposits once covered at least part of this range. This is supported by the presence of sparse volcanic detritus within Santa Fe Group sediments in this well and by fission-track thermochronology (Behr, 1999). Exposures near Tio Bartolo Canyon, ~ 5 km southwest of Trigo Canyon, contain abundant limestone, sandstone, with subordinate to sparse chert, quartzite, granitic, and volcanic clasts that may record a phase of unroofing of the southern Manzano Mountains.

SESSION 6—PALEONTOLOGY

MICROSCOPIC MACROFOSSILS, BISHOP CAP FORMATION, PENNSYLVANIAN, FRANKLIN MOUNTAINS, TEXAS—JUVENILES OR DWARFS?, by *William C. Cornell*, Department of Geological Sciences, University of Texas at El Paso, El Paso, TX 79968

A diverse assemblage of minute (0.4–10 mm) fossils is present in the "two-foot fossil bed" in the upper Bishop Cap Formation (Desmoinesian, Pennsylvanian) in Vinton Canyon, on the west slope of the Franklin Mountains. Fossils present include bivalves (*Edmondina*, *Nuculopsis*, *Myalina*) and gastropods (*Bellerophon*, *Euphemites*, *Donaldina*, *Leptoptygus*, *Pseudozygopleura*, and *Glabrocingulum*) thought to be autochthonous. In addition, brachiopods (*Mesolobus*), bryozoan fragments, crinoid columnals, ostracods (*Cavellina*, *Bairdia*), and unidentified fusulinids are present. Fragmentary orthocone cephalopods and possible scaphopods occur in small numbers. Fragments of the dental hinge portions of pelecypods are the most common components; *Mesolobus* is second in abundance, followed by *Glabrocingulum*. Shells of epifaunal taxa are encrusted, to varying degrees, by sabelliform worm tubes, suggesting that these shells are post-mortem, allochthonous components of the assemblage. Dimensions of the fossils suggest that most are juveniles. Gastropods, however, are microscopic replicas of normal-size specimens in their morphology and thus may be dwarfs that lived in a stressed environment.

A NEW GENUS OF SYNCARID CRUSTACEAN FROM THE LATE PENNSYLVANIAN (MISSOURIAN) ATRASADO FORMATION OF CENTRAL NEW MEXICO, by *Allan J. Lerner* and *Spencer G. Lucas*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

New Mexico's fossil record contains two endemic occurrences of syncarid crustaceans, both from the extinct Paleozoic order Palaeocaridacea. *Uronectes kinniensis* Schram & Schram, 1979, is known from the upper Virgilian Kinney Quarry *Lagerstätten*, and *Erythrogaulos carrizoensis* Schram, 1984, is known from the upper Virgilian to lower Wolfcampian Carrizo Arroyo section. An addition to this important record comes from New Mexico Museum of Natural History locality 4667, in the Upper Pennsylvanian (Missourian) strata of the Atrasado Formation (Madera Group), near Tinajas Arroyo, Socorro County. Six specimens representing a new syncarid genus with uncertain family assignment have been found. Characteristic features include a reduced first thoracomere, circular thoracomere ornamentation, a spinescent spatulate telson, long caudal rami, and distally rounded uropods bearing strong median ribs. It is distinctive in possessing well-developed furca near the terminus of the telson, a feature placing it outside of the Palaeocaridacea and making it the only Paleozoic syncarid known to have preserved this primitive crustacean structure. This syncarid may belong to the extant order Anaspidacea, from which only one fossil anaspidid anaspidacean, *Anaspidites antiquus* Chilton, is known from the Triassic of Australia.

The syncarid fossils at locality 4667 occur in a 4-m thick unit of thinly laminated black shale. The paleoenvironment is interpreted as being lacustrine. Darwinuloid ostracods and conchostracans assigned to *Pseudestheria* sp. are highly abundant, indicating alkaline conditions at the time of deposition. A maxillopodan crustacean and a phyllocarid crustacean, both showing soft-bodied preservation, are known from single occurrences. Other faunal elements are low in abundance, including paleoniscoid and coelacanth scales, isolated fish bones, and coprolites. A sparse paleoflora that consists primarily of seed ferns is also present.

BRACHIOPODS FROM THE RED TANKS FORMATION (MADERA GROUP) NEAR THE PENNSYLVANIAN–PERMIAN BOUNDARY, LUCERO UPLIFT, NEW MEXICO, by *Barry S. Kues*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

The Red Tanks Formation, of latest Pennsylvanian to earliest Permian age (or entirely latest Pennsylvanian by a recent proposal to raise the boundary), is about 100 m thick at its type section in Carrizo Arroyo, and is coeval with the Bursum and Laborcita Formations elsewhere in central and south-central New Mexico. The Red Tanks consists mainly of red or green nonmarine shales, with a few thin limestone and shale beds containing marginal marine mollusc faunas. The only thick marine interval with well-developed, stenohaline, invertebrate faunas is a 5-m-thick sequence of limestones and calcareous shales about in the middle of the formation, and this interval contains diverse brachiopods comprising about 25 species. The most abundant taxa are the productoids *Juresania* n. sp. aff. *nebrascensis*, and *Linoproductus* (represented by three species, *L. magnispinus*, *L.* aff. *prattenianus*, and *L.* aff. *platyumbonus*), and the small spiriferid *Crurithyris planoconvexa*. *Neochonetes granulifer* (including the form *N.* "*transversalis*"), *Composita subtilita*, *Neospirifer alatus*, *Meekella mexicana*, *Reticulatia americana*, *Hystriculina* aff. *wabashensis*, and *Wellerella* aff. *osagensis*, are moderately common in some beds, and such species as *Phricodothyris perplexa*, *Punctospirifer kentuckyensis*, *Echinaria* aff. *semipunctatus*, *Derbyia* sp. and *Orbiculoidea missouriensis* are rare. Above these middle Red Tanks marine units brachiopods are completely absent, with the exception of *Lingula carbonaria*, which occurs in a thin bed about 20 m below the top of the formation that contains a low-diversity, predominantly molluscan fauna. A bed of dark gray shale at the boundary between the Red Tanks and the underlying Atrasado Formation also contains *L. carbonaria* in abundance. Nearly all of these brachiopod species are also known from earlier Virgilian strata in central New Mexico, and many also occur in the Bursum Formation, although the Red Tanks brachiopod fauna appears to be taxonomically more diverse. In contrast, there is little evidence in the Red Tanks Formation of brachiopod taxa that characterize early Wolfcampian strata in the west Texas region.

MICROPALEONTOLOGY OF THE UPPER TRIASSIC (APACHEAN) SLOAN CANYON FORMATION, NORTHEASTERN NEW MEXICO, by *Andrew B. Heckert*, *Spencer G. Lucas*, and *K. K. Kietzke*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

We report here a diverse microfauna and flora from NMMNH locality 325 in the type section of the Upper Triassic (Apachean: late Norian–Rhaetian) Sloan Canyon Formation in Union County, northeastern New Mexico. The calcareous microflora and microfauna of the Sloan Canyon Formation contain a new species of charophyte (*Porochara* n. sp.), two species of the ostracode *Darwinula*, one new (*Darwinula accuminata* Belousova, 1961; *Darwinula* n. sp.), and two species of the ostracode *Gerdalia*, one new (*Gerdalia triassica* (Belousova), 1961; *Gerdalia* n. sp.). The fine (100–230 mesh) screens used to recover the calcareous microfossils also facilitated the recovery of many microvertebrates, including selachians, osteicthyans, and tetrapods. Shark fossils from the Sloan Canyon locality are predominantly small teeth of the hybodont *Lissodus*. The osteichthyan fauna is more diverse and includes numerous redfieldiid fossils as well as less abundant colobodontids, semionotids and palaeoniscids. The tetrapod fauna includes sphenodontians, cynodonts, and fragmentary teeth of larger tetrapods, principally phytosaurian archosaurs. These records are an important addition to the Sloan Canyon vertebrate fauna, which is otherwise dominated by indeterminate phytosaurs and metoposaurid amphibians. Vertebrate trace fossils from the Sloan Canyon Formation include tracks of aetosaurs (*Brachychirotherium*) and theropod dinosaurs (cf. *Grallator*) and sauropodomorph dinosaurs (*Tetrasauropus*).

NMMNH locality 325 occurs in an intraformational conglomerate and limestone we interpret as a lacustrine beach deposit. Fish scales comprise at least 20% of the clasts in the conglomerate. The Sloan Canyon microfauna apparently lived in a permanent water body with a depth of about 6 m or less. This water body was highly mineralized, and the fauna/flora indicates a typical Triassic association of diverse darwinulid ostracodes and rarer charophytes. The associated hybodont shark, *Lissodus*, may have preyed on the ostracodes.

TAPHONOMY OF THE LATE TRIASSIC LAMY AMPHIBIAN QUARRY (GARITA CREEK FORMATION: CHINLE GROUP), CENTRAL NEW MEXICO, by *Kate E. Ziegler*, kaerowyn@unm.edu, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131; and *Spencer G. Lucas,* New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

The Lamy amphibian quarry, located near Lamy in Santa Fe County, New Mexico (sec. 7 T12N R11E), is in the Garita Creek Formation of the Chinle Group, which is of Adamanian age (~ 215–220 Ma). The quarry is dominated by the remains of large metoposaurid amphibians assigned to *Buettneria perfecta*, and has long been considered to have been produced by drastic drought conditions. However, an examination of the original field data together with specimens from the quarry reveals that the Lamy amphibian quarry is, in fact, a hydrodynamically sorted, semi-attritional accumulation. The quarry is in fine-grained sediments that lack mudcracks and fine laminations that would be expected in a pond that has dried up. The fossil bones show a strong preferred long-axis orientation, which is indicative of interaction of the fossil material with a strong current of water. The material is also hydrodynamically sorted, with the assemblage consisting of predominantly large, flat skeletal elements such as skulls, mandibles, and pelvic and shoulder girdle elements. The skulls and girdle elements are often imbricated, providing further evidence for the transport of the material in a current. The population is dominated by adult animals, which raises the potential of an earlier catastrophic event affecting a population of metoposaurs. There are no signs of scavenging, nor of advanced weathering on the bones. The best explanation of the taphonomic data is that a catastrophic mortality event killed a group of metoposaurid amphibians, and the corpses were subsequently quickly disarticulated and transported over a significant distance before deposition in a topographic low. There is no evidence, however, for the drought hypothesis that has long been advocated to explain the Lamy amphibian quarry.

OLDEST OCCURRENCE OF THE CRETACEOUS SHARK, *PTYCHODUS WHIPPLEI* MARCOU, FROM THE CENOMANIAN OF CENTRAL NEW MEXICO, by *Sally C. Johnson, Spencer G. Lucas,* New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; and *Virginia Friedman,* Geosciences Department, University of Texas (Dallas), 2601 N. Floyd Road, P.O. Box 830688, Richardson, TX 78053

The middle Rio Puerco valley in Bernalillo County, New Mexico, contains a thick succession of sediments deposited in and along the western margin of the Late Cretaceous Interior Seaway. Many of the sediments are fossiliferous and well exposed throughout the valley, and some strata contain numerous shark teeth. The upper part of the intertongued Dakota–Mancos succession is one such interval. These sediments have yielded well-preserved ammonite and other invertebrate faunas, but till now no selachian remains. NMMNH locality 4517 is in the Clay Mesa Member of the Mancos Formation, a unit with an ammonite fauna that establishes its age as middle Cenomanian. This locality is unique because it represents the oldest Late Cretaceous shark fauna reported in New Mexico as well as the oldest occurrence of *Ptychodus whipplei*. Teeth of *P. whipplei* from NMMNH locality 4517 can be distinguished from teeth of *P. anonymus* Williston by their size and the shape of the cusp. Thus, the *P. whipplei* teeth from this site have a tall, nipple-shaped cusp, the cusp shape is cylindrical, and the angle between the cusp and the basal occlusal surface is approximately 90°. In contrast, the teeth of *P. anonymus* have a more conical lower cusp, the height of the cusp is roughly equal to the diameter of the cusp, and the angle between the basal occlusal surface and the cusp exceeds 90°. All of the characteristics of the teeth from this site are very similar to those of the teeth of *P. whipplei*. This site thus extends the range of P. *whipplei* from the Turonian back to the middle Cenomanian.

A NEW LATE PUERCAN (EARLY PALEOCENE) LOCAL FAUNA FROM THE SAN JUAN BASIN, NEW MEXICO—A PRELIMINARY REPORT, by *Thomas E. Williamson*, twilliamson@nmmnh.state.nm.us, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; and *Anne Weil*, annew@duke.edu, Department of Biological Anthropology and Anatomy, Duke University, 08 Biological Sciences Building, Durham, NC 27708

A new fossil vertebrate local fauna (NMMNH localities 4723, 4725) at the head of Willow Wash, northwestern San Juan Basin, represents the first new Puercan site from New Mexico to be reported in almost a century. It is approximately midway between the classic late Puercan (Pu3) sites at the heads of the West Fork of Gallegos Canyon and Alamo Wash. Fossils are stratigraphically restricted to a narrow zone about 3.5 m thick at the base of a channel sandstone complex approximately 15 m above the base of the Nacimiento Formation. This zone correlates with the "*Taeniolabis* zone" of other localities and is therefore of late Puercan (Pu3) age. The fauna from this site is here termed the Split Lip Flats local fauna.

The Split Lip Flats local fauna is unique among late Puercan faunas previously reported from the San Juan Basin in that it includes a rich microfauna. Initial surface collecting and wet screening and picking of approximately 100 kg of matrix from several sites have yielded a diverse fauna that includes gars, stingrays, turtles, glyptosaurine lizards, crocodilians, and mammals. Mammals, represented primarily by isolated teeth, are the most abundant and diverse component of the fauna.

A preliminary list of mammals from the site includes *Taeniolabis taoensis*, *Periptychus* sp., *Mithrandir gillianus*, *Conacodon cophator*, *Choeroclaenus turgidunculus*, numerous unidentified arctocyonids, numerous small multituberculates, several isolated teeth of small marsupials, and numerous small eutherians. Significant among the small eutherian specimens is an associated partial set of lower teeth referrable to the poorly known Cimolestid *Cimolestes simpsoni*, as well as teeth of several new or poorly known taxa. Additional collecting and a thorough description of the Split Lip Flats local fauna will result in a better characterization of late Puercan mammals and add to a better understanding of the evolutionary radiation of mammals at the beginning of the Paleogene of North America.

LATE PLIOCENE (BLANCAN) VERTEBRATES FROM MESA DEL SOL, ALBUQUERQUE BASIN, NORTH-CENTRAL NEW MEXICO, by *Gary S. Morgan*, morgan@nmmnh.state.nm.us, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; and *Sean D. Connell*, connell @gis.nmt.edu, New Mexico Bureau of Geology and Mineral Resources—Albuquerque office, New Mexico Institute of Mining and Technology, 2808 Central Ave SE, Albuquerque, NM 87106

We report an important late Pliocene (Blancan) vertebrate fauna in the upper Arroyo Ojito Formation, below Mesa del Sol and south of Tijeras Arroyo in the Albuquerque Basin, Bernalillo County, New Mexico. The Mesa del Sol local fauna (MdS LF) has the most diverse Blancan small-mammal fauna from New Mexico. The productive microvertebrate site is in fine-grained sediments and has a limited stratigraphic extent (10 cm thick, < 2 m wide). The MdS LF contains 18 species of vertebrates, primarily small-bodied taxa, including frog/toad, small tortoise, two snakes, two birds, and 12 mammals. The small-mammal fauna includes 10 taxa: a shrew (Soricidae); the mole *Hesperoscalops*; the rabbit *Hypolagus*; and seven species of rodents, including the kangaroo rat *Prodipodomys*, the pocket gopher *Geomys*, the cotton rat *Sigmodon medius*, the pygmy mouse *Baiomys*, the extinct mouse *Calomys* (*Bensonomys*) *arizonae*, the extinct vole *Mimomys meadensis*, and the extinct muskrat *Pliopotamys meadensis*. Two large mammals occur in the MdS LF: the horse *Equus scotti* is represented by an articulated partial hind limb and a large undescribed species of the camel *Camelops* is known from two teeth.

The mammalian genera *Hesperoscalops*, *Hypolagus*, *Prodipodomys*, *Calomys* (*Bensonomys*), *Mimomys*, and *Pliopotamys* are indicative of the Blancan land mammal age (~4.5–1.8 Ma). The association of *Calomys* (*Bensonomys*) *arizonae*, *Mimomys meadensis*, *Pliopotamys meadensis*, and *Sigmodon medius* in the MdS LF further restricts its age to "medial" or late early Blancan (~3 Ma). The presence of the microtine rodents *Mimomys* and *Pliopotamys* is significant because there is a well-established biochronology for North American Plio–Pleistocene faunas based on this group. The co-occurrence of *Mimomys meadensis* and *Pliopotamys meadensis* is indicative of the Blancan IV microtine age (~3.2–2.6 Ma). Broadly correlative Blancan IV faunas are Benson and Clarkdale in Arizona and Sanders in Kansas. The MdS LF is approximately 45 m below an unconformable contact with the early Pleistocene (early Irvingtonian) Sierra Ladrones Formation. To the south the Arroyo Ojito Formation contains fluvially reworked 2.6–2.7 Ma pumice pebbles, further constraining the MdS LF to the younger part of the Blancan IV age.

PROBABILITY PLOTS DISTINGUISH MORPHOLOGICAL GROUPINGS IN BIOMETRIC DATA: ANALYSIS OF COELOPHYSIS AND COMPARISON TO OTHER DIAPSIDA, by *L. F. Rinehart*, lrinehart@msn.com, *S. G. Lucas*, and *A. B. Heckert*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

Probability plotting is a simple, powerful analytical method that can graphically separate and define the components of mixed statistical distributions. Measurement data from animal populations contain normally distributed components that represent size groupings. These components can arise from yearly age groups in animals that have a distinct breeding season, sexual dimorphism, heterochrony, and other causes. We introduce the use of probability plotting, a method previously employed in engineering sciences, to resolve component distributions in morphometric data for the dinosaurs *Coelophysis*, *Allosaurus*, *Maisaura*, and two extant outgroups, alligators and cassowaries.

Resolved component distributions define the proportions of adults and juveniles, yearly size groupings of juveniles, extent of sexual dimorphism, and growth asymptotes for these taxa. Where enough specimens are known, growth curves can be constructed. We show that the sexual dimorphism indices (SDI) of the dinosaurs fall between those of the bird and crocodilian outgroups (significance uncertain). Within our small sample the data obey Rensch's rule (SDI increases with size where males are larger); probably males were the robust forms in *Coelophysis* and *Allosaurus*. In every group, proportions of robust and gracile adults are equal to within 33%, and juveniles always outnumber either adult morph. We also compare hypothetical growth curves for the dinosaurs to the outgroups. Additionally, we show that the size of the Peterson quarry theropod is much greater than the growth asymptote of *Allosaurus* and therefore cannot represent an exceptionally large individual of that genus.

POSTER SESSION 1—STRUCTURE AND TECTONICS

GROUND MAGNETIC PROFILING OF FAULTS IN THE ALBUQUERQUE BASIN, NEW MEXICO: IMPLICATIONS FOR FAULT STRUCTURE IN SEDIMENTARY BASINS, by *Brant W. Cole* and *Harold Tobin*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

High-resolution aeromagnetic data has recently been used to effectively map fault traces in sedimentary basin settings. Aeromagnetic data collected by the USGS exhibits prominent magnetic anomalies along known and buried faults, explained either by (A) contrasting magnetic susceptibility of faults themselves or by (B) syndeformational deposition of layers of anomalous susceptibility. Recent modeling has supported the latter of the two hypotheses.

We have obtained ground magnetic field surveys as a high-resolution tool for ground truthing in comparison to aeromagnetic surveys. A series of five lines were collected perpendicular to and across the Sand Hill fault for this study using a cesium magnetometer. The Sand Hill fault is a major down to the east, north-trending normal fault on the northwestern boundary of the Albuquerque Basin, well exposed in parts of the badlands topography in this area. Detailed mapping of the fault was combined with magnetic susceptibility information to produce geologically realistic models of the magnetic profiles. These preliminary models generally support conclusions similar to those for aeromagnetic data modeling: the magnetic anomalies result from broad magnetic features interpreted as depositional units, rather than as a fault of anomalous magnetic properties. Implications for magnetic properties in relation to fault zone structure will be discussed.

PRELIMINARY GEOLOGIC MAP OF THE GUAJE MOUNTAIN 7.5-MIN QUADRANGLE, EASTERN JEMEZ MOUNTAINS, NEW MEXICO, by *Kirt A. Kempter*, 2365 Camino Pintores, Santa Fe, NM 87505; and *Shari Kelley*, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The Guaje Mountain 7.5-min quadrangle contains some of the most spectacular volcanic geology in the state, including voluminous lava and ignimbrite deposits, thick sequences of volcaniclastic sediments, and numerous faults related to the Pajarito and Embudo fault zones. The majority of the Cerro Grande burn area lies within the quadrangle, which in its current state of stripped vegetation provides exceptional exposures of bedrock and surface features. From west to east, rocks in the quadrangle record the geographic transition from pre-caldera, Tschicoma rim rocks, to valley-fill Bandelier Tuff deposits, to rift-fill fanglomerates of the Puye Formation. Major rock units in the map area include late Miocene to Pliocene silicic lavas of the Tschicoma Formation and their associated Puye fanglomerates, Quaternary Cerro Toledo tephras and sediments, upper Bandelier Tuff (Tshirege Member), and alluvial deposits.

Three major silicic lava units of the Tschicoma Formation have been differentiated in the quadrangle, providing greater insight into the pre-caldera eruptive history of the region. The oldest (late Miocene/early Pliocene) and most voluminous unit, termed the Rendija lavas, forms the bulk of the highlands immediately west and north of Los Alamos, including Sierra de los Valles, Guaje Ridge, and Guaje Mountain. Most likely, the formation of these volcanic highlands had an immediate sedimentary impact, resulting in a rapid eastward progradation of Puye fanglomerates into the Rio Grande rift. At approximately 3 Ma, another episode of silicic volcanism occurred, as viscous lavas erupted from vents at/near Pajarito Mountain and Caballo Mountain along the western boundary of the quadrangle.

The Otowi Member of the Bandelier Tuff, erupted from the Toledo caldera at ~ 1.6 Ma, is exposed in canyon bottoms in the southern portion of the quadrangle. In the northern half of the quadrangle (north of Rendija Canyon), however, this unit is missing, suggesting that the northern Tschicoma highlands created a depositional shadow zone during the eruption of this ignimbrite. Between caldera events (1.6–1.2 Ma), Cerro Toledo interval deposition was widespread in the quadrangle, including tephras, conglomerates, and other epiclastic sediments. Eruption of the Tshirege Member of the Bandelier Tuff at ~ 1.2 Ma filled in large paleovalleys along the Tschicoma highlands and created the Pajarito Plateau. Prior to the incision of modern canyons into the Pajarito Plateau, a brief interval of Quaternary sedimentation occurred upon the Bandelier Tuff, forming alluvial caps to many of the present mesa tops, including several locales in the town of Los Alamos. Other, minor sedimentary units in the map area include landslide, terrace, and recent alluvial deposits.

Faults in the map area transect all of the major stratigraphic units, with the older Tschicoma Rendija lavas showing the greatest measurable degree of offset. The majority of the faults trend north-south and show down-to-the-west displacement, contrary to offset along the Pajarito fault zone south of the map area. In the northern portion of the quadrangle structural trends veer to the northwest, parallel to the Embudo fault system and the Jemez lineament.

GEOLOGY OF THE ESPAÑOLA 7.5-MINUTE QUADRANGLE AND IMPLICATIONS REGARDING MIDDLE MIOCENE DEPOSITION AND TECTONISM IN THE RIO GRANDE RIFT, NORTH-CENTRAL NEW MEXICO, by *Daniel J. Koning*, danchikoning@hotmail.com, 14193 Henderson Dr., Rancho Cucamonga, CA 91739

Geologic mapping and sedimentologic study of the Tesuque Formation in the Española 7.5-minute quadrangle elucidates middle Miocene (~ 11–16 Ma), rift-related deposition and tectonics in the central Española Basin. This work also demonstrates the utility of lithosomes A and B of Cavazza (1986). Lithosome B consists of clastic sediment containing a mixed assemblage of gravel (sandstone, siltstone, limestone, quartzite, tuff, and granite) derived from the northeast across the Peñasco embayment. Lithosome B was deposited by a relatively large, broad fluviatile system that trended south-southwest on the basin floor. Near the eastern quadrangle boundary, Lithosome B interfingers with, and grades into, piedmont deposits of sand, silt, and granite-bearing gravel (Lithosome A) derived from the local Sangre de Cristo Mountains to the east. Mapping of the contact between these two lithosomes and study of well cuttings indicate that this contact was probably near the eastern quadrangle boundary for at least 1 m.y. prior to the deposition of the No. 4 White Ash (15.3–15.5 Ma). After 15.3 Ma, this contact shifted more than 7 km to the west throughout the remainder of the middle Miocene (11–15 Ma) as the piedmont (Lithosome A) alluvium prograded westward. It is assumed that such a significant progradation was due to either a climate change or a change in rift tectonic style or rate. Westward progradation probably occurred slightly before a sharp marine $\delta^{18}O$ increase at 13–15 Ma. This observation and comparison of approximate accumulation rates suggest that a change in rift tectonism was at least partly responsible for this extensive and prolonged progradation. This change in tectonism may have influenced rift volcanism, which perhaps explains the deposition of coarse, locally derived basaltic lapilli shortly after 13.7 Ma.

GEOLOGIC MAPPING OF THE BLUE MOUNTAIN QUADRANGLE, SAN MATEO MOUNTAINS, NEW MEXICO, by *Scott D. Lynch*, lynch@nmt.edu, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Geologic mapping and $^{40}Ar/^{39}Ar$ geochronology in the west-central San Mateo Mountains of southwestern New Mexico suggest that the Nogal Canyon cauldron (source cauldron of the Vicks Peak Tuff) is larger than previously proposed and was a topographic high until at least 27.4 Ma. Six kilometers northwest of the generally accepted cauldron margin, more than 290 m of Vicks Peak Tuff with no exposed base is found overlain by 260 m of rhyolite lavas. Several granite porphyries intrude this sequence. The Vicks Peak Tuff, rhyolite lavas, and granite porphyries were all emplaced over a <90 k.y. span (28.23–28.32 Ma). The thickness of the Vicks Peak Tuff and the occurrence of lava domes and intrusions indicate that the margin of the Nogal Canyon cauldron is actually north of the field area. Overlying the lava domes and intrusions are a thin sequence of volcaniclastic sediments and the 24.3 Ma Turkey Springs Tuff. Missing from this stratigraphy is the 27.4 Ma South Canyon Tuff, a regional ignimbrite that came from a cauldron less than 15 km to the north. This suggests that the Vicks Peak Tuff, domes, and intrusions formed a topographic high during the 27.4 Ma eruption of the South Canyon Tuff. This topographic high probably formed by some combination of pre-cauldron uplift, resurgent uplift, and rapid lava dome accumulation.

GEOLOGY AND STRUCTURE OF THE PAJARITO FAULT SYSTEM AT LOS ALAMOS NATIONAL LABORATORY, LOS ALAMOS, NEW MEXICO, by *Alexis Lavine*, alavine@lanl.gov, *Jamie N. Gardner, Claudia J. Lewis, Steve L. Reneau, Giday WoldeGabriel, Don J. Krier,* and *Dave T. Vaniman,* Earth and Environmental Sciences Division, Los Alamos National Laboratory, Los Alamos, NM 87545

The Los Alamos National Laboratory (LANL) Seismic Hazards Program has done detailed geologic mapping of the Pajarito fault system for several years to better understand the location and nature of faulting, which is essential to assessing ground motion and seismic surface rupture hazards at the laboratory. We have developed a mapping technique using a total station for precise mapping of flow and cooling unit contacts in the 1.2 m.y. old Tshirege Member of the Bandelier Tuff. The technique enables us to locate faults that would be overlooked by conventional mapping techniques and have as little as 15 cm of vertical displacement. Total station mapping has allowed us to define broad zones of small faults and varying styles of deformation along strike of individual faults in the Pajarito fault system. Total station bedrock mapping has been accompanied by conventional geologic and geomorphic mapping, shallow drilling on urbanized mesa tops, and paleoseismic trenching. Within LANL, deformation in the fault system is distributed across a 1.8–>3.5 km-wide, dominantly north- to northeast-trending, complex zone to the east of the main Pajarito fault escarpment. Along strike the Pajarito fault zone can be expressed at the surface as a monocline, a large normal fault, or a distributed zone of deformation with >135 m of down-east vertical offset in the Bandelier Tuff. The associated zone of deformation to the east includes normal and strike-slip faulting and monoclinal folding, with 0–>30 m of distributed down-west vertical offset in the Bandelier Tuff.

CRUST AND UPPER MANTLE STRUCTURE IN THE SOUTHWESTERN UNITED STATES FROM TELESEISMIC RECEIVER FUNCTIONS, by *David Wilson*[1], *Richard Aster*[1], *James Ni*[2], *John Schlue*[1], *Steve Grand*[3], *Scott Baldridge*[4], *Mike West*[2], *Rengin Gok*[2], *Steve Semken*[5], and *Wei Gao*[3], [1]Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; [2]Department of Physics, New Mexico State University, Las Cruces, NM 88003; [3]University of Texas, Austin, TX 78712; [4]Los Alamos National Laboratory, Los Alamos, NM 87545; and [5]Diné College, Shiprock, Navajo Nation, NM 87420

We investigate the crust and upper mantle structure in the southwestern United States using receiver functions calculated from over 3,000 teleseismic arrivals recorded by the LA RISTRA (Colorado PLAteau, Rio Grande RIft, Great Plains Seismic TRAnsect) project. LA RISTRA is a 950-km long (approximately great-circle), 54-station PASSCAL broadband seismic array extending from Lake Powell, Utah, to Pecos, Texas, and crossing the Rio Grande rift near Belen, New Mexico. The line is approximately parallel to the regional Proterozoic continental accretionary gradient. We calculate crust and upper mantle structural model along the array by migrating receiver functions to produce a P-to-S converted phase image of the subsurface. Results indicate that crustal thickness ranges from 48 km beneath the Colorado Plateau to 35 km beneath the center of the Rio Grande rift. The crust beneath RISTRA array appears to comprise discrete crustal packages, each with a distinct seismic character, possibly an imprint of Proterozoic continental growth from northwest to southeast. The 410-km discontinuity is depressed, and the 660-km discontinuity is elevated, centered near the Jemez lineament. This anticorrelation is consistent with warmer than normal upper mantle. Mesozoic and Cenozoic sediments within the rift and thick Paleozoic sediments of the Delaware Basin produce strong free surface multiple reverberations that allow us to interpret basin depth and velocity structure.

THE NATURE OF RESURGENCE IN THE VALLES CALDERA, JEMEZ MOUNTAINS, NEW MEXICO, by *Erin H. Phillips, Philip Kyle, William C. McIntosh*, and *Matt Heizler*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Preliminary $^{40}Ar/^{39}Ar$ dates from rhyolite lavas on and near the resurgent dome of the Valles caldera imply that lavas previously considered to be associated with resurgence actually predate resurgence. The timing of resurgence is constrained by the upper Bandelier Tuff (UBT), erupted at 1.22 Ma, and the eruption of the oldest ring fracture dome, Del Medio, between approximately 1.13 and 1.21 Ma (Spell et al., 1996; Izett and Obradovich, 1994). According to prior mapping and interpretations, the Deer Canyon (DC) member of the Valles Rhyolite Formation was erupted after caldera collapse but before resurgence, and the Redondo Creek (RC) member was erupted during resurgence of the caldera (Smith and Bailey, 1968). In contrast to this interpretation, $^{40}Ar/^{39}Ar$ ages on sanidine phenocrysts range from 1.70 ± 0.02 to 1.45 ± 0.05 Ma for the DC member, and 1.63 ± 0.11 to 1.28 ± 0.03 Ma for the RC member. These data indicate that the mapped DC and RC members represent multiple geologically and temporally distinct rhyolite eruptions, most or all of which are older than the UBT, and therefore were erupted before caldera collapse and not during resurgence. The exposure of these older rhyolite lavas on the resurgent dome implies that the magnitude of resurgence relative to caldera fill thickness is considerably greater than previously thought, and was sufficient to expose rhyolites that were originally part of the pre-collapse caldera floor.

Izett, G. A., and Obradovich, J. D., 1994, Journal of Geophysical Research, v. 99, pp. 2925–2934.

Smith, R. L., and Bailey, R. A., 1968, Geological Society of America, Memoir 116.

Spell, T. L., McDougall, I., and Doulgeris, A. P., 1996, Geological Society of America, Bulletin, v. 108, pp. 1549–1566.

POSTER SESSION 2—IGNEOUS AND METAMORPHIC PETROLOGY, MINERALOGY

MAJOR ELEMENT GEOCHEMISTRY OF THE NEOPROTEROZOIC CHUAR GROUP, GRAND CANYON, by *Crystal L. Dodson*, lotus@unm.edu, *Laura J. Crossey*, lcrossey@unm.edu, *John D. Bloch*, Department of Earth and Planetary Sciences, University of New Mexico, Northrop Hall, Albuquerque, NM 87131; and *Carol M. Dehler*, Department of Geology, Utah State University, 4505 Old Main Hill, Logan, UT 84322

Bulk chemical analysis of the Neoproterozoic Chuar Group (~770–746 Ma), Grand Canyon, was undertaken to better understand the petrology of this near-shore marine, predominantly shale succession. The Chuar Group is composed of two formations, the Galeros and the Kwagunt, subdivided into seven members. Major element (Si, Al, Fe, Mg, Mn, Ca, K, Na, Ti, and P) analysis by X-ray fluorescence spectrometry (XRF) was done on samples from five of these members. The five members, in ascending order, are the Tanner, Jupiter, and Carbon Canyon Members from the Galeros Formation and the Awatubi and Walcott Members from the Kwagunt Formation.

Cross-plots of TiO_2–Al_2O_3, SiO_2–Al_2O_3, K_2O–Al_2O_3 reveal stratigraphically significant geochemical variations within the Chuar Group. TiO_2 and Al_2O_3 show a positive correlation, and the Jupiter and the Awatubi Members have higher TiO_2 concentrations than the Carbon Canyon and the Walcott Members. SiO_2 and Al_2O_3 show a negative correlation that suggests that clays (Al_2O_3-bearing) are mixed with quartz silt. The Awatubi Member shows an excellent correlation (R^2 = 0.98) suggesting that kaolinite is the dominant clay mineral in this unit. The Walcott Member contains the greatest amount of SiO_2 and therefore the most silt. Overall, K_2O and Al_2O_3 have a good positive correlation, but the Walcott Member has a very strong positive correlation (R^2 = 0.98) indicating a mineralogical control. The Tanner Member contains the largest amount of K.

Distinct chemical and mineralogical compositions for members of the Chuar Group may result from source, depositional processes, and/or diagenesis. Additional geochemical and mineralogical data will help to determine the controls on the composition of the Chuar Group.

GEOCHEMICAL OBSERVATIONS OF THE VICTORIO MOUNTAINS MINING DISTRICT, LUNA COUNTY, NEW MEXICO, by *Kelly M. Donahue*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; *Virginia T. McLemore*, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *Andrew R. Campbell*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The Victorio mining district, southwestern New Mexico, hosts three types of mineral deposits that are spatially related (from the outer most zone to central zone): carbonate-hosted lead-zinc replacement, W-Be-Mo skarn/vein, and porphyry-Mo deposits.

There are three types of fluid inclusions found within the different deposits; primary two-phase liquid-vapor, primary three-phase inclusions that include liquid CO_2, and secondary three-phase inclusions that contained a solid mineral phase. Fluid inclusions that contain liquid CO_2 are primarily found in fluorite and quartz from the granite, the skarn, and porphyry deposits. Two-phase liquid-vapor inclusions show evidence of dissolved liquid CO_2 and are primarily found in the carbonate-hosted deposits. The inclusions with the solid mineral phases are found in fluorite from the skarn deposits.

The fluid inclusions from the porphyry deposit have a homogenization temperature range from 208° to 315°C and salinities between 2.0–11.9 eq. wt% NaCl. The fluid inclusions from the skarn deposits have a range of homogenization temperatures from 180° to 350°C and have salinities 2–22.5 eq. wt% NaCl. The fluid inclusions from the carbonate-hosted replacement samples have a range of homogenization temperatures from 105° to 289°C and salinities <2–5 eq. wt% NaCl. The carbonate-hosted replacement deposits contain two types of primary inclusions: liquid-vapor inclusions and two-phase inclusions that only contain liquid and vapor CO_2. The presence of two separate primary phases indicates that boiling may have occurred during the mineralization of this deposit. The results from the fluid inclusion analysis indicate the carbonate-hosted replacement deposits are slightly lower in temperature and salinity than the skarn and porphyry deposits.

Gases analyzed from fluid inclusions plot in two different compositional fields. The porphyry, skarns, and siliceous veins from the carbonate-hosted replacement deposits fall between the boundary of magmatic and shallow meteoric waters. The samples that plot in the magmatic and shallow meteoric fields also contain more CO_2 gas and hydrocarbons. Two samples, a breccia pipe sample and a sulfide sample from the carbonate-hosted replacement deposit, plot in the crustal waters field.

Pyrite and molybdenite from the skarns and porphyry samples and galena, sphalerite, and pyrite from the carbonate-hosted deposits were analyzed for sulfur isotopes. The $\delta^{34}S$ values ranged from 2.9 to 6.0 ‰ for the skarns and granite; one pyrite sample value was –11.2 ‰ from the skarns. The molybdenum samples in the skarns and granites had values that ranged from 4.7 to 6.7 ‰. The carbonate-hosted value for pyrite was 4.8 ‰; galena had a value of 4.0 ‰; sphalerite values ranged from 4.4 to 4.5 ‰. Using the fractionation factors for sulfides shows the majority of the calculated $\delta^{34}S_{H2S}$ values for the skarns, granite, and carbonate-hosted deposits plot between 2.0 and 6.0‰. This indicates calculated $\delta^{34}S_{H2S}$ values for the mineralizing fluid of the skarns, carbonate-hosted deposits, and granite are similar and are consistent with the three types of mineral deposits being derived from a similar mineralizing fluid.

Limestone and calcite sampled from drill hole GVM 21, within the skarn deposits, were analyzed for carbon and oxygen isotope values. The results indicate that both carbon and oxygen isotope values shift from unaltered values with increased Mo and WO_3 concentrations. This evidence suggests a greater water/rock ratio for the samples with high metals concentrations.

Collectively, the geochemical and isotopic evidence suggests that the skarns and porphyry-Mo deposits are related to the intrusion of the Victorio granite, and it is possible that the carbonate-hosted lead-zinc replacement deposits were mineralized during this same event. These data are consistent with a proposed model for the district that requires a change in temperature and salinity to move from high temperature skarn mineralization to lower temperature carbonate-hosted replacement mineralization.

ELECTRON MICROPROBE AGES OF DETRITAL(?), METAMORPHIC, AND IGNEOUS MONAZITE FROM THE BURRO MOUNTAINS, SOUTHWEST NEW MEXICO, by *Amos S. Sanders* and *Jeffrey M. Amato*, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003

The Burro Mountains of southwestern New Mexico consist of Precambrian metasedimentary rocks intruded by Proterozoic diabase and granitic rocks. The metasedimentary rocks are pervasively deformed. We determined the age of monazite by analyzing three metapelitic rocks and one granite using an electron microprobe in order to evaluate the age of the protoliths and the timing of peak metamorphism. For each thin section, we analyzed >5 points on 4–7 monazite grains, for a total of 161 analyses. Most grains were zoned in concentrations of the light rare-earth elements, as well as Th, U, and Pb. The cores of some grains contain high Y and low Th and U. These cores give the oldest ages. Rims of some of these grains have lower Y and high Th concentrations and younger ages. Other grains show minimal chemical zonation.

The ages have a histogram distribution that shows three distinct events. The oldest ages range from ~2.30 to ~2.125 Ga. The next youngest group of ages ranges from ~1.65 to ~1.375 Ga with peaks at 1.42 Ga and ~1.48 Ga. The youngest ages range from ~1.225 to ~1.100 Ga with a mean of ~1.175 Ga.

Typically, older ages have lower Pb, Th, and U concentrations resulting in larger analytical uncertainties. For example, core ages of ~2.20 Ga have 1 sigma errors of ~100 Ma, whereas the younger ages of ~1.45 Ga have errors of ~8–10 Ma.

Although the oldest ages (> 1.7 Ga) are probably speculative given the large uncertainties and small number of analyses, perhaps they represent the ages of detrital monazite grains. The oldest protolith dated in the Burro Mountains is a diabase ~1.630 Ga (McLemore et al., in press). In the data presented, no major event is recorded at ~1.630 Ga, but a group of ages randomly cluster from ~ 1.600 to 1.65 Ga, which may be related to magmatism at that time. The age clusters at 1.42 Ga and 1.48 Ga are similar to the ages of granitic plutons common in the southwest U.S., such as the 1445 ± 10 Ma Burro Mountain granite (Stacey and Hedlund, 1983). The older dates in the youngest group, ~1.225–1.100 Ga, could represent metamorphism associated with granitic intrusions in the Burro Mountains that yield Ar/Ar hornblende and biotite cooling ages of 1.22–1.20 Ga (McLemore et al., 2000).

GENETIC EVOLUTION OF THE MAGMATIC HYDROTHERMAL BRECCIA AND STOCKWORK VEINLETS OF THE GOAT HILL OREBODY, QUESTA PORPHYRY MOLYBDENUM SYSTEM, NEW MEXICO, by *A. Rowe*[1], *Virginia T. McLemore*[2], *B. M. Walker*[3], *David Norman*[1], and *N. Blamey*[1]; [1]Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; [2]New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801; [3]Molycorp, Inc., P.O. Box 469, Questa, NM 87556

The Goat Hill orebody of the Southwest ore zone of the porphyry molybdenum deposit at Questa, New Mexico, was mined from 1983 to 2000 with a total extracted production of 21.11 Mt at 0.318% MoS_2. Molybdenite in the Goat Hill orebody occurs in a magmatic-hydrothermal breccia (MHBX) that was cut by later quartz-molybdenite stockwork veinlets. The MHBX contributed 40% of the MoS_2 to the Goat Hill, whereas the younger stockwork veinlets contributed 60% of the molybdenite to the orebody. Ross et al. (2001) defined five distinct facies (A–E) from the bottom of the breccia body (A) adjacent to the source aplite intrusion, to the top and distal edges (E), respectively. Based upon quantitative study of breccia textures and preliminary stable isotope data, Ross concluded that the MHBX is primarily magmatic in origin with little or no meteoric component with $\delta^{18}O_{H2O}$ values of + 5.5–8.1 per mil and δD values of from – 125 to – 99 per mil.

The majority of fluid inclusions in the MHBX matrix quartz are primary with a minor secondary or pseudosecondary contribution. Fluid inclusion types observed in the matrix quartz are monophase liquid and vapor, vapor-rich and liquid-rich two phase, multiphase solid, and multisolid inclusions. Halite, hematite, and opaque daughter minerals are common. Preliminary homogenization temperatures of matrix fluid inclusions range from 381°C to 443°C. Salinities range from 8 to 50 eq. wt. % NaCl.

Fluid inclusions in the stockwork quartz-molybdenite veinlets are small (≤ 7.5 microns) and include both primary and secondary or pseudosecondary inclusions. Fluid inclusion types observed in the veinlet quartz are monophase liquid and vapor, vapor-rich and liquid-rich two phase, and multiphase solid. Only opaque daughters were observed in the vein inclusions. Preliminary homogenization temperatures of vein fluid inclusions range from 197 °C to 392°C. Salinities range from 0.7 to 8.5 eq. wt. % NaCl.

In contrast to the conclusion by Ross (2001), preliminary gas analyses of the C-zone matrix quartz have ratios of Ar-He-N_2 that suggest the MHBX ore fluid is primarily meteoric in origin with minor admixed magmatic fluid. Conversely, gas analysis of the quartz-molybdenite veinlets suggests that the veins are magmatic in origin.

Ross, P.S ., Jebrak, M., and Walker, B. M., 2001, Brecciation processes proximal to the apex of a crystallizing magma chamber—Insights from the Questa porphyry molybdenum deposit, New Mexico (abs.): GAC–MAC Joint Annual Meeting.

THE EFFECT OF WELDING AND POROSITY ON FAULT-ZONE STRUCTURES IN IGNIMBRITE DEPOSITS: EXAMPLES FROM THE BANDELIER TUFF, LOS ALAMOS, NEW MEXICO, by *Jennifer E. Wilson*, jenw@nmt.edu, *Laurel B. Goodwin*, lgoodwin@nmt.edu, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *Claudia J. Lewis*, clewis@lanl.gov, Earth and Environmental Sciences Division, Los Alamos National Laboratory, Los Alamos, NM 87545

Characteristics of faults in ignimbrite sequences are of interest for a variety of reasons, including their potential impact on fluid flow and contaminant transport. Small-displacement faults in the Bandelier Tuff of Los Alamos, New Mexico, display a range of deformation characteristics that are linked to petrophysical characteristics, such as porosity and degree of welding. The two basic structural features found among the ignimbrite units are shear fractures and deformation bands. The primary control on which of these features forms in response to deformation is degree of welding (cohesion of volcanic ash). Low-porosity welded units deform by transgranular fracture, resulting in shear fractures that are similar to well-studied faults in low-porosity crystalline rock. In contrast, high-porosity, non-welded units deform by cataclastic grain crushing and pore collapse within deformation bands. Deformation bands have been described previously only in high-porosity sandstones and poorly lithified sediments. Our investigation of the impact of variations in welding and protolith porosity on deformation characteristics strengthens the established link between porosity and mode of deformation in sedimentary rocks, and identifies welding as a critical component in this link. Through this research, we hope to develop criteria by which we can predict whether fractures or deformation bands will form in a given ignimbrite. Such criteria are necessary to develop accurate hydrologic models in ignimbrites since fractures and deformation bands affect porosity and permeability in very different ways. This has been illustrated in sedimentary rocks, where the presence of fractures increases fault-zone porosity and permeability, and deformation bands reduce porosity and saturated permeability.

POSTER SESSION 3—PALEONTOLOGY

TAXONOMY AND BIOSTRATIGRAPHIC SIGNIFICANCE OF THE ORNITHISCHIAN DINOSAUR *REVUELTOSAURUS* FROM THE CHINLE GROUP (UPPER TRIASSIC), ARIZONA AND NEW MEXICO, by *Andrew B. Heckert*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

Ornithischian dinosaur body fossils are extremely rare in Triassic rocks worldwide, and to date the majority of such fossils consist of isolated teeth. *Revueltosaurus* is the most common Upper Triassic ornithischian dinosaur and is known from Chinle Group strata in New Mexico and Arizona. Historically, all large (>1 cm tall) and many small ornithischian dinosaur teeth from the Chinle have been referred to the type species, *Revueltosaurus callenderi* Hunt. A careful re-examination of the type and referred material of *Revueltosaurus callenderi* reveals that: (1) *R. callenderi* is a valid taxon, in spite of cladistic arguments to the contrary; (2) many teeth previously referred to *R. callenderi*, particularly from the *Placerias* quarry southwest of St. Johns, Arizona, instead represent other, more basal, ornithischians; and (3) teeth from the Blue Hills north of St. Johns and Lamy, New Mexico, previously referred to *R. callenderi* pertain to a new species. The new species is more derived than *R. callenderi* and is one of the most derived Triassic ornithischians. However, detailed biostratigraphy indicates that the new species is older (Adamanian: latest Carnian) than *R. callenderi* (Revueltian: early-mid Norian). Both taxa have great potential as index taxa of their respective faunachrons and support existing biochronologies based on other tetrapods, megafossil plants, palynostratigraphy, and lithostratigraphy.

NEW MEXICO'S OLDEST DINOSAUR TRACK: A THEROPOD FOOTPRINT FROM THE UPPER TRIASSIC (ADAMANIAN: LATEST CARNIAN) OF WEST-CENTRAL NEW MEXICO, by *Andrew B. Heckert* and *Spencer G. Lucas,* New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

Tetrapod footprints are known from the Upper Triassic Chinle Group in Wyoming, Utah, Colorado, Arizona, and New Mexico. Most of these tracks are from the upper part of the Chinle Group in strata of the Rock Point Formation and its correlatives—strata of Apachean (late Norian-Rhaetian) age. Tracks older than Apachean are relatively rare in the Chinle Group, apparently due to the presence of more facies favorable to track preservation in the younger portion of the Chinle than in pre-Apachean strata. One of the oldest and most interesting pre-Apachean records is an apparent dinosaur track from the lower part of the Chinle at Fort Wingate, New Mexico. This specimen is from Museum of Northern Arizona (MNA) locality 530, catalogued as MNA V1581, and was originally described by Hasiotis et al. (1994; GSA Abstracts w/Programs, 26(6), 17). MNA V1581 is a single track preserved in convex epirelief on a matrix of olive-gray siltstone. The middle digit is 43 mm long, and is flanked by shorter digits that are 29 and 25 mm long (Fig. 1). The digits are long and slender, and the tips are pointed. The digits converge posteriorly to a "heel" that appears to be rounded, although it may not be complete. Each digit appears to preserve phalangeal pads, in the formula 2-3-4. On face value, MNA V1581 appears to be the tridactyl pes impression of a theropod dinosaur, usually referred to the ichnogenus *Grallator*. This seems a reasonable identification of MNA V1581, especially given its relatively long middle toe (mesaxonic), which is characteristic of *Grallator*. However, given that MNA V1581 is a single track, we consider the identification tentative. Therefore, contra previous assertions, this is not the track of a new ichnospecies, the oldest dinosaur from the Chinle, or an unexpected record. The Bluewater Creek Formation, and thus the track, is of Adamanian (latest Carnian) age, and probable trackmakers (small theropods) were diverse and locally abundant by Adamanian time. The oldest dinosaurs, including theropods, from the Chinle Group are from demonstrably older (Otischalkian) strata. Consequently, tracks of *Grallator* are not unexpected in the Chinle Group generally and the Bluewater Creek Formation in particular. Other tracks associated with MNA V1581 include a poorly preserved track of *Brachychirotherium(?)* and another, unidentifiable trace, both catalogued as MNA V3303.

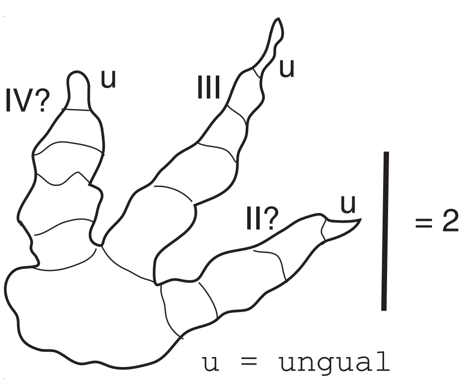

FIGURE 1—MNA V1581 from the Bluewater Creek Formation near Fort Wingate, New Mexico.

TETRAPOD ICHNOFAUNA FROM THE LOWER PERMIAN ABO FORMATION, FRA CRISTOBAL MOUNTAINS, SIERRA COUNTY, NEW MEXICO, by *Spencer G. Lucas, Allan J. Lerner*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; and *K. Krainer*, Institute for Geology and Paleontology, University of Innsbruck, Innrain 52, A-6020 Innsbruck, Austria

The presence of tetrapod footprints in the Abo Formation of the Fra Cristobal Mountains has been in the geological literature since the 1980s, but we have only recently been able to confirm and better document earlier reports. An extensive assemblage of tetrapod tracks is present in the Red Gap area in the lower part of the Abo Formation, ~ 20 m above the Bursum–Abo contact. The footprints occur in a 1–1.5-m thick bed of thin-bedded, ripple-laminated sandstone that can be traced laterally for at least 1 km. Vertebrate footprints in this bed can be referred to three ichnotaxa: *Batrachichnus delicatulus* (Lull), *Dromopus* Marsh, and *Limnopus* Marsh. Also present are conifer impressions (*Walchia*) and a single invertebrate bedding-plane burrow that is simple lined with meniscate backfill and regular curved branches along one side; it appears to represent the ichnogenus *Cladichnus* D'Allesandro & Bromley.

In the track-bearing interval, *Batrachichnus delicatulus* is extremely abundant, whereas other ichnotaxa are relatively uncommon. Individual tracks of *Batrachichnus delicatulus* range in size from 3 to 7 mm in length. Most tracks are preserved as digitigrade undertracks, some showing long drag marks indicating that they were made in a soft, wet substrate. Mid-line drag marks and indistinct trampled surfaces also occur. Mud cracks are present and indicate subaerial conditions at the time of track making.

The vertebrate ichnofauna in the Abo Formation at Red Gap shows low diversity when compared to other New Mexico Lower Permian tracksites. *Dimetropus* and *Gimoreichnus*, common elements that are attributed to large and small pelycosaurs, appear to be absent from the Red Gap ichnofauna. However, the Red Gap site may not yet have been adequately sampled and/or it may represent a facies different from other known Abo tracksites in New Mexico.

PROVENANCE OF THE HOLOTYPE OF *BELODON BUCEROS* COPE, 1881, A PHYTOSAUR FROM THE UPPER TRIASSIC OF NORTH-CENTRAL NEW MEXICO, by *Spencer G. Lucas*, *Andrew B. Heckert*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; and *Kate E. Zeigler*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

In the fall of 1874, Edward Drinker Cope (1840–1897) collected Triassic vertebrate fossils in an area just north of Gallina, Rio Arriba County, New Mexico. Subsequently, Cope's hired fossil collector, David Baldwin, obtained other Triassic vertebrate fossils in north-central New Mexico. Among the fossils Baldwin sent Cope is an incomplete phytosaur skull, AMNH (American Museum of Natural History) 2318, the holotype of *Belodon buceros* Cope, 1881. This skull is the first phytosaur skull described from the American West, and its exact provenance has never been ascertained.

The holotype skull has a packing slip written by David Baldwin that indicates it was "Sack 5. Box 5" shipped to Cope on 21 June 1881. The shipping manifest written by Baldwin, in AMNH archives, states the following for fossils shipped that date: "Sack 5. Box 5. Large reptile head, southeastern side of Rincon, Huerfano Camp, Arroyo Seco, end of snout or jaw dug out showing some front teeth, June 1881." The Arroyo Seco drainage is near Ghost Ranch in Rio Arriba County, and Baldwin evidently collected some of the syntypes and referred specimens of the dinosaur *Coelophysis* here in 1881. Furthermore, Baldwin's use of the term Huerfano camp may refer to Orphan Mesa (Huerfano is Spanish for orphan), an isolated butte just south of Arroyo Seco. Fossils collected by Baldwin, and our subsequent collections from Orphan Mesa, are from a fossiliferous interval high in the Petrified Forest Formation of the Chinle Group. It is thus highly likely that this is the stratigraphic provenance of the holotype of *Belodon buceros*. Indeed, the preservation of the specimen is similar to that of other vertebrate fossils from this horizon. Furthermore, elsewhere in the Chama Basin Chinle section, other fossils of *Belodon buceros* occur at this horizon, and only at this horizon.

We conclude that David Baldwin collected the holotype of *Belodon buceros* in the Arroyo Seco drainage near Orphan Mesa in Rio Arriba County, New Mexico (in, or near, T24N R4E). The fossil almost certainly was collected from a horizon in the upper part of the Petrified Forest Formation of the Chinle Group.

THE RAY *PSEUDOHYPOLOPHUS MCNULTYI* FROM THE CONIACIAN AND SANTONIAN OF CENTRAL NEW MEXICO, by *Sally C. Johnson* and *Spencer G. Lucas*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

The small, brackish water and marine ray *Pseudohypolophus mcnultyi* Thurmond is a common component of Late Cretaceous North American shallow marine selachian assemblages. Teeth of this ray have an external morphology that is nearly identical to those of other ray species such as *Hypolophus* and *Myledaphus,* but the histology of the *P. mcnultyi* teeth is very distinctive. Thus, the teeth of *P. mcnultyi* have an osteodentine root with either a layered or homogenous orthodentine crown. However, many times, the necessary histological work to identify these teeth is not undertaken. In this study, teeth from three localities NMMNH L-297, NMMNH L-342, and NMMNH L-4730 were studied to identify these ray teeth to species. These localities are in the Rio Puerco valley of central New Mexico, NMMNH L-342 and L-4730 are in the upper Coniacian Dalton Sandstone, and NMMNH L-297 is in the Santonian Hosta Tongue of the Point Lookout Sandstone. All three localities represent shallow marine depositional settings. The teeth from these three localities show a homogenous orthodentine crown and an osteodentine root. Seasonal growth lines can be seen in the enamel. The *Pseudohypolophus* teeth from these three sites are nearly identical in their internal structure and can be assigned with certainty to *P. mcnultyi*. Thus, they represent the first verified records of *P. mcnultyi* from the Cretaceous of New Mexico.

INVERTEBRATE FAUNAS OF THE LOWER ATRASADO FORMATION (PENNSYLVANIAN, MISSOURIAN), CERROS DE AMADO, SOCORRO COUNTY, NEW MEXICO, by *Barry S. Kues*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131; *Spencer G. Lucas*, *Allan J. Lerner*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; and *Garner L. Wilde*, GLW International, Midland, TX 79705

The Atrasado Formation crops out extensively in the Cerros de Amado, east of Socorro, but little detailed information on the stratigraphy and paleontology of the formation has been published. Fossil assemblages low in the 72-m-thick Atrasado section along Arroyo de los Pinos (sec. 25 T2S R1E) document a transition from nonmarine to marine environments. Near the base of this section, less than 10 m above the base of the Atrasado Formation, a 4-m-thick interval of thinly laminated, dark-gray shale contains plants, fish scales, conchostracans, and malacostracans indicative of a lacustrine environment. Near the top of this unit a thin bed of fissile "paper shale" is largely composed of vast numbers of densely packed, decalcified, complete valves of the bivalve *Dunbarella*. The presence of both juvenile and adult valves, and abnormally high density of the shells, suggest that this may represent a mass-kill event, possibly from a sudden influx of marine water into the brackish environment in which these bivalves lived. The transition to a marine environment is marked by a thin overlying bed of gray shale and profuse irregular encrusting algal growths with a fauna dominated by the brachiopods *Derbyia* and *Crurithyris*, representing a pioneering marginal marine community. The overlying 2 m of interbedded thin gray limestones and shales contain a diverse, stenohaline fauna distinguished by large numbers of the brachiopods *Hustedia* and *Hystriculina*, with lesser abundances of other brachiopods (*Juresania*, *Cancrinella*, *Rhipidomella*, *Composita*, *Punctospirifer*, *Beecheria*, *Cleiothyridina*, *Crurithyris*). The brachiopod *Chonetinella flemingi*, a widespread Missourian index species, supports the early to medial Missourian age (fusulinacean zones MC-1 to MC-2) indicated by fusulinaceans (*Triticites*) about 60 m higher in the section. Solitary rugose corals, fenestrate bryozoans, and crinoid fragments are also common, but molluscs and trilobites are rare. This phase of marine deposition ended with deposition of a thin, sparsely fossiliferous gray limestone unit bearing a fauna essentially limited to solitary rugose corals, *Crurithyris*, and crinoid debris, possibly representing a slightly hypersaline lagoon.

MAMMAL FOOTPRINTS FROM PLEISTOCENE LAKE OTERO, TULAROSA BASIN, WHITE SANDS MISSILE RANGE, DOÑA ANA COUNTY, NEW MEXICO, by *Gary S. Morgan*, gmorgan@nmmnh.state.nm.us., *Spencer G. Lucas*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; *John W. Hawley*, Hawley Geomatters, P.O. Box 4370, Albuquerque, NM 87196; *David W. Love*, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *Robert G. Myers*, U.S. Army, STEWS NR-ES-E, White Sands Missile Range, NM 88002

The Cenozoic strata of New Mexico contain a sparse record of fossil mammal footprints, including sites of Eocene, Oligocene, Miocene, and Pliocene age. We report the first Pleistocene record of mammal footprints, from the Tularosa Basin on the White Sands Missile Range in Doña Ana County, southern New Mexico. The footprint site is at an elevation of about 1,195 m on Alkali Flat (NM Museum of Natural History site L-4979), along the western shore of Pleistocene Lake Otero. The footprints were discovered in 1932 by a government trapper named Ellis Wright. Love, Hawley, and Donald Wolberg examined the footprints in 1981 and identified them as belonging to elephant (mammoth) and artiodactyl (camel). Lucas, Morgan, Myers, and Pete Reser visited the tracksite in 2001 and collected metric data on representative footprints.

The fossil footprints from the Lake Otero site were made by proboscidean (mammoth) and camelid trackmakers. The tracks, preserved in convex relief, appear to be undertracks. They occur in lacustrine sediments of the Otero Formation exposed over an area of about 75,000 m^2. The 25 preserved mammoth tracks are very large (maximum diameter 430–620 mm), round to ovoid in shape, and closely resemble published tracks identified as proboscidean. Two preserved mammoth trackways, one of six tracks and one of four tracks, indicate a 2–3 m stride length. A smaller heart-shaped track with two distinct digits and a pointed anterior end, photographed in 1981 is characteristically camelid. Although no such clearly preserved tracks remain at the site, a trackway of six footprints shows the pacing gait characteristic of camelids. These tracks have diameters of 160–180 mm and a stride length of about 1.3 m, dimensions compatible with a large camel. Teeth and postcranial bones found near the tracksite suggest the trackmakers were probably the Columbian mammoth (*Mammuthus columbi*) and a large extinct, llama-like camel (*Camelops hesternus*). Oriented trackways indicate these large ungulates walked to and from the waters of Lake Otero, probably to drink.

THE DIVERSITY OF NEW MEXICO TYRANNOSAUROIDEA, by *Thomas D. Carr*, thomasc@rom.on.ca, Department of Palaeobiology, Royal Ontario Museum, 100 Queen's Park, Toronto, Ontario, M5S 2C6; and *Thomas E. Williamson*, twilliamson@nmmnh.state.nm.us, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

Recent discoveries of diagnostic tyrannosaur specimens from late Campanian and late Maastrichtian strata of New Mexico coupled with a robust phylogeny of Tyrannosauroidea shed light on their biogeographic distribution in western North America.

Three incomplete tyrannosauroid skeletons collected from late Campanian beds of the San Juan Basin can be referred to two genera and species. The smallest skeleton is a juvenile of a new species of *Daspletosaurus*. Two large partial skeletons, presumably adults, are of a new genus of basal tyrannosauroid. The late Campanian tyrannosauroid fauna is similar to that of synchronous deposits in the northern Rocky Mountain region, in which sympatric genera are present (e.g., *Daspletosaurus* and *Albertosaurus* of the Dinosaur Park Formation).

Late Maastrichtian tyrannosauroids include incomplete isolated cranial and postcranial elements and isolated teeth from the Naashoibito Member, Kirtland Formation of the San Juan Basin, northwestern New Mexico that can be tentatively referred to *Tyrannosaurus rex* and a partial skeleton of an adult *T. rex* from the Hall Lake Member, McRae Formation at Elephant Butte Reservoir, south-central New Mexico. The occurrence of a single tyrannosauroid in the late Maastrichtian of New Mexico is congruent with the rest of western North America, in which *T. rex* is the only giant top predator.

The tyrannosauroid fauna of New Mexico differs from that of the northern Rocky Mountain region in the presence of a basal tyrannosauroid. Geographic isolation, in part, may account for this occurrence. However, a detailed examination of the historical biogeography of other Late Cretaceous dinosaur taxa of western North America is required to test this hypothesis. The presence of the basal genus and the new species of *Daspletosaurus* indicates that tyrannosauroid diversity in the late Campanian was higher than previously thought, which may be expected to increase as new fossils are sampled throughout Eurasia and North America. This diversity suggests that high rates of speciation may characterize the evolution of dinosaurs in western North America during the Late Cretaceous.

A JUVENILE PACHYCEPHALOSAUR (DINOSAURIA: PACHYCEPHALOSAURIDAE) FROM THE FRUITLAND FORMATION, NEW MEXICO, by *Thomas E. Williamson* twilliamson@nmmnh.state.nm.us, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; and *Thomas D. Carr*, thomasc@rom.on.ca, Department of Palaeobiology, Royal Ontario Museum, 100 Queen's Park, Toronto, Ontario, M5S 2C6

A juvenile specimen (NMMNH P-33893) of a pachycephalosaurid from the Fruitland Formation of Hunter Wash, Bisti/De-na-zin Wilderness Area (Hunter Wash local fauna), northwestern New Mexico (NMMNH locality L-4716) consists of a complete frontoparietal dome. The specimen is the first genuine report of a pachycephalosaur from the Fruitland Formation and represents only the fifth pachycephalosaur to be collected from the state.

The specimen is considered a juvenile because it resembles juvenile specimens of *Stegoceras* in that the frontoparietal is small (length = 75.5

mm), the frontoparietal suture and the suture dividing the frontals are distinguishable across the ventral surface of the skull roof (but not on the dorsal surface), the supratemporal fenestra are relatively large, the dome is restricted to the anterior two-thirds of the frontoparietals, and the sutural contacts for the marginal skull roofing bones are shallow resulting in a prominent parietosquamosal shelf.

The specimen is tentatively referred to a new genus and species of Pachycephalosauridae reported from the De-na-zin Member, Kirtland Formation (Williamson and Carr, in press). It lacks synapomorphies of *Stegoceras* (e.g., high frontonasal boss bordered laterally by grooves) and can be referred to Pachycephalosauridae by presence of a rostrocaudally inclined roof of the temporal fossa. NMMNH P-33893 shares with the holotype of the new pachycephalosaurid genus and species a narrow exposure of the parietals between the squamosals and a lack of nodes on the parietal. However, the specimen lacks squamosals that carry diagnostic autapomorphies of the new taxon, and therefore, a referral to the Asian genera *Prenocephale* and *Tylocephale* cannot be precluded.

This new pachycephalosaur specimen helps to reconstruct a hypothetical sequence of ontogenetic development of the dome in Pachycephalosauridae in which the skull roof is initially flat and the dome arises and develops with maturity. Juvenile pachycephalosaurids have a restricted dome and retain open temporal fenestrae and a prominent parietosquamosal shelf. The ontogenetic variability of the dome in pachycephalosaurids has important implications for pachycephalosaur taxonomy and phylogeny.

TURONIAN AMMONITES FROM THE UPPER CRETACEOUS D-CROSS MEMBER OF THE MANCOS SHALE, CEBOLLITA MESA, CIBOLA COUNTY, NEW MEXICO, by *Paul L. Sealey* and *Spencer G. Lucas*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

At Cebollita Mesa southeast of Grants in Cibola County (T6N R10W), the D-Cross Member of the Mancos Shale is ~52 m thick and is underlain by the Tres Hermanos Formation and overlain by the Gallup Sandstone. The ammonite fauna includes *Scaphites ferronensis* Cobban, *Prionocyclus novimexicanus* (Marcou), and *Coilopoceras inflatum* Cobban and Hook.

S. ferronensis is locally abundant in the D-Cross Member of the Mancos Shale at Cebollita Mesa. Specimens are clustered in small concretions low in the section, ~8 m above the base of the D-Cross.

P. novimexicanus is abundant in the D-Cross Member at Cebollita Mesa and occurs throughout most of the D-Cross Member's thickness, from its base up to ~9 m below the D-Cross–Gallup contact. Although two inner whorls were collected, most specimens are adult whorls in concretions and are delicate and difficult to extract. *P. novimexicanus* is characterized by a conspicuous, finely serrate keel, a compressed whorl section (higher than wide) that is subquadrangular, sinuously ribbed, and possesses a single row of ventrolateral tubercles.

C. inflatum is restricted to the lowermost 5–6 m of the D-Cross Member. The adult robust specimens are characterized by a distinctive inflated appearance with a prominently ribbed shell possessing radial swellings. All but one specimen collected at Cebollita Mesa are the robust form of *C. inflatum*.

The occurrence of the *Scaphites ferronensis* zone at Cebollita Mesa indicates correlation of the lower part of the D-Cross there with the upper part of the Juana Lopez Member of the Mancos Shale at the type section and the lowest part of the D-Cross Member of the Mancos Shale at Puertecito. S*caphites whitfieldi* Cobban has not been recovered from the D-Cross at Cebollita Mesa, but the middle-upper part of the member there should be in that zone.

POSTER SESSION 4—STRATIGRAPHY AND SEDIMENTOLOGY

PETROLOGY AND DEPOSITIONAL ENVIRONMENTS OF THE MENEFEE FORMATION NORTH OF REGINA, NEW MEXICO, by *J. F. Alberto Amarante*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM, 87801; *Brian S. Brister*, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801; *William Peabody* and *T. H. McElvain, Jr.,* McElvain Oil and Gas Co., Santa Fe, NM 87504

The Menefee Formation is generally regarded to be nonmarine in origin, underlain by the regressive marine Point Lookout Sandstone and overlain by the transgressive marine Cliff House Sandstone. The three formations comprise the Mesaverde Group. Most previous research of the Menefee Formation has focused on the coal and humate deposits mined today in the southern part of the San Juan Basin. In the northern part of the basin, sandstones in the Menefee are potentially important underdeveloped natural gas reservoirs. Their complex depositional facies, stratigraphy and reservoir characteristics have been poorly understood. A 147 m stratigraphic section was measured on the eastern hogback of the basin north of Regina, New Mexico, 1.2 km north of highway 96. A detailed description of the strata, focusing on the sandstone beds, was compiled.

Four major lithofacies represent distal floodplain (coastal swamp to marsh) to deltaic deposition. Lithofacies Jm-1 (21% of total) consists of laminated gray mudstone, interpreted to represent distal deltaic (subaqueous) inter-distributary channel deposition. Lithofacies Jm-2 (25% of total) is dominated by brown mudstone and coally mudstone to humate, interpreted to represent overbank swamp to coastal marsh deposition. Lithofacies Jm-3 (12% of total) comprises planar bedded sandstone, interpreted to be crevasse splay deposits in part. Lithofacies Jm-4 (42% of total) is trough crossbedded, channelized sandstone, interpreted to have been deposited in deep and narrow deltaic distributary channels. Some channel sands are *Thalassinoides*-burrowed, interpreted to indicate distributary channel backflooding (estuarine environment).

Petrography of six thin sections from sandstone beds yields point-counted framework grain composition of quartz (46%), chert (30%), feldspar (4%), and other rock fragments (3%). Chert is anomalously high compared to published data. Clay matrix averages 14% and cement 3%. Two major cement associations are observed, including coarse crystalline (poikilotopic) calcite-glauconite-dolomite-siderite-hematite (replacing dolomite) in lithofacies Jm-4; and fine-crystalline calcite-glauconite-hematite in lithofacies Jm-3. Gamma ray measurements reveal that the Menefee sandstone beds have higher counts than bounding formations, particularly high in the sideritic sandstone. Glauconite, and authigenic and detrital dolomite, both potentially of marine origin, are recognized in interpreted estuarine sandstone beds. A bentonite bed in coal at the top of the formation yielded a sanidine $^{40}Ar/^{39}Ar$ age of 78 ± 0.26 Ma (2σ error).

Although further work is required, it is possible that, in contrast to previous published research, more distal depositional models should be applied to the Menefee Formation in the northern, gas-productive part of the San Juan Basin than have been described in the southern part of the basin. This could have important implications for exploration and development of this resource as increased-density drilling proceeds.

TYPE SECTION OF THE PENNSYLVANIAN ATRASADO FORMATION, LUCERO UPLIFT, VALENCIA COUNTY, NEW MEXICO, by *K. Krainer,* Institute for Geology and Paleontology, University of Innsbruck, Innrain 52, A-6020 Innsbruck, Austria; and *Spencer G. Lucas*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

In 1946 Kelley and Wood (USGS Oil and Gas Inv. Prelim. Map 47) named the Missourian–Virgilian Atrasado Member of the Madera Formation in the Lucero uplift, but did not describe a type section. An excellent lectostratotype section of the Atrasado Formation of the Madera Group is exposed in secs. 35–36 T6N R3W. Here, the Atrasado Formation is ~100 m thick and can be divided into five lithologically distinct units.

Unit A (31.5 m) starts with a 0.5-m thick conglomerate and sandstone that rests on limestone at the top of the Gray Mesa Formation. A covered interval is followed by gray, fossiliferous, bedded limestone forming several ledges up to 2 m thick. Limestones in the lower part of this unit contain abundant fusulinaceans; some beds contain brachiopods, bryozoans, calcareous algae, and crinoid fragments. Unit B (22 m) consists of 4 cycles, each composed of (from base to top): (1) massive gray algal limestones, (2) dark-gray, micritic, bioclastic limestones, and (3) covered intervals (shale).

A polymict conglomerate forms the base of unit C (18.4 m). It is overlain by gray, bedded fossiliferous limestone that in the lower part is indistinctly wavy bedded, bioturbated, and contains chert nodules. Overlying limestones are fossiliferous, with abundant bryozoans. The topmost bed is a dark-gray, micritic limestone. Above this follow 14.1 m of greenish-grayish shale, mostly covered, with two intercalated, fine-grained, sandstone beds in the middle (unit D). The uppermost unit, E (13.6 m), is composed of wavy to irregularly bedded gray limestone, locally containing calcareous algae, crinoids or fusulinaceans. In the upper part, nodular shale and pale-green shale are present. The base of the overlying 2.5-m thick sandstone interval is the base of the Red Tanks Member of the Bursum Formation.

Limestones of the type Atrasado Formation are characterized by muddy textures and diverse biota indicating deposition in an open shelf environment below the wave base within the photic zone under normal marine salinity. Coarse clastics most probably document tectonic events.

DEPOSITIONAL ENVIRONMENT OF A LIMESTONE AND CHERT UNIT IN THE MIOCENE POPOTOSA FORMATION, CAÑONCITO DE LAS CABRAS AREA, SOCORRO COUNTY, NEW MEXICO, by *Becky J. McGill*, bmcgill@nmt.edu, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Several thin carbonate and chert units of unknown origin occur within 15–20 m of section in a clastic succession in the Popotosa Formation near Cañoncito de las Cabras. The two most continuous units are 20–60 cm thick and can be followed over several kilometers. They have not been studied in detail and have the potential to provide significant information about local depositional environments. A preliminary study was made of the upper, most fossiliferous unit in order to determine depositional environment. Data were collected by examining features of the unit in outcrop, hand sample, and thin section, with study concentrated at three type locations representing different ratios of chert to limestone. Numerous fossils were found, including thin-shelled ostracods, pelecypod fragments, root casts, plant debris, and unidentified large and small tube-shaped fossils, which are suggestive of some type of encrusted aquatic plant. Other features observed include small-scale compositional layering and solution breccias. The presence and distribution of these features suggest deposition in a lacustrine environment of moderate salinity, with littoral and profundal environments represented, although other environmental influences (e.g. springs) may have been present.

POSTER SESSION 5—GROUND WATER/ GEOMORPHOLOGY

NATURAL ARSENIC DISTRIBUTION IN GROUND WATER IN THE SOCORRO, NEW MEXICO, AREA OF THE MIDDLE RIO GRANDE RIFT, by *Lynn A. Brandvold* and *Patricia L. Frisch*, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Arsenic occurs naturally in ground waters in the Socorro and San Antonio area of the middle Rio Grande rift in central New Mexico. The Socorro geothermal springs (33°C) have arsenic levels of ~40 ppb and have been used by the city as drinking water sources for over 150 yrs; two other municipal supply wells (20°C –23°C) have levels of 22–25 ppb. Some Bosque del Apache Wildlife Refuge irrigation wells, including one geothermal well (32°C), show elevated arsenic. The high arsenic ground waters were studied in the field by Eh, pH, temperature, alkalinity, and conductivity. Some samples were also field separated for As(III) and As(V). Arsenic was in the As(V) form in all these samples. Major and trace element analyses were performed in the laboratory. The springs and wells in the study area are located in part of the middle Rio Grande rift zone, which is characterized by north-south trending high angle extensional faults. Elevated levels of arsenic in the Socorro area are found in waters that spring from silicic volcanic rock and issue from a well-defined rift-fault line. These springs further coincide with an ancient hydrothermal system that formed several small orebodies; minerals reported in this area include mimetite, $(PbCl)Pb_4(AsO_4)_3$. In the Bosque del Apache, arsenic levels of 10–39 ppb are found in several wells that correlate with basin sediments that include volcanics and a known deep fault. The geothermal well is centrally located in this lineament. Ground-water geochemistry has not been correlative with high-arsenic waters. The relationship between rock type and arsenic concentration in water is not well defined in this study area. What is most evident is the linearity of anomalous arsenic wells. Our data suggest that arsenic is being supplied from deep circulating ground waters that have long residence times and are enriched in arsenic. These arsenic enriched waters are mixing with shallow recharge and are issuing from springs in the Socorro area. The mid-range arsenic in the two municipal supply wells located down gradient from the springs is possibly a further result of mixing. In the Bosque del Apache, wells that intersect the Rio Grande rift faults show elevated arsenic, and it is postulated that these deeper waters are the source of elevated arsenic in this study.

FRACTURE CHARACTERIZATION OF THE BANDELIER TUFF IN CAÑON DE VALLE, LOS ALAMOS, NEW MEXICO, FOR SEISMIC HAZARDS AND FLOW AND TRANSPORT ANALYSIS, by *R. A. Channell*, *C. Lewis*, Los Alamos National Laboratory, Los Alamos, NM 87545; *C. W. Criswell*, Roy F. Weston, Inc., Albuquerque, NM; *A. Lavine* and *K. V. Bostick*, LA-UR-02-0796, Los Alamos National Laboratory, Los Alamos, NM 87545

A seismic hazards investigation and the need to understand hydrologic transport through fractured bedrock motivated fracture characterization in the Tshirege Member of the Bandelier Tuff (welded and non-welded units 3, 3T, and 4) at material disposal area P (MDA-P) at Los Alamos National Laboratory. We measured 454 fractures along eight traverses to characterize fracture distribution, orientation, and aperture in three dimensions. Removal of over 50,000 cu yd of waste from MDA-P exposed 87% of the bedrock along traverses. Fractures show a preferred orientation of N15°W with some scatter due to cooling joints. Background fracture density in the non-welded tuff is 20 fractures/100 ft, representing a tectonic signature. Apertures in all units are bimodal (0–4 mm and 10–14 mm); 79% of large apertures (20–110 mm) are in welded units 3 and 3T. Higher fracture densities (to 40 fractures/100 ft) and larger apertures in the welded tuffs demonstrate the influence of cooling joints. Only a few fractures are open; 89% are filled with clay and roots. The fractures dissecting MDA-P have a mean trace length of only 9.5 ft, and therefore are not large structural features. Geologic mapping adjacent to the study area indicates that fracturing may be related to monoclinal folding associated with deformation in the hanging wall of the Pajarito fault. Characterizing fractures at MDA-P also establishes a foundation for modeling flow and transport in fractured Bandelier Tuff.

USE OF FLEXIBLE LINERS IN UNSTABLE ANGLED BOREHOLES AT LANL, by *William J. Stone*, u113583@pobox1663.lanl.gov, Los Alamos National Laboratory, Los Alamos, NM 87545

A low-head weir was installed in lower Los Alamos Canyon to eliminate off-site transport of contaminant-bearing sediment by fire-enhanced runoff. Perched water occurs in basalt beneath the area. To monitor the impact of ponding at the weir on subsurface water quality, three boreholes (one vertical, one at 43°, and one at 34°) were drilled. As the basalt is highly fractured and unstable, holes had to be drilled by casing-advance methods. To keep the angled holes open when casing was retrieved, but still permit the flexible liners used for monitoring to contact the basalt, a shield was inserted. It consists of 6-inch PVC in which three 30-inch scallops were cut out per 10-ft length. The ideal orientation for the shield is with scallops on the bottom. However, cutting scallops resulted in sufficient weight loss that the shield rotated upon insertion down the casing, placing the scallops on top. This would have allowed rock to fall in when the casing was pulled. Alternating blank and scalloped sections of PVC solved the problem in the 43° hole (but not the 34° hole). When the liner was everted into the 43° hole by inflation, it tried to go out into the annulus through the first scallop encountered. To prevent this, the liner was installed un-inflated and bundled with its bottom in a sleeve tied to the tip of a small diameter PVC rod used to push the material into the cased hole. A centralizer at the end of the rod guided it past scallops. When the bottom of the hole was reached, the liner was partially inflated. Weak thread selected to bundle and attach the liner to the rod broke upon inflation, permitting the rod and centralizer to be readily retrieved. Plans call for drilling out the shield in the 34° hole and casing it with perforated PVC along most of its length. The annular space shall be filled with material to provide continuity between the highly fractured basalt and the PVC. Such construction will permit frequent neutron-probe moisture surveys, as well as sampling soil water with an absorbent liner.

A COMBINED GIS–HEC FLOODPLAIN MAPPING TECHNIQUE FOR MOUNTAINOUS WATERSHEDS, by *Mark E. Van Eechkout, Marcia A. Jones*, and *Stephen G. McLin*, sgm@lanl.gov, Los Alamos National Laboratory, Los Alamos, NM 87545

A combined GIS–HEC modeling application for floodplain analysis of pre- and post-burned watersheds is described. The burned study area is located on Pajarito Plateau near Los Alamos, New Mexico (USA), where the Cerro Grande wildfire burned 42,878 acres (17,353 ha) in May 2000. This area is dominated by rugged mountains that are dissected by numerous steep canyons. Vegetation consists of piñon-juniper woodlands located between 6,000–7,000 ft (1,829–2,134 m) above mean sea level (ft MSL), and ponderosa pine stands between 7,000–10,000 ft MSL (2,134–3,048 m). Approximately 17% of the burned area is located within Los Alamos National Laboratory, and the remainder is located in upstream or adjacent watersheds. Pre-burn floodplains were previously mapped in 1990–91 using early HEC models as part of the RCRA/HSWA permitting process. Numerous recording precipitation and stream gages have also been installed. These data provide essential information characterizing rainfall-runoff relationships before and after the fire. They are also being used to monitor spatial and temporal changes as forest recovery progresses. Post-burn changes in HEC–HMS predicted rainfall-runoff patterns are related to changes in watershed vegetation cover and hydrophobic soil conditions. The 2000 and 2001 summer monsoon seasons provided several significant runoff events for model calibration. HEC–HMS modeled responses were sequentially refined so that observed and predicted hydrograph peaks were matched at numerous channel locations. The 100-yr, 6-hr design storm was eventually used to predict peak hydrographs at critical sites. These results were compared to pre-fire simulations so that new flood-prone areas could be systematically identified. Stream channel cross-sectional geometries were extracted from 1-ft (0.3-m) DEM data using ArcView GIS. Then floodpool top widths, depths, and flow velocities were remapped using the HEC–RAS model. Finally, direct comparisons are made to floodplains created with USGS 3- m DEM data.