Abstracts

New Mexico Geological Society spring meeting

The New Mexico Geological Society annual spring meeting was held on April 11, 2003, at New Mexico Institute of Mining and Technology, Socorro. Following are the abstracts from all sessions given at that meeting.

SESSION 1—CAVES AND KARST

CLIMATE VARIABILITY DURING THE LATE HOLOCENE IN THE SOUTHWEST UNITED STATES FROM HIGH-RESOLUTION SPELEOTHEM DATA, by *Jessica B. T. Rasmussen*, jbtoledo@unm.edu, *Victor J. Polyak*, and *Yemane Asmerom*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

The effort to constrain past climate change depends on the availability of high-resolution records. This is especially true in continents, where datable material is scarce. Annual growth banding has been shown to occur in some speleothems; this, combined with U-Th ages that have an uncertainty of around 25 yrs (2-sigma) in clean Holocene samples, suggests that speleothems have the potential to provide robust, quantitative climate data. In moisture-limited regions, such as the southwestern U.S., stalagmite growth and growth hiatuses, annual band thickness, and mineralogical, elemental, and isotopic variations in speleothems can be used as a record of regional effective moisture. From stalagmite growth in the Guadalupe Mountains of New Mexico, this region is shown to have experienced greater than present-day moisture beginning ~4 ka, specifically between ~3 ka and 0.8 ka, following a dry middle Holocene. From the annual band thickness of multiple stalagmites, an indicator for growth rate, this region experienced distinct wet and dry events over this time period; for instance wet events (intervals of increased growth rate) are observed at 2.8 and 2.0 ka, and a dry event (hiatus) between 0.7 and 0.45 ka. A wet interval is also observed between 0.46 and 0.17 ka, correlating to the Little Ice Age. Calibration of the speleothem record to the historical climate record is currently in progress, along with analyses of these and other stalagmites for elemental variations. Ultimately this study will constrain specific relationships between physical, mineralogical, elemental and possibly isotopic variations in speleothems and changes in effective precipitation.

TIMING OF CLIMATE CHANGE IN THE SOUTHWESTERN UNITED STATES AROUND THE YOUNGER DRYAS, by *Victor J. Polyak*, polyak@unm.edu, *Jessica B. T. Rasmussen*, and *Yemane Asmerom*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 87131

Speleothem growth in moisture-limited regions, such as the Guadalupe Mountains, New Mexico, is a good indicator of past regimes of effective precipitation. Although the Holocene is seen as a dry period in the southwestern United States, periods of stalagmite growth are helping to resolve the wetter episodes from the drier ones. The Pleistocene–Holocene transition, an important and interesting period in the southwestern United States, coincides with the Younger Dryas event, best-documented early human colonization, and extinction of some important megafauna. Six columnar stalagmites from three caves in the Guadalupe Mountains show growth beginning near the start of the Younger Dryas and ending abruptly in the earliest Holocene. This period of growth reflects overall wetter conditions for the southwestern United States from about 12,500 years ago to no later than 10,500 years ago. Lack of, or less stalagmite growth from about 14,000 to 12,500 years ago indicates somewhat drier conditions during this interval. Growth hiatuses show the onset of distinctly drier conditions around 11,000 years ago with no growth represented after 10,500 years ago. The climate remained significantly drier until the late Holocene. The period of most significant growth started during and extended a millennium beyond the Younger Dryas event. We conclude that, although overall wetter conditions prevailed during the Pleistocene–Holocene transition, there is a lack of synchroneity between the Younger Dryas event and effective precipitation in the southwestern United States.

THE CAVES OF FAJA DE ORO, by *Dan M. Cox*, 1402 Hidden Terrace Dr., Sugar Land TX 77479

Seismic interpretation of the Santa Agueda field 3-D survey reveals a complex history of repeated exposures of the Lower Cretaceous El Abra reef front, along the western edge of the Faja de Oro atoll. The highest primary porosity is found within the back-reef debris apron. This depositional facies tract subsequently controlled permeability pathways that lead to cavernous secondary porosity development. Repeated subaerial exposure resulted in this cave system reaching late stage maturity with the "collapse" of the largest caverns. Within this readily mappable "collapse" zone all remnants of cavernous porosity are filled with cave breccias, syn- and post-exposure Tertiary clastics. Along the eastern edge of the "collapse," there are preserved lesser caverns as the original higher porosity and permeability facies that controlled subsequent cave development pinched out into the mud-rich lagoonal facies. Structural and depositional reconstructions over the "collapse," identification of the last paleo-water table (base of porosity), and circular seismic anomalies (possibly representing deepest preserved cave development) deeper within the platform suggest several periods of exposure in which the El Abra reef was sub-aerially exposed to altitudes of several thousand feet. The Santa Agueda field 3-D seismic survey and interpretation was the first acquisition and mapping along the western edge of the Faja de Oro atoll. Special thanks to PEMEX Exploration-Alfredo Guzman for permission to present this work.

ROLE OF EVAPORITE KARST IN REGIONAL GROUND WATER CIRCULATION IN THE LOWER PECOS VALLEY, by *Lewis A. Land*, New Mexico Bureau of Geology and Mineral Resources CEMRC, 1400 University Dr., Carlsbad, NM 88220

Natural ground water discharge occurs from a series of cenotes, or sinkhole lakes, along the east side of the Pecos River floodplain at Bottomless Lakes State Park, Chaves County, New Mexico. The lakes are fed by submarine spring discharge from the underlying San Andres artesian aquifer, which has caused subsurface dissolution and collapse of overlying gypsum and mudstones of the Artesia Group. The lakes are unique in that they occur in a semi-desert setting, where annual evaporation rates exceed mean annual precipitation by a factor of seven or more. An increase in spring discharge at Lea Lake in recent years reflects the combined effects of rising water levels in the artesian aquifer and enhanced spring flow because of mass wasting processes along the steep eastern margin of the lake. Although the Bottomless Lakes cenotes formed before European settlement in New Mexico, catastrophic solution collapse and sinkhole formation remain active processes along this portion of the lower Pecos.

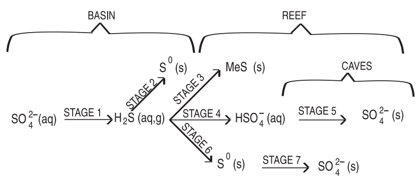
HIGH-RESOLUTION DIGITAL TOPOGRAPHIC MODELS OF SPELEOTHEMS OBTAINED FROM A 3-D LASER SCANNING SURVEY, by *Seiichi Nagihara*, seiichi.nagihara@ttu.edu, Department of Geosciences, Texas Tech University, Lubbock, TX 79409

A detailed three-dimensional topographic map of the interior of a natural cavern, if available, would be very useful in understanding its geomorphic development. However, obtaining such a map is extremely difficult and time-consuming, if one simply relies on conventional surveying techniques. Here we test the feasibility of using a 3-D laser scanner to quickly generate high-resolution topographic models of the interior of a cavern. A 3-D laser scanner is a type of land-based LIDAR (LIght Detection And Ranging) instrument. It sweeps the surrounding environment with optical rays. The rays produce reflections when they encounter solid objects. The instrument records the angle of each ray and measures the two-way travel time of the corresponding reflection. The survey data can be displayed on a computer screen as a cloud of reflection points that delineate the geometrical shape of the scanned objects. Individual reflection points can be spaced within 1 cm from one another. Here we report data from a 3-D scanning survey conducted in the Big Room of the

Carlsbad Cavern. Almost 8 million reflection points were recorded in the vicinity of a flowstone feature called "Frozen Niagara Falls" during an overnight experiment. Later, we constructed a continuous, 3-D surface model of the flowstone by interpolating the point cloud.

SULFUR REDOX REACTIONS: HYDROCARBONS, NATIVE SULFUR, MISSISSIPPI VALLEY-TYPE DEPOSITS, AND SULFURIC ACID KARST, DELAWARE BASIN, NEW MEXICO AND TEXAS, by *Carol A. Hill*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Sulfuric acid karst should be considered as an integral part of the evolution of petroleum-evaporite basins. In the Delaware Basin, New Mexico and Texas, sulfuric acid karst is related to hydrocarbons, native sulfur, and Mississippi Valley-type ore deposits through a series of sulfur redox reactions:



Stage 1 in the above redox-reaction diagram represents the microbial (*Desulfo-x*) production of isotopically light H_2S from hydrocarbons in the basin. Stage 2 represents the non-microbial production of economic native sulfur deposits in the basin (e.g., Culberson sulfur mine). Stage 3 represents H_2S that migrated from basin to reef to form Mississippi Valley-type ore deposits (metal sulfides), located in the same structural and stratigraphic traps as the caves. Stages 4 and 5 represent the migration of H_2S into the Capitan reef complex and the dissolution of cave passages by a sulfuric acid mechanism, with gypsum forming as a by-product. *Thiobacillus* could have been involved in the reactions of these two stages. Stage 6 represents the formation of cave sulfur from H_2S in the zone of aeration, and Stage 7 represents the oxidation of this sulfur to gypsum within the cave environment.

SULFURIC AND HYDROFLUORIC ACID SPELEOGENESIS ASSOCIATED WITH FLUORITE-JAROSITE MINERALIZATION ALONG THE RIO GRANDE RIFT, NEW MEXICO, by *Virgil W. Lueth*, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining & Technology, Socorro, NM 87801; and *Robert O. Rye*, U.S. Geological Survey, Denver Federal Center, Denver, CO 80225

Caves associated with fluorite-jarosite mineralization in the Hansonburg and North Franklin Mountains districts may have formed from different solution types. These caves display spongiform and irregular walls and contain significant amounts of halloysite clay.

The caves at Hansonburg are mineralized and large masses of gypsum contain mineralized limestone rafts and textures indicating limestone replacement. The low $\delta^{34}S$ values of gypsum (-7.2‰) and jarosite (-25 ‰) are similar to those for gypsum and alunite, respectively, at Carlsbad Caverns, New Mexico and also to those of hydrothermal pyrite (-23‰), consistent with cave formation during ore deposition. The aqueous sulfate that formed jarosite and some of the primary gypsum was likely derived from the oxidation of isotopically light H_2S. Some of the later cave-fill gypsum at Hansonburg has high $\delta^{34}S$ values (6.5 to 13.9‰) indicating aqueous sulfate derivation from the overlying Permian formations.

The cave at the Copiapo deposit in the North Franklin district is unmineralized and is located below the level of ore, a feature commonly observed in the Illinois–Kentucky fluorspar district. The presence of prosopite, $CaAl_2(F,OH)_8$, and fluorite in the halloysite envelope around the deposit attest to the high F activity in the earliest mineralizing solutions. Exceptionally low $\delta^{34}S$ values for some of the jarosite (~-25‰) and gypsum (-11‰) also indicate that aqueous sulfate formed from isotopically light H_2S, as it did at Hansonburg and Carlsbad. However, the occurrence of the cave below the level of jarosite formation suggests that the fluids from depth were already acidic before H_2S was oxidized at higher levels and implies cave formation by hydrofluoric acid speleogenesis.

MINERAL DEPOSITS, MINING, AND KARST, by *Virginia T. McLemore*, ginger@gis.nmt.edu, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Karst terrains contain many types of mineral deposits by providing ideal deposition cavities for minerals. Minerals associated with karst have been exploited for many years. More than 80 mining districts in New Mexico are in carbonate rocks, and most have some indication of karst before, during, or after mineral deposition. Many of these deposits could not have formed without some karstification. Mineralization and alteration are strongly controlled by secondary porosity such as faults, fractures, brecciation, and dissolution features produced as a result of karstification. Lead-zinc deposits hosted by carbonate rocks in New Mexico account for 37% of the lead and 56% of the zinc production from the state. Mines from the Todilto Limestone in the Grants district account for 2% of the total uranium production. Uraniferous collapse-breccia pipes in the Cliffside, Doris, and Jackpile–Paguate mines have yielded uranium ore as part of mining adjacent sandstone deposits. More than 600 collapse-breccia pipes are found in the Ambrosia and Laguna subdistricts, but only a few are uranium bearing. The pipes were probably formed by solution collapse of underlying limestone or evaporate.

Furthermore, the sedimentary rocks subjected to karst are potential commodities. New Mexico is known for large reserves of limestone, gypsum, potash, and halite. The Carlsbad potash district is the largest potash producing area in the U.S. New Mexico ranked 7th in gypsum production in the U.S. in 2001. Limestone is quarried throughout New Mexico for aggregate, cement, concrete, crushed stone, dimension stone, and specialty uses. More than 70% of crushed stone produced in the U.S. is from carbonate rocks. Guano (a source of nitrate) also was mined from caves throughout New Mexico in the late 1800s and early 1900s.

Geologic hazards related to mining of mineral deposits in karst terrains include removal of rock that results in subsidence (i.e. formation of induced sinkholes, caves), lowering of the ground water (locally resulting in subsidence), contamination of ground water (i.e. waste water discharge, acid mine drainage), and changing ground-water flow patterns (including increased mine water drainage). However, the effects of mining in karst in New Mexico are poorly documented. Future production of these resources can be accomplished with no significant impacts to the environment, if done carefully with a complete understanding of the geology.

METER SCALE CALCITE SPELEOTHEMS IN THE MISSION TUNNEL, SANTA BARBARA, CALIFORNIA: A 90-YR RECORD OF GROWTH IN FRACTURED ARKOSIC SANDSTONE, by *J. R. Boles*, boles@magic.ucsb.edu, University of California, Santa Barbara, Department of Geological Sciences, Santa Barbara, CA 93106

The 6-km-long Mission Tunnel was completed in 1912 to provide water from Gibraltar Dam to Santa Barbara, California. The subhorizontal, partially unlined tunnel cuts through steeply dipping marine sandstone and shale of the Santa Ynez Mountains, to a depth of 670 m beneath the ground surface. Ground water seeping from the unlined sandstone sections has produced extensive and spectacular calcite speleothems on the roof and sides of the tunnel, including large stalactites, cave bacon, flowstone (1.5 m), thick rinds on wood beams and cables, and rare stalagmites. Calcite growth rates are up to an order of magnitude higher than estimated in natural caves. The extensive precipitation of calcite records almost 100 yrs of evolving fluid flow from fractures and water-rock interaction.

The cements in the Mission Tunnel exhibit growth bands with episodes of dissolution and precipitation, resulting in a loosely cemented structure. Both manganese oxide and ferric oxides are associated with some speleothems. The earliest calcite tends to be more porous than the latest calcite in the speleothems.

Based on carbon dating, the source of carbon in the calcite appears to be largely modern (CO_2 from soil?). Sr isotopic values suggest that the calcium is derived from feldspar or clay reactions. Oxygen and carbon isotopic values from the calcite range from -4.5 to -9 and -4 to -15 (PDB), respectively. The oxygen isotopic composition in the most recent calcite is about 5 per mil higher than expected for isotopic equilibrium with the present 26°C seep water, which is about -7.5 SMOW in the central part of the tunnel. This disequilibrium suggests that biological processes are involved in the crystallization. Both oxygen and carbon isotopes show systematic trends of heavier values (as great as 5 per mil) with growth. This trend and the decreasing porosity with growth may result from gradual slowing of the flow because of self sealing of the fracture pathway, slowing of the water-rock interactions during leaching of the mineral surfaces, or the evolution of biological communities.

CAVE FERROMANGANESE DEPOSITS: SUBTERRANEAN SOIL DEVELOPMENT?, by *Michael N. Spilde*, mspilde@unm.edu, Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131; *Penelope J. Boston*, Department of Earth and Environmental Science, New Mexico Institute of Mining and

Technology, Socorro, NM 87801; and *Diana E. Northup*, Department of Biology, University of New Mexico, Albuquerque, NM 87131

Accumulations of low density, soil-like material line the walls, floors, and ceilings of some caves. In Lechuguilla and Spider Caves in Carlsbad Caverns National Park, New Mexico, this material is particularly well developed, but similar material has recently been found in Jewel Cave, South Dakota. The deposits are diverse in composition with variable amounts of clay and Al-oxide minerals, and all are rich in Mn- and/or Fe-oxides. The mineralogy and microbiology of these deposits bear striking resemblance to terrestrial soils in which iron, aluminum, and manganese oxides have accumulated.

Lithiophorite [$(Al,Li)Mn^{4+}O(OH)_2$], nordstrandite and gibbsite [$Al(OH)_3$], goethite, kaolinite, and illite have been identified by XRD, and abundant nanocrystalline Fe-oxides were found by TEM examination, similar to minerals found in laterite soils. Likewise, todorokite [$(Mn^{2+},Ca,Na,Mg,K)Mn_3^{4+}O_7 \bullet H_2O$] and birnessite [$(Ca,Na)_{0.5}(Mn^{4+},Mn^{3+})_2O_4 \bullet 1.5H_2O$], often observed in soil nodules, are also present in these cave deposits. A diverse microbial community has been identified in these ferromanganese deposits by 16S rDNA sequence analysis, and includes microorganisms whose closest relatives are manganese- and iron-oxidizing bacteria and nitrogen-fixing bacteria.

The similarities in mineral and microbial species composition to that in soils suggest that these cave deposits undergo a process similar in some ways to terrestrial soil development. Both chemical and microbial processes may influence the formation of these cave deposits. Chemical weathering from the condensation of weak carbonic acid in the cave atmosphere may contribute to the dissolution of the bedrock carbonate, but microbial breakdown of bedrock probably plays a more significant role. The oxidation of reduced iron and manganese releases H^+ ions, and the microorganisms themselves may release organic acids, both of which contribute to dissolution of carbonate. The residual weathered products, rich in secondary minerals and organic matter, are essentially subterranean soils.

PARTNERING WITH BIOLOGISTS: BETTER ANSWERS THROUGH COLLABORATION, by *D. E. Northup*, Department of Biology, University of New Mexico, Albuquerque, NM 87131

Multidisciplinary studies that involve geochemists, mineralogists, microbiologists, and molecular biologists can be crucial to our quest to investigate the role that microorganisms play in various geological materials and processes. Biologists have developed a suite of techniques such as DNA stains that reveal cell shapes in rock material, redox dyes that reveal live vs dead cells, and molecular phylogenetic techniques that assist in identifying living organisms present in geological materials using genetic sequences. Functional gene studies also can identify whether genes are present to carry out particular processes such as manganese oxidation.

Our study of the origin of ferromanganese deposits in Lechuguilla and Spider Caves illustrates the effectiveness of multidisciplinary studies. Incubation of deposits with INT (a redox dye) and counter-staining with acridine orange revealed the presence of stalked bacteria (putative manganese-oxidizing bacteria) in the deposits and the underlying punk rock. Analysis of genetic sequences of DNA extracted from the deposits showed only weak evidence for iron- and manganese-oxidizing bacteria. Therefore, enrichment cultures were designed to target these organisms and document their production of iron and manganese oxides. DNA extracted from these enrichments showed the presence of known manganese-oxidizing bacteria. Geological techniques, such as scanning electron microscopy, energy dispersive spectroscopy, X-ray diffraction, and bulk chemistry were used to characterize the mineralogy of the deposits and to search for evidence of bacterial morphologies at every step of the study. Thus, the combination of techniques from the two disciplines more effectively allowed us to tease apart the various aspects of the production of these ferromanganese deposits.

THE EXTINCT FREE-TAILED BAT *TADARIDA CONSTANTINEI* AND ASSOCIATED VERTEBRATES FROM PLEISTOCENE DEPOSITS IN SLAUGHTER CANYON CAVE, CARLSBAD CAVERNS NATIONAL PARK, SOUTHEASTERN NEW MEXICO, by *Gary S. Morgan*, gmorgan@nmmnh.state.nm.us, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

In April 2002, a field crew consisting of paleontologists, cave specialists, and volunteers from the New Mexico Museum of Natural History (NMMNH), Carlsbad Caverns National Park, and Kartchner Caverns State Park in Arizona, conducted excavations of the fossiliferous Pleistocene bat guano deposits in Slaughter Canyon Cave (also known as New Cave) in Carlsbad Caverns National Park, Eddy County, southeastern New Mexico. We collected 21 bags of sediment (~300 kg) from two test pits in different areas of the cave. Test Pit 1 is ~2 m deep by 1 m wide; Test Pit 2 is ~1 m deep by 1 m wide. The soft, unconsolidated guano deposits are overlain throughout the cave by a thin (~10–15 cm thick) multilayered flowstone deposit. We excavated the sediments from the vertical walls of trenches (some up to ~5 m deep) left behind by miners who dug the guano for fertilizer. Because most of the fossils consist of tiny bat bones, the sediments were carefully excavated and placed into nylon bags for transport to the NMMNH for screenwashing and sorting.

Except for the description of the extinct free-tailed bat *Tadarida constantinei*, little paleontological research has been conducted in Slaughter Canyon Cave. The vast majority of fossils from this cave, numbering in the thousands of bones, belong to *Tadarida constantinei*. This species is very similar to the living Mexican free-tailed bat *Tadarida brasiliensis* but is ~20% larger in most measurements. Other fossil samples of a large *Tadarida* that may be referable to *T. constantinei* are known from Mammoth Cave in Kentucky and Hamilton Cave in West Virginia, both of which are medial Pleistocene (Irvingtonian) in age. *T. brasiliensis* forms large colonies in caves throughout the southwestern U.S., including the main cave at Carlsbad Caverns. The tremendous abundance of *T. constantinei* fossils in Slaughter Canyon Cave strongly suggests that this extinct species also formed large colonies. Ten other species are represented in the Slaughter Canyon Cave vertebrate fauna: desert tortoise *Gopherus agassizi*, lizard, snake, large raptorial bird; the bat *Myotis*, desert cottontail rabbit *Sylvilagus auduboni*, the pocket mouse *Perognathus*, the woodrat *Neotoma*, extinct pronghorn antelope *Capromeryx minor*, and a large carnivore—possibly the short-faced bear *Arctodus simus*. Previous attempts to radiocarbon date the guano and fossil bat bones from Slaughter Canyon Cave have proven unsuccessful, suggesting these deposits are older than 40,000 yrs Before Present.

SESSION 2—PALEONTOLOGY

REDISCOVERY OF HERRICK'S "COAL-MEASURE FOREST" IN THE PENNSYLVANIAN SANDIA FORMATION, SOCORRO COUNTY, NEW MEXICO, by *Spencer G. Lucas*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104; *William A. DiMichele* and *Dan S. Chaney*, Department of Paleobiology, National Museum of Natural History, Smithsonian Institution, Washington, D. C. 20560; and *John Nelson*, Illinois State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

In 1904 Clarence Luther Herrick (1858–1904) published an article titled "A coal-measure forest near Socorro, New Mexico" in the *Journal of Geology.* In it, Herrick described a lycopsid flora (including three new species of *Lepidodendron*) from "fire clay" of Pennsylvanian age being mined for brick manufacturing in Socorro. Herrick's description of the locality was vague, and it has not been revisited in nearly a century. In 2002 we relocated Herrick's locality, which is east of Socorro near Arroyo de la Presilla in sec. 11 T3S R1E (NMMNH locality 5312). The "fire clay" is a refractory dark-gray to black shale in the lower part of the Middle Pennsylvanian (Atokan) Sandia Formation that can be followed on strike for more than 2 km, and that is fault repeated often along this transect. The Sandia Formation section at the lycopsid locality begins with ~4 m of trough-crossbedded quartzose sandstone and quartzite-pebble conglomerate scoured into the underlying Proterozoic granite. These coarse clastics are sharply overlain by ~2.5 m of gray and yellow, fine-grained, massive to thinly laminated sandstone. The lycopsid bark is concentrated in the top of this fine sandstone interval, which is overlain by the "fire clay" interval, ~ 4 m of gray and black shale, siltstone, and fine sandstone, which in the lower part contains localized lenses of coal, a few *Lingula,* and an extensive flora. We suggest this succession represents a fan-delta (coarsening-up basal clastics) directly overlain by an estuarine deposit (lycopsid beds and fire clay). Our collections of fossil plants from the lycopsid bed include *Lepidodendron* cf. *L. aculeatum*, *L.* cf. *L. mannabachense* and *L.* cf. *L. jaraczewskii*, *Lepidostrobus*, *Synchysidendron*, *Sphenophyllum*, stigmarian roots and strap-like leaves of the lepidodendrids. The type specimens of the species of *Lepidodendron* Herrick named were destroyed in a fire in 1910, so newly collected lycopsid specimens are topotypes of the species. However, Herrick's species appear to be within the range of variability known from single trunk specimens, or to be sufficiently similar to previously described species to be problematic. This lycopsid locality in the Sandia Formation is significant because it indicates that a typical coal swamp flora existed in New Mexico during early tectonism of the Ancestral Rocky Mountain orogeny.

AMPHISAUROPUS FROM THE LOWER PERMIAN ABO FORMATION, CERROS DE AMADO, SOCORRO COUNTY, CENTRAL NEW MEXICO, by *Allan J. Lerner*, *Spencer G. Lucas*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, New Mexico 87104; and *Sebastian Voigt*, Geiseltalmuseum, Martin-Luther University, Domstrasse 5, Halle D-06108 Germany

Amphisauropus, a tetrapod footprint ichnogenus that is widely distributed in the Lower Permian of Europe, has previously been recorded in the United States only from Abo Pass in central New Mexico. New Mexico Museum of Natural History locality 5075 in the Cerros de Amado of central New Mexico contains a second occurrence of tracks that are readily assigned to *Amphisauropus latus* Haubold. These tracks are attributed to a seymouriamorph trackmaker. They are found in a 5-m thick crossbedded and ripple-laminated sandstone about 94 m above the base of the Wolfcampian Abo Formation, which is near the middle of an approximately 190-m-thick Abo section locally. At present, no associated ichnotaxa have been recovered from this unit. The *Amphisauropus* tracks are well preserved, and occur in a laterally confined area of several meters width that represents a levee or channel margin. There are no extensive trampled surfaces at locality 5075, as seen in the *Amphisauropus* occurrence at Abo Pass.

In Europe, *Amphisauropus* tracks are found in alluvial plain and lake margin facies of the Lower Permian red beds in Germany, France, the Czech Republic, Poland, and Italy. In New Mexico *Amphisauropus* is not found in Wolfcampian tracksites from the southern or northern parts of the state, which were formed on a coastal plain and in an upland environment, respectively. The distribution of *Amphisauropus* in New Mexico thus appears to be restricted to the central part of the state, which is interpreted as an inland alluvial floodplain.

HERBIVOROUS DINOSAUR SPECIMENS FROM THE UPPER TRIASSIC (REVUELTIAN) BULL CANYON FORMATION OF EAST-CENTRAL NEW MEXICO AND WEST TEXAS, by *Adrian P. Hunt*, *Andrew B. Heckert*, *Spencer G. Lucas*, and *Kate E. Zeigler*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

The Bull Canyon Formation (Upper Triassic: Revueltian) of east-central New Mexico and west Texas contains the most diverse Late Triassic dinosaur fauna in the world. The majority of dinosaur specimens represent theropods, but several ornithischian and prosauropod specimens are known.

Ornithischian dinosaurs are represented by at least three taxa. *Revueltosaurus callenderi* Hunt, 1989 is known from five localities in the lower (R1) portion of the formation. *R. callenderi* is the most abundant herbivorous dinosaur in the Bull Canyon Formation, although it is only known from isolated teeth. *Technosaurus smalli* Chatterjee, 1984 is a second R1 ornithischian represented by a dentulous dentary from one locality. New Mexico Museum of Natural History specimen NMMNH P-17483 is a portion of a proximal femur with a prominent fourth trochanter. This specimen represents a small ornithischian in the R1 portion of the Bull Canyon Formation. It could represent a juvenile of *R. callenderi* or *T. smalli* or a separate small taxon. *Lucianosaurus wildi* Hunt and Lucas, 1993 is only known from one locality in the upper (R2) portion of the formation and is represented by isolated teeth.

Prosauropods are poorly represented in the Bull Canyon Formation. The R1 fauna includes only an indeterminate premaxilla and a lower jaw fragment. The R2 fauna includes one dorsal centrum and a number of isolated teeth.

In conclusion, the lower R1 fauna of the Bull Canyon Formation includes *R. callenderi*, *T. smalli*, a possible third ornithischian, and an indeterminate prosauropod, and the upper R2 fauna includes *L. wildi* and an indeterminate prosauropod.

THE ELEPHANT BUTTE _TYRANNOSAURUS REX_, by *Thomas E. Williamson*, twilliamson @nmmnh.state.nm.us, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104; and *Thomas D. Carr,* thomasc@rom.on.ca, Royal Ontario Museum, 100 Queen's Park, Toronto, Ontario, M5S 2C6 Canada

During the spring of 1984, the New Mexico Museum of Natural History (NMMNH) collected a portion of a skeleton (NMMNH P-3698) from the Hall Lake Member, McRae Formation, exposed near the margin of Elephant Butte Reservoir (NMMNH locality 353) and referred it to *Tyrannosaurus rex*. The specimen included a left dentary, right prearticular, a partial right palatine, several loose teeth, and a hemal arch. Additional parts of the specimen were reported to remain at the site. However, the locality was drowned by rising lake levels and had been inaccessible for nearly 19 yrs.

During September 2002 the NMMNH recovered additional portions of this specimen following a drop in lake level. Disarticulated bones were found clustered in a conglomerate; these include a partial right splenial, a partial right angular, a right articular, a right squamosal, a right postorbital, portions of several isolated teeth, and several additional hemal arches. Diagnostic characters of the postorbital and palatine are the basis of our referral of the specimen to *T. rex*.

The Elephant Butte *T. rex* is significant for several reasons: 1) it represents the only specifically diagnostic dinosaur to be collected from the McRae Formation and supports a late Maastrichtian age for the Hall Lake Member; 2) it confirms previous identification of this specimen as *T. rex* and verifies the presence of *T. rex* in the southern Rocky Mountain region; and 3) it is the most complete *T. rex* from New Mexico and the southern United States. The specimen is far more complete than the single maxilla that has been referred to *T. rex* from the Javelina Formation of Big Bend, Texas. Moreover, the referral of the Big Bend specimen to *T. rex* has been questioned though we agree with the original identification. *T. rex* has also been tentatively identified in the Naashoibito Member of the Kirtland Formation based on the presence of isolated teeth, a partial dentary, a phalanx, and a partial metatarsal IV.

Recent identification of *T. rex* from the North Horn Formation of Utah and the tentative identification of *T. rex* from the Denver Formation of Colorado show that *T. rex* was widespread in western North America at the end of the Cretaceous. *T. rex* has also been identified in upper Maastrichtian deposits of Wyoming, Montana, South Dakota, North Dakota, Alberta, and Saskatchewan. *T. rex* is the most widespread Mesozoic dinosaur species, and the genus *Tyrannosaurus* (= *Tarbosaurus*) is also one of the most widespread as relatively complete and diagnostic remains are present in both Asia and western North America.

The pattern of tyrannosaur diversity during the Late Cretaceous resembles that of other North American non-avian dinosaurs as a whole in that there is a decline in generic diversity approaching the end of the Cretaceous. This is due, in part, to a decrease in provinciality as faunas in western North America become increasingly more homogeneous. The distribution of *T. rex* does not reflect the general biogeographic division between north and south Laramidia as seen in other Late Cretaceous dinosaurian clades and in this sense *T. rex* is an unusual component of the late Maastrichtian fauna.

SELACHIAN-DOMINATED VERTEBRATE FOSSIL ASSEMBLAGE FROM THE LATE CRETACEOUS PICTURED CLIFFS SANDSTONE, SAN JUAN BASIN, NEW MEXICO, by *Sally C. Johnson* and *Spencer G. Lucas*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

In the San Juan Basin, the uppermost strata of the Pictured Cliff Sandstone record the last traces of the Cretaceous Interior Seaway as it retreated across the continent. A vertebrate fossil locality in the Pictured Cliffs Sandstone at Mesa Portales near Cuba contains many more terrestrial elements than do other marginal marine sandstones lower in the Upper Cretaceous section. This site is dominated by selachians with 15 species: *Squalicorax pristodontus*, *Ischyrhiza mira*, *Hybodus* sp., *Synechodus* sp., *Squatina* sp., *Pseudohypolophus mcnultyi*, *Odontaspis cheethami*, *Odontaspis sanguinei*, *Cretodus arcuata*, *Cretolamna appendiculata*, *Ptychotrygon triangularis*, *Ptychotrygon* sp. *A, Brachaelurus* sp., *Cretodus borodini*, *Cretodus* sp. and calcified selachian centra. The site also contains teleost centra of at least two different species as well as teleost bone fragments and some very large teeth of *Enchodus*. There are at least five kinds of reptiles present: turtles, elasmosaurs, alligators, ornithischians, and saurischians. Also, some very tiny mammal teeth are found at this locality. The selachian fauna contains some members that are age diagnostic, such as *Squalicorax pristodontus*. Whereas this fauna compares well with other late Campanian selachian faunas, there is at least one species that is obviously missing, the teeth of *Ptychodus mortoni*. This has some paleoecological implications for the locality and suggests that the water during the time of deposition was very shallow. The presence of dinosaur and mammal teeth also suggests that this site was very close to land.

A NEW LATE PALEOCENE TILLODONT MAMMAL FROM THE SAN JUAN BASIN OF NEW MEXICO AND THE ORIGIN OF TILLODONTS, by *Shirley A. Libed*, albinque@ earthlink.net, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131; and *Spencer G. Lucas,* New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

A new taxon, *Nacimientotherium silvestrei* gen. et sp. nov., is described from the northwestern San Juan Basin, New Mexico. Represented by a single crushed maxillary fragment preserving LP2-M2, *Nacimientotherium* corresponds in size to North American Paleocene *Deltatherium*, but is smaller than the tillodont *Esthonyx* (late Paleocene–Eocene). Comparable to several Asian alleged tillodonts (e.g. late Paleocene *Meiostylodon*), the new genus appears temporally and morphologically intermediate between the earliest *Esthonyx* (*E. xenicus*) and *Deltatherium*. Similar to *Deltatherium* in premolar morphology, *Nacimientotherium* is advanced in acquisition of a distinct P3 lingual cone, further development of the P4 protocone, reduction of the metastylar lobe, and augmentation of the hook-shaped parastyle in P3-4. The wide, wing-like stylar shelves of *Deltatherium*'s primitive triangular molar dentition are superseded in *Nacimientotherium* by subrectangular, anteroposteriorly compressed molars. Exhibiting greater posterolingual hypocone flare, crown hypsodonty, and moderately wide, bilobate, stylar shelves, the new genus approaches in form the cosmopolitan undisputed tillodont *Esthonyx*. Resemblances among North American and Asian late Paleocene assemblages indicate faunal interchange. However, confirmation of North American *Nacimientotherium* as a late Paleocene tillodont transitional to *Esthonyx* confounds generic derivation from the oldest putative tillodont, the Asian early Paleocene *Lofochaius*. Lending decisive support to *Deltatherium*'s recent inclusion within Tillodontia, discovery of *Nacimientotherium* resuscitates a North American origination of the order, defies tillodont classification of aforementioned Asian specimens, and complicates conventional theories of speciation, radiation, immigration, and timing during the Paleocene–Eocene faunal turnover.

SESSION 3—SEDIMENTOLOGY/ STRATIGRAPHY

CYCLE AND SEQUENCE STRATIGRAPHY OF THE MIDDLE PENNSYLVANIAN (DESMOINESIAN) GRAY MESA MEMBER OF THE MADERA GROUP, LUCERO BASIN, NEW MEXICO, by *Lea Anne Scott*, lascott@unm.edu, and *Maya B. Elrick*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

The Middle Pennsylvanian (Desmoinesian) Gray Mesa Member (240 m) of the Madera Group is well exposed in the Lucero uplift region in central New Mexico along Mesa Sarca. Facies present include: 1) terrigenous mudstones, 2) dark, thin-bedded, fine-grained wackestones, 3) medium- to thick-bedded skeletal wackestones to wackestone/packstones, 4) medium- to thick-bedded phylloidal wackestone/packstones, 5) skeletal packstones to grainstones, and 6) rare pebbly sandstones. These facies represent deposition in deeper subtidal (facies 1 and 2) to shallower subtidal waters (facies 3–6). Facies stack into ~60-m-scale upward-shallowing cycles. Cycle tops commonly display early diagenetic features (irregular black calcite infilling vertical and horizontal cracks, oxidized burrow mottling, and brecciated fabrics) suggestive of subaerial exposure.

Two major cycle types are present: Type 1 cycles (4–7 m thick) are characterized by basal mudstones overlain by either skeletal or phylloidal wackestone/packstone or skeletal packstone caps. Type II cycles (3–5 m thick) are composed of basal, fine-grained wackestones overlain by skeletal or phylloidal wackestone/packstone or skeletal packstone caps. These cycle types are interpreted to record <100 ky relative sea-level fluctuations.

The two cycle types stack systematically into seven larger-scale (25–50 m) depositional sequences. Type I cycles, which contain basal mudstone facies, are found predominantly in the lower parts of sequences, whereas, limestone-dominated type II cycles (with skeletal packstone to grainstone caps), are dominant in the upper parts of sequences. Stratigraphic distribution of specific meter-scale cycle types within sequences suggests that longer-term (0.5–1 my) relative sea-level fluctuations were superimposed upon the high-frequency oscillations recorded by cycles.

THE BURSUM FORMATION—INTEGRATED LITHOSTRATIGRAPHY OF THE PENNSYLVANIAN–PERMIAN TRANSITION IN NEW MEXICO, by *Spencer G. Lucas*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104; and *Karl Krainer*, Institute for Geology, University of Innsbruck, Innrain 52, Innsbruck A-6020 Austria

The dominant depositional basin across much of New Mexico during the Pennsylvanian–Permian transition was the Orogrande Basin of the southern and central parts of the state. Strata that encompass that transition have been given several names: Bruton (1944), Bursum (1946), Aqua Torres (1946), Red Tanks (1946), Laborcita (1957), and Oso Ridge (1994) formations or members. In other areas, the transitional strata have either been assigned to the Abo Formation or to the Madera (Magdalena) Group/Formation without a separate name. A single formation name, Bursum Formation, best describes these strata, which constitute a mappable lithostratigraphic unit throughout their outcrop area. The Bursum Formation thus is as much as 330 m thick and is interbedded siliciclastic red beds and marine limestone and shale. The Bursum is distinguished from underlying Madera Group strata by its substantial content of red-bed shale and mudstone and some beds of limestone-pebble conglomerate and trough-crossbedded sandstone. Unlike the overlying Abo Formation, the Bursum contains beds of marine limestone and calcareous shale. Thus, the Bursum represents a transitional facies between the dominantly shallow marine carbonate facies of the underlying Madera Group and the continental red-bed facies of the overlying Abo Formation. In the keel of the Orogrande Basin (southern Oscura Mountains–northern San Andres Mountains), the Bursum grades laterally into the upper part of the Panther Seep Formation and the lower part of the overlying Hueco Group.

Regional and local variation in Bursum lithofacies is best expressed by recognizing four members of the formation: (1) Oso Ridge Member, a thin (<12 m) unit containing much reworked local Proterozoic basement in the Zuni Mountains representing a very proximal facies; (2) Red Tanks Member, a moderately thick (<100 m) unit dominated by nonmarine shale and mudstone present in the Lucero uplift, Sandia, Manzano, and Los Pinos Mountains, and locally in the Joyita Hills; (3) Bruton Member, a moderately thick (<85 m), dominantly marine lithofacies present in the Joyita Hills, Cooke's Range, and the Oscura, northern San Andres, Fra Cristobal, and Caballo Mountains (= upper member of Bar-B Formation of previous usage); and (4) Laborcita Member, a thick (<330 m) unit dominated by nonmarine red beds, basement-cobble conglomerates, and algal bioherms in the Sacramento Mountains. Sedimentation of the Bursum was strongly influenced by synsedimentary tectonic movements of the Ancestral Rocky Mountain orogeny, resulting in conspicuous lateral variations in lithofacies and thickness. The widespread Bursum Formation, of Virgilian and early Wolfcampian age, thus represents a significant tectonic pulse in the Ancestral Rocky Mountain orogeny.

STRATIGRAPHY AND TAPHONOMY OF THE UPPER TRIASSIC SALITRAL FORMATION, CHINLE GROUP, IN NORTH-CENTRAL NEW MEXICO, by *K. E. Zeigler*, *S. G. Lucas*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104; *J. Spielmann*, Dartmouth College, Hanover, NH 03755; and *V. Morgan*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

In the Chama Basin of north-central New Mexico, the Upper Triassic Salitral Formation, originally referred to as the Salitral Shale Tongue, is part of the lower Chinle Group, and is generally described as a blocky bentonitic mudstone with some interbedded sandstones and siltstones. The mudstones are mottled and contain carbonate nodules, indicating paleosol development. The Salitral Formation lies conformably above the Agua Zarca (= Shinarump) Formation and disconformably below the Poleo Formation. Fossils recovered from the Salitral Formation indicate an Adamanian (late Carnian) age. The Salitral may be broken into three discrete lithostratigraphic units: a lower green mudstone, a thin medial sandstone bench, and an upper red mudstone. We propose formal designation of these units as members of the Salitral Formation.

The majority of the vertebrate fossils recovered from the Salitral Formation during survey work in the summer of 2002 were recovered from the bases of slopes in the upper member. The fossils are predominantly fragments of metoposaur amphibian skull and girdle elements, together with a few bone fragments that could only be referred to Archosauria indet. The bone fragments are abraded and moderately weathered, and are found mixed with calcrete nodules that cover the mudstone slopes. The calcrete nodules, as well as the vertebrate fossil material, are weathering out of the base of a very thick calcrete-pebble conglomerate at the base of the overlying Poleo Formation. However, although the fossils are weathering out of the basal Poleo Formation, they were most likely incorporated into the conglomerate as reworked Salitral clasts and thus were originally deposited in the upper Salitral Formation. The advanced degree of weathering indicates a moderate time of subaerial exposure (>3 yrs), whereas the abrasion of the surfaces indicates exposure and transport of the bone fragments.

LUMINESCENCE AND RADIOISOTOPE CHRONOLOGY OF THE LATE QUATERNARY MESCALERO SANDS, SOUTHEASTERN NEW MEXICO, by *Stephen A. Hall*, Red Rock Geological Enterprises, 17 Esquina Rd., Santa Fe, NM 87508; *Ronald J. Goble*, Department of Geosciences, University of Nebraska, Lincoln, NE 68588; and *Hewitt W. Jeter*, Mass Spec Services, P.O. Box 163, Orangeburg, NY 10962

The Mescalero Sands is a sand sheet of eolian origin that occurs between the Pecos River valley and the caprock escarpment of the Ogallala Formation in southeastern New Mexico. The sand sheet formed on the eroded surface of the Mescalero paleosol, a regional petrocalcic soil that may have developed largely during the Sangamonian. The sand sheet incorporates two distinct eolian sand units, the older accumulating 90–70 ka directly on the eroded Mescalero paleosol and the younger one accumulating 9–5 ka on top of the older sand; their ages are provided by optically stimulated luminescence. The older sand unit is derived from the Ogallala. During the time interval between deposition of the older and younger eolian units, a noncalcic red argillic soil developed on the older sand; the noncalcic character of the paleosol may be in response to the mesic climate of the Wisconsinan. Small parabolic and shrub-coppice dunes mark the modern surface of the sand sheet; luminescence ages of one coppice dune place it wholly within the 20th century, and cesium-137 content indicates that the upper 22 cm of the coppice dune accumulated since 1954.

SESSION 4—HYDROGEOLOGY

EVALUATION OF GROUND WATER / SURFACE WATER INTERACTIONS ALONG A CRITICAL REACH OF THE MIDDLE RIO GRANDE, NEW MEXICO, by *Brad T. Newton*, *Laura J. Wilcox*, and *Robert S. Bowman*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The primary goal of this project is to quantify connections between the surface water and shallow ground water systems in the Rio Grande valley between San Acacia and Elephant Butte Reservoir. The surface water system is dominated by the Rio Grande, the Low Flow Conveyance Channel (LFCC), and irrigation canals and drains. Ground water and surface water samples were collected along several transects crossing the river and LFCC in February, June, and October of 2002 and analyzed for major cations and anions and stable isotopes of oxygen and hydrogen.

Stable isotope data indicate that water in the shallow aquifer and the LFCC is primarily river water. Most ground water between the river and the LFCC was characterized by a fairly constant water chemistry with TDS values between 380 and 420 mg L^{-1}, very similar to values for the Rio Grande, indicating that ground water between the river and the LFCC is derived directly from river seepage. The water chemistry for ground water to the west of the LFCC was highly variable with TDS values between 370 and 1,240 mg L^{-1} , which probably reflects the influence of irrigation recharge and water/mineral interactions. TDS values for the LFCC are slightly higher than those of the river, suggesting that much of the LFCC water comes from river seepage. However, the interpretation is complicated by several diversions that feed water into the LFCC.

DETAILED MODELING OF GROUND WATER/SURFACE WATER INTERACTIONS NEAR SAN ANTONIO, NEW MEXICO, by *Laura J. Wilcox*, ljwilcox@nmt.edu, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, *Nabil Shafike*, nshafike@ose.state.nm.us, New Mexico Interstate Stream Commission, 121 Tijeras NE, Suite 2000, Albuquerque, NM 87102; and *Robert S. Bowman*, bowman@nmt.edu, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Under the Rio Grande Compact, New Mexico is obligated to deliver a specified amount of water to satisfy demands in New Mexico and Texas below Elephant Butte Reservoir. This indicates that a finite amount of water is available to New Mexico north of Elephant Butte Reservoir for habitat preservation and agricultural, industrial, and domestic uses. Previous investigations have observed significant seepage losses from the Rio Grande to the shallow aquifer between Socorro and the Bosque del Apache. Small scale modeling of a 6-mi reach of the river between Brown Arroyo and San Antonio is aimed at determining the causes for surface water loss and investigating methods for minimizing such losses. Simulations will include alternative river channel locations, riparian vegetation changes, and changes in river/aquifer interactions. Layers included in the model extend upward from the Santa Fe Group and lie within the lateral extent of the floodplain. Grid cell size is 100 by 100 ft. Information collected to help calibrate the model includes: floodplain geologic cross sections; monthly ground water elevations; monthly surface water elevations in drains, canals, and the river; surface water flow data; precipitation records; aquifer pump tests; seepage run results; and three water chemistry snapshots in 2002, including the stable isotopes ^{2}H and ^{18}O. This model is a telescopic version of a regional model of the Rio Grande reach from San Acacia to Elephant Butte Reservoir that is being developed by the New Mexico Interstate Stream Commission.

WATER PARTITIONING AT THE SOIL-BEDROCK INTERFACE OF HILLSLOPES, by *Huade Guan* and *John L. Wilson*, Department of Earth and Environmental Science New Mexico Institute of Mining and Technology, Socorro, NM 87801

Variably saturated, steady state numerical simulations were conducted on 100-m-long conceptual hillslopes representing conditions typical of mountains bounding New Mexico's Rio Grande rift. Water partitions between interflow in the soil layer and percolation across the soil-bedrock interface. The latter eventually leads to subsurface recharge of adjacent valleys. Simulations suggest that water percolation into bedrock is significant for bedrock with permeability greater than 10^{-16} m^2. This permeability threshold is below frequently reported fractured rock permeability. Given a hillslope with bedrock permeability above this threshold, the mechanism of water partitioning at the soil-bedrock interface dynamically depends on the ratio of infiltration rate over saturated bedrock hydraulic conductivity (R). When R is about 3 or larger, interflow dominates, and the amount of percolation depends on the magnitude of bedrock permeability. When R is about one-third or lower, percolation is dominant, and the amount of percolation depends on infiltration rate. When R is about 1, both bedrock topography (slope and depression) and soil characteristics affect water partitioning by affecting the water pressure distribution at the soil-bedrock interface. When the soil becomes saturated, the effects of bedrock surface topography and soil properties become smaller or insignificant. This suggests that water availability with respect to bedrock permeability and water pressure at the soil-bedrock interface are two critical parameters needed to estimate water partitioning on hillslopes.

CHEMICAL AND MICROBIAL COMPOSITION OF SUBSURFACE-, SURFACE-, AND ATMOSPHERIC WATER SAMPLES IN THE SOUTHERN SACRAMENTO MOUNTAINS, NEW MEXICO, by *Dirk Schulze-Makuch*, Department of Geological Sciences, University of Texas, El Paso, TX 79968

Several environmental samples near the Sun Spot Observatory in the southern Sacramento Mountains were analyzed for chemical and microbial content. The samples were obtained within 1 km^2 of each other, one from a drinking well of the observatory, one from a nearby spring, one from surface soil, and one from fallen snow that was sampled about 1 cm beneath its icy surface. All samples were analyzed for main cations and anions, total phosphorus, total organic carbon, total biomass, phospho-lipid fatty acids (PLFA), and denaturing gradient gel electrophoresis (DGGE). The surface soil sample exhibited the highest amount of nutrients, biomass, and species diversity. Surprisingly, the snow sample exhibited the 2nd highest amount of biomass with higher values than the spring and the ground water sample. This was consistent with total organic carbon results that showed a total organic carbon content of 16 mg/L in the snow sample. For a follow-up study, precipitation samples were collected and analyzed for microbial content. A culturable cell abundance of 4,800 cells per mL of water was counted. Extractable DNA sequences pointed to soil-associated bacteria primarily, but also to plant pathogens and possibly human pathogens. These results indicate that the atmosphere may be a much more important environment for microbes than traditionally realized, at least representing an important transitional habitat for transport purposes.

SESSION 5—VOLCANOLOGY/ STRUCTURE/GEOPHYSICS

COLLAPSE AND RESURGENCE OF THE VALLES CALDERA, JEMEZ MOUNTAINS, NEW MEXICO: FIELD RELATIONSHIPS AND $^{40}AR/^{39}AR$ AGES OF MEGABRECCIA BLOCKS AND CONSTRAINTS ON THE TIMING OF RESURGENCE, by *Erin H. Phillips*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; *Fraser Goff*, Los Alamos National Laboratory, Los Alamos, NM 87545; *Philip R. Kyle*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; *William C. McIntosh*, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining

and Technology, Socorro, NM 87801; *Jamie N. Gardner*, Los Alamos National Laboratory, Los Alamos, NM 87545

Detailed geologic mapping and $^{40}Ar/^{39}Ar$ dating reveal that megabreccia blocks as large as 600 x 400 m were emplaced within intracaldera, upper Bandelier Tuff (UBT) during eruption and collapse of the Valles caldera, and suggest that subsequent resurgence probably was complete within, at most, 90 ky of caldera formation at approximately 1.23 Ma. The distribution and sources of intracaldera megabreccia blocks are highly variable. $^{40}Ar/^{39}Ar$ ages of selected megabreccia blocks indicate that they are composed of older pre-caldera units that include the 1.6 Ma lower Bandelier Tuff (LBT; clasts yield ages of 1.64 ± 0.04 Ma (2σ)), and a dacitic tuff dated at 8.08 ± 0.08 Ma.

The timing of resurgence is constrained by the eruption of the UBT and emplacement of the oldest ring fracture dome, Cerro Del Medio; $^{40}Ar/^{39}Ar$ dating places these time constraints at 1.232 ± 0.018 Ma (UBT) and 1.19 ± 0.03 Ma (Cerro Del Medio). The Deer Canyon and Redondo Creek Members of the Valles Rhyolite Formation, erupted before and during resurgence, respectively, stratigraphically overlie the UBT. However, these units are not shown by $^{40}Ar/^{39}Ar$ dating to be measurably younger than the UBT, suggesting that resurgence commenced soon after collapse of the Valles caldera and eruption of the UBT.

Abundant clasts of LBT, derived from the reworking of LBT-bearing megabreccia blocks, are found within caldera fill volcaniclastic deposits. Fieldwork shows that these 1.6 Ma clasts are not syneruptive with Deer Canyon lavas associated with resurgence, as previously suggested by Phillips et al. (2002, Proc. NM Geol. Soc. Spring Meeting).

SEISMIC STRUCTURE OF THE LITHOSPHERE FROM THE COLORADO PLATEAU/RIO GRANDE RIFT/GREAT PLAINS SEISMIC TRANSECT (LA RISTRA) EXPERIMENT, by *David Wilson*, davew@nmt.edu, *Richard Aster*, and the *RISTRA research team*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

We examine the structure of the lithosphere in the southwestern United States using the seismic impulse response of the earth (receiver functions) calculated from teleseismic arrivals recorded in the LA RISTRA experiment. LA RISTRA was a northwest–southeast trending, 950.7 km linear network of 57 broadband PASSCAL seismometers, deployed during 1999–2001 from Lake Powell, Utah, to Pecos, Texas. It was oriented approximately parallel to the regional Proterozoic continental accretionary gradient, and oblique to the predominantly north–south trend of faulting during Ancestral Rocky Mountain and Laramide compression and Cenozoic extension and rifting. We estimate crustal thickness and Vp/Vs ratios using the travel times of direct P-to-S converted seismic phases and converted phases that have been reflected multiple times within the crust.

Crustal thickness reaches a minimum of 35 km in the center of the Rio Grande rift, and ranges between 42 and 50km thick in both the Great Plains and Colorado Plateau. We observe considerable topography at the base of the crust, with thickness changes as great as 7 km over lateral distances of 50 km. The current structural features of the crust coincide with regions of Paleozoic and Mesozoic tectonic activity as well as Proterozoic suture zones. This implies that ancient lithospheric structures, possibly as old as the age of lithospheric formation, may determine current regional deformation styles.

IS THE DEPTH INTERVAL OF THE SOCORRO SEISMOGENIC ZONE CONTROLLED BY A REDUCTION IN ROCK STRENGTH SUGGESTED FROM EXPERIMENTALLY DETERMINED ELASTIC MODULI?, by *Marshall Reiter*, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The Socorro seismogenic zone is an upper crustal layer containing earthquakes above the intensely studied Socorro magma body within the Rio Grande rift. The depth of the seismogenic zone varies; however, microearthquake studies show that the thickness is typically between 2 km and 3 km. Near the Arroyo del Coyote swarm site, a reliable heat-flow measurement allows reasonable subsurface temperature estimates. It has been suggested that the base of the seismic zone occurs at temperatures of ~300°C where quartz becomes ductile in response to tectonic stress. These temperature estimates, along with an approximation of the confining pressure with depth, allow depth equivalent estimates of normalized elastic moduli from experimental data, which can be used to estimate rock strength across the entire seismic depth interval. Although the depth of a seismogenic zone is likely to depend on a number of parameters, data for several granitic rocks from two studies are combined to approximate normalized Young's moduli (E/E_0) at the top and bottom of the seismogenic zone (7 and 9 km depth) as ~0.8 and ~0.65. The normalized bulk moduli (K/K_0) at the top and bottom of the zone are ~0.45 and ~0.33. Reduction of the elastic moduli, and therefore rock strength, begins at depths below 3 km to 5 km because of temperature dependence. The reduction of elastic moduli predicted across the seismic zone at Arroyo del Coyote suggests a weakened crustal layer that is qualitatively consistent with a semi-brittle zone of reduced strength predicted from wet quartz rheologies. Experimentally derived elastic moduli values may be used to predict upper crustal strength–depth profiles for regions of different tectonic and thermal regimes. At Arroyo del Coyote increasing differential stress with depth may intersect a weakened semi-brittle zone to create the seismogenic depth interval.

MAPPING FAULTS IN THE LIGHTNING DOCK KNOWN GEOTHERMAL AREA, ANIMAS VALLEY, NEW MEXICO, USING SOIL CO_2 FLUX MEASUREMENTS, by *Kristie McLin*, *Philip Kyle*, and *David Norman*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

When geothermal fluids rise they often boil giving off their dissolved gases especially carbon dioxide, which is the predominant vapor phase in geothermal systems. The CO_2 is likely to rise along the same faults that act as pathways for the rise of the geothermal fluids. By measuring soil CO_2 flux, it is possible to detect the CO_2 plume associated with a fault and is therefore useful in locating faults that may be buried. By mapping out the location of faults drill targets are more easily identified and can save money when exploring for geothermal fluid reservoirs.

The Lightning Dock Known Geothermal Resource Area is located southwest of Lordsburg, New Mexico, and has no known surface expression. The geothermal waters are used to heat greenhouses used to grow long-stem roses and raise fish fingerlings. There is also interest in exploiting the water as a renewable source of energy for the region.

Geothermal waters rise convectively, then commonly flow laterally near the surface. The plume of thermal water resembles a mushroom cloud. Faults in the Lightning Dock Known Geothermal Resource Area are covered by hundreds of meters of alluvium, and have been difficult to locate by geophysical methods. Even when faults are located, it is difficult to identify which ones carry geothermal fluids. More than 200 soil CO_2 flux measurements at 50–100 m spacing were made near the main surface heat anomaly of the Lightning Dock Known Geothermal Resource Area to develop and test the soil CO_2 technique as a method of geothermal exploration. Measurements were made by the accumulation method using an aluminum box with volume of 0.01 m^3, which was placed on the ground well away from any vegetation. The flux of CO_2 into the box was measured over 10 minutes and showed a range from a low value of 0.01 $ppm.s^{-1}$ to a maximum of 0.51 $ppm.s^{-1}$. The sites of the highest CO_2 flux are believed to mark buried faults trending northeast-southwest. These faults may carry the geothermal fluids from a source in the southwest to the main heat anomaly. Previous well water analyses show that the shallow ground waters trending southwest of the discovery well have anomalous CO_2. Soil flux measurements were repeatable over several days time. Future CO_2 flux measurements will be used to refine the locations of these faults

POSTER SESSIONS, MORNING
SEDIMENTOLOGY AND STRATIGRAPHY

IDENTIFICATION AND MAPPING OF EVAPORITE MINERAL ENDMEMBERS IN LAKE LUCERO AND ALKALI FLAT, WHITE SANDS, USING LANDSAT 7 ETM+, by *H. A. Ghrefat*, haghrefat@utep.edu , and *P. C. Goodell*, goodell@geo.utep.edu, University of Texas, El Paso, TX 79968

Evaporite minerals are the main source of several industrial and agricultural minerals important to the U.S. and world economy. Landsat ETM+ data covering the White Sands, New Mexico, have been used in this study. Lake Lucero and Alkali Flat have been chosen as target sites. The study aims to: 1) determine the number of endmembers that can be detected and mapped, 2) determine the spatial distribution of fractional abundances of identified endmembers assuming a linear mixing model, and 3) the ultimate objective will be the application of this initial study to future hyperspectral studies. The Minimum Noise Fraction (MNF) transform and Principal Component Analysis (PCA) were employed to determine a reduced set of noise-free spectral bands. The Pixel Purity Index (PPI) and n-D Visualization (nDV) were conducted on the reduced set of spectral bands to identify spectrally pure endmembers in the image. The following endmembers have been identified in the Alkali Flat and Lake Lucero: 1) gypsum, 2) gypsum with sparse vegetation, 3) bloedite, and 4) clay plus carbonate. Of these endmembers, only gypsum and bloedite are evaporite mineral endmembers. Mineral maps of the spatial distribution and relative abundance of evaporite minerals were performed using three different algorithms: Spectral Angle Mapper (SAM), Matched Filtering (MF), and Mixture Tuned Matched Filtering (MTMF). The results showed that gypsum has high fractional abundance in North and South Lake Lucero and Alkali Flat, whereas the fractional abundance of bloedite is low in Alkali Flat, but is higher in North Lake Lucero. The results of SAM, MF, and MTMF are validated by collecting field samples from different locations within the White Sands. A good match has been determined between results of Landsat ETM+ data, the U.S. Geological Survey library, and field and laboratory determined spectra. ASTER, ALI, AVIRIS, and Hyperion data are available and are in the process of being evaluated for mapping evaporite mineral endmembers. Mapping of playa evaporite minerals is of potential importance for the goal of saline soil characterization, regional ground water hydrology and quality mineral resource development, and climate change.

MODERN SAND DUNE MIGRATION RATES OF LOS MEDAÑOS IN SOUTHEASTERN NEW MEXICO, by *Christopher Mahoney*, New Mexico State University, Las Cruces, NM 88003

The small dune field referred to as Los Medaños, located 25 mi southeast of Carlsbad, New Mexico, provides an excellent opportunity to observe the migration rates of eolian features. The field, covering approximately 0.6 km^2, consists of active transverse and parabolic sand dunes, indicating consistent west-southwest winds. Barchan and barchanoid forms are less abundant. Eolian formations typically caused by more complex wind patterns, such as reversing, seif, or star dunes, are absent. Bare areas found among central interdune spaces demonstrate a limited amount of sand in relation to the amount potentially transported by local winds. Los Medaños is located adjacent to a much larger set of dunes stabilized by vegetation. These dune areas are likely sources for the active dunes.

Annual to semi-annual aerial photographs of Los Medaños since the early 1980s show that dunes are forming and migrating in recent years. From 1990 to 1996, dune crests shifted west-southwest a total of 78 m over the 6-yr period. Active perimeter dunes containing more vegetation move more slowly than formations in the center. Mesquite and other small trees, located sparsely throughout the field, develop roots from the trunk as they are buried by advancing dunes. As the dunes continue to migrate, exposing the vegetation, roots develop bark. The mesquite and other trees may be helpful in understanding dune movement beyond the photographic record.

THE BURSUM FORMATION AND A LATE PENNSYLVANIAN UNCONFORMITY IN THE SOUTHERN COOKE'S RANGE, LUNA COUNTY, NEW MEXICO, by *Karl Krainer*, Institute for Geology, University of Innsbruck, Innrain 52, Innsbruck A-6020 Austria; *Spencer G. Lucas*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104; and *Garner L. Wilde*, 5 Auburn Court, Midland, TX 79705

Upper Paleozoic strata in the southern Cooke's Range at Fryingpan Canyon (NW¼ sec. 17 T21S R8W) have previously been assigned to the Pennsylvanian Magdalena Group and the Lower Permian Abo Formation. Recent re-examination of these strata indicates they encompass three lithostratigraphically distinct units: (1) 18 m of cherty limestone and shale; (2) 25 m of interbedded shale, marine limestone, and limestone-cobble conglomerate; and (3) 100 m of red-bed mudstone, arkosic sandstone, and limestone/siliceous-pebble conglomerate overlain by the Lower Cretaceous Mojado Formation ("Sarten Sandstone"). The base of unit 1 is composed of thin-bedded fossiliferous limestone containing abundant fusulinaceans, overlain by cherty limestone composed of gray limestone nodules embedded in brownish cherty matrix, and interbedded brownish to reddish, cherty shale. Near its base, unit 1 yields the Desmoinesian (DS 1 or 2, Strawn) fusulinaceans *Beedeina* ex. gr. *euryteines* (Thompson) and *Wedekindellina* ex. gr. *euthysepta* (Henbest). Unit 1 is thus best assigned to the Madera Group as a Desmoinesian correlative of the Nakaye and Gray Mesa Formations to the north and northeast. Unit 2 does not yield age diagnostic fossils but is interbedded shallow marine limestones (thin nodular limestone beds rich in crinoidal debris in the lower part, fossiliferous nodular limestone in the middle and upper part), limestone-pebble conglomerates, red-bed siliciclastics, and reddish mudstones containing abundant pedogenic limestone nodules. Unit 2 represents a transitional facies of thin limestones deposited during short, shallow marine episodes, and fine-grained red beds, mainly of pedogenic origin. This sequence is strikingly similar to the Bursum Formation, to which we assign it. Unit 3 is the Wolfcampian Abo Formation composed of red mudstones and siltstones with intercalated conglomerates, sandstones, and pedogenic horizons. The presence of Bursum strata directly above Desmoinesian limestones suggests a profound hiatus between units 1 and 2 equivalent to at least Missourian time. Indeed, the Madera–Bursum contact in Fryingpan Canyon is marked by a 3-m-thick pedogenic calcrete at the Bursum base directly overlying cherty marine limestone at the Madera top, indicative of a profound unconformity. The presence of a Late Pennsylvanian unconformity in the southern Cooke's Range is further evidence of a regional tectonic event(s) in the Orogrande Basin during Missourian time.

PETROGRAPHIC ANALYSIS OF REDUCTION ZONES IN THE RED BEDS OF THE ABO FORMATION, NEW MEXICO, by *Joel P. Bensing* and *Peter S. Mozley*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Reduction features are commonly observed in red beds, including the Abo Formation, yet are still not fully understood. In particular, the exact nature of the mineralogical changes accompanying reduction are poorly understood. By using the electron microprobe to gain back-scattered electron images and X-ray maps of elements, ours will be one of only a few studies to employ modern analytical techniques to study reduction. Fifteen thin sections were made of samples collected from the Abo type section near Mountainair, New Mexico, as well as from the Quebradas area east of Socorro, New Mexico. The samples include a variety of reduction features and grain sizes. Reduction features included in the samples are reduction spheres, alternating layers of reduced and non-reduced rock, and shrinkage cracks filled with reduced sediment. The lithologies of the samples collected vary from mudstones to conglomerates. Preliminary studies of thin sections show a significant difference in the hematite content between the white portions and red portions of the samples. Hematite is present as grain coatings on detrital grains in red portions, but is completely absent in the white portions. In some instances the amount of detrital opaques is equal between red and white portions. This contradicts observations from most previous studies, and it suggests that the source of iron for the hematite grain coatings in red portions of the Abo Formation is not from the dissolution of iron-bearing opaques. Porosity and grain size are both greater in the white layers compared to adjacent red layers, yet in reduction spheres porosity and grain size are unchanged across the boundaries of the reduction sphere.

STRATIGRAPHY AND CORRELATION OF THE UPPER CRETACEOUS TOHATCHI FORMATION, CHUSKA MOUNTAINS, WESTERN NEW MEXICO, by *Justin A. Spielmann*, Dartmouth College, Hinman Box 4571, Hanover, NH 03755; *Spencer G. Lucas,* New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104; and *Dennis R. Braman*, Royal Tyrrell Museum of Palaeontology, Box 7500, Drumheller, AB T0J 0Y0, Canada

The Upper Cretaceous Tohatchi Formation is at least 160 m of nonmarine siliciclastic strata exposed in western New Mexico along the southeast and east flank of the Chuska Mountains. The Tohatchi Formation conformably overlies the Menefee Formation, is unconformably overlain by the Paleogene Deza Member of the Chuska Sandstone and consists of a lower, sandstone-dominated member and an upper, mudstone-dominated member. A significant change in sandstone lithology and bedform at the base of the Tohatchi Formation is a mappable contact and justifies continued recognition of the unit as a distinct formation.

Dinosaur fossils found throughout the Tohatchi Formation indicate a Late Cretaceous age, and extensive palynomorph assemblages refine this age assignment to early Campanian. The presence in the Tohatchi Formation of such species as *Accuratipollis lactiflumis*, *Brevimonosulcites corrugatus*, *Callialasporites dampieri*, *Microfoveolatosporis pseudoreticulatus*, *Periretisynolporites chinookensis*, and *Rugubivesiculites reductus* suggests links to upper Santonian assemblages of the Milk River and lower Eagle Formations of Alberta–Montana. However, other Tohatchi species such as *Aquilapollenites attenuatus*, *A. trialatus*, *A. turbidus*, *Pulcheripollenites krempii*, and *Tricolpites reticulatus* are more closely related to assemblages from the Pakowki Formation and Judith River Group of Alberta and the Claggett and Judith River Formations of

Montana. The palynomorph assemblages in the Tohatchi Formation thus fall within the *Aquilapollenites senonicus* interval zone of early Campanian age. Therefore, the Tohatchi Formation is not, as has been thought for 50 yrs, a correlative of part of the upper Campanian Pictured Cliffs–Fruitland–Kirtland Formations succession to the east. Instead, the Tohatchi Formation is the uppermost part of the Mesaverde Group in western New Mexico, younger than the underlying Allison Member of the Menefee Formation locally, and older than the late Campanian turnaround of the Cliff House– Pictured Cliffs shoreline to the east.

PROBLEMS WITH THE EXISTING STRATIGRAPHIC NOMENCLATURE OF THE SANTA FE GROUP IN THE ESPAÑOLA BASIN AND SUGGESTED REVISIONS, by *Daniel J. Koning*, danchikoning@yahoo.com, Rt. 1, Box 28A, Santa Cruz, NM 87567

Recent mapping of the Santa Fe Group near Española, New Mexico, elucidates the stratigraphy of the Española Basin and underscores some long-standing problems regarding current stratigraphic nomenclature. The lower 180–200 m of the Chamita Formation type section, located southeast of Black Mesa and west of the Rio Grande, is similar to the Cejita Member of the Tesuque Formation, particularly in its fluvial facies and clast composition (corresponding to Lithosome B of Cavazza, 1986). At the Chamita Formation type section, >200 m of granite-rich piedmont sediment (Lithosome A of Cavazza, 1986) conformably overlies Lithosome B. Biostratigraphic data, geologic mapping, and compositional similarities support the correlation of much of the upper Tesuque Formation east of the Rio Grande (particularly northeast of the San Juan Indian Reservation) to the lower and middle Chamita Formation type section. This correlation, and the lack of significant sedimentologic differences between the Chamita Formation type section and upper Tesuque Formation, raises significant concerns about whether to retain the Chamita Formation as a member of the Tesuque Formation or abandon it altogether. In addition, I suggest differentiating the Tesuque Formation into members using compositional and textural criteria; this would retain the current Chama–El Rito, Ojo Caliente Sandstone, and Cejita Members. However, the Nambé, Skull Ridge, and Pojoaque Members are less lithologically distinct and difficult to differentiate south of Tesuque Pueblo and north of the Santa Cruz River. The Nambé, Skull Ridge, and Pojoaque Members each contain Lithosomes A and B; thus, differentiating this sediment using the lithosome approach of Cavazza (1986) would be more objective and more regionally applicable.

DETRITAL ZIRCON U/PB AGES FROM PROTEROZOIC METASEDIMENTARY ROCKS IN THE BURRO MOUNTAINS, MAZATZAL PROVINCE, SOUTHWEST NEW MEXICO, by *Jeffrey M. Amato*, *Amos Sanders*, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003; and *George Gehrels*, Department of Geosciences, University of Arizona, Tucson, AZ 85721

The Burro Mountains in southwest New Mexico expose Proterozoic metasedimentary rocks cut by several plutons ranging in age from 1.6 to 1.2 Ga. The age of the source rocks and the age of deposition were investigated using LA-MC-ICPMS U/Pb isotope analysis of individual detrital zircons. Our previously reported electron microprobe ages of detrital monazite ranged from 2.3 to 1.7 Ga, but low Pb concentrations resulted in 50–150 Ma uncertainties.

Zircons from one of these metasedimentary rocks were analyzed in order to better constrain the age of the source rocks and the depositional age. A 35-micrometer laser beam was used to analyze zircon cores. We analyzed 49 different zircons, which have a range of $^{207}Pb/^{206}Pb$ ages from 1,655 ± 37 to 1,892 ± 62 Ma with a mean of 1,725 Ma. The 1σ uncertainties range from 18 to 62 Ma with a mean of 25 Ma. Histograms indicate a main peak of ages at 1,725 Ma with smaller peaks at 1,680 Ma, 1,792 Ma, and 1,841 Ma. One grain yielded a Late Archean age of 2,878 ± 26 Ma.

Source rocks for the Burro Mountains metasedimentary rocks therefore contain zircons that range in age from 1.65 to 2.88 Ga. Most Mazatzal province source rocks are thought to be <1.7 Ga, whereas Yavapai basement rocks are as old as 1.85 Ga and may be providing some of the source material for these samples, though Mojave or Wyoming province or other sources cannot be ruled out. The metasedimentary rocks were deposited between 1,655 Ma (the youngest detrital zircon) and 1,633 Ma (the age of a cross-cutting diabase), which is consistent with the ages of other Mazatzal province volcano-sedimentary sequences. Comparison of these data with those from detrital zircon studies in adjacent areas in eastern Arizona indicates that maximum age of deposition, 1,655 ± 37 Ma, is the same as for sedimentary rocks in the Little Dragoon Mountains (1,655 ± 4 Ma). The detrital zircon ages in the Burro Mountains are significantly older than those from the Cochise Block (1,697–1,729 Ma) and Pinal Block (1,678–1,731 Ma, with one grain at 2,448 Ma) in southeast Arizona. This probably reflects a greater contribution from Yavapai province igneous rocks as well as from older continental rocks either in the continental interior or possibly from a source other than North America.

^{40}AR/^{39}AR THERMOCHRONOLOGICAL CONSTRAINTS ON THE TIMING OF BASEMENT EXHUMATION AND METASOMATISM IN THE SOUTHERN SANGRE DE CRISTO RANGE, NEW MEXICO, by *Robert E. Sanders*, sanders@nmt.edu, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *Matthew T. Heizler*, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801

$^{40}Ar/^{39}Ar$ step-heating analyses of K-feldspar from crystalline basement rocks located beneath the Precambrian–Paleozoic unconformity in the southern Sangre de Cristo Mountains, New Mexico, reveal complex exhumation. Thermal histories deduced from Multiple Diffusion Domain modeling of eight igneous and metamorphic K-feldspars collected from rocks between Santa Fe and Las Vegas display a dominant 1,000–800 Ma cooling signature. The ~150°C temperature decrease during this time is interpreted to represent 4–5 km of denudation. In contrast, three K-feldspar samples collected from basement penetrating petroleum exploration well cuttings in the Las Vegas Basin, east of the range-bounding Montezuma fault zone, show that basement unroofing in this area occurred later, between ~700 and 600 Ma. Disparity in thermal histories between these samples suggests that the basin samples remained approximately 5 km deeper (and subsequently hotter) than the Sangre de Cristo basement samples until the basin K-feldspars closed to ^{40}Ar loss (150°C) around 600 Ma. However, by Mississippian time, these rocks resided at a similar structural position below the extensive carbonate deposits that unconformably overly the Proterozoic basement across much of New Mexico. Thermochronologic and geometric constraints implicate fault initiation with east-side-up motion at ca. 700 Ma to bring the Las Vegas Basin samples up to the same structural level as the Sangre de Cristo samples before Mississippian sedimentation. Thus, the Laramide Montezuma fault that presently separates these samples represents a reactivation of this preexisting Neoproterozoic structural weakness.

Ten additional step-heating analyses were conducted on metasomatic K-feldspar separated from hydrothermally altered igneous and metamorphic basement rocks in the Pecos River Valley near the Picuris–Pecos fault zone. Alteration is characterized by K-feldspar ± epidote replacement of albite in host lithologies, and was facilitated by fluid migration along brittle structures including fractures and zones of brecciation. $^{40}Ar/^{39}Ar$ age spectra from these samples are complex and commonly exhibit intermediate age maxima. The nature of these intermediate age maxima is enigmatic but may be due to post-crystallization diagenetic or hydrothermal alteration, or mechanical fracturing of diffusion domains either by natural processes or laboratory heating procedures. Thermal histories from these samples suggest a range in the timing of mineral growth between ca. 1,000 Ma and ca. 600 Ma. These data indicate two episodes of metasomatism; one before ~1,000 Ma while the basement was regionally ~300°C, and a second that initiated at ca. 700 Ma when the basement was relatively cool at ~150°C. Additionally, basement K-feldspars from opposing sides of the Picuris–Pecos fault do not display evidence for significant vertical offset during the Neoproterozoic, and metasomatic fluids, therefore, infiltrated fractures and zones of brecciation formed largely by strike-slip deformation. The later episode of metasomatism may be contemporaneous with the initiation of exhumation at ca. 700 Ma. Deformation and metasomatism in northern New Mexico during these times could represent inboard tectonic processes related to the rifting of Rodinia.

GEOLOGIC MAP OF THE ALBUQUERQUE–RIO RANCHO METROPOLITAN AREA AND VICINITY: STRUCTURAL AND STRATIGRAPHIC FRAMEWORK OF THE ALBUQUERQUE BASIN, NEW MEXICO, 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

Fourteen geologic maps by the New Mexico Bureau of Geology and Mineral Resources and U.S. Geological Survey, and drillhole data were compiled into a 1:50,000-scale map encompassing 2,200 km^2 of the Albuquerque–Rio Rancho metropolitan area and vicinity. Sediment-distribution patterns and paleocurrent data document south-southeast-flowing paleorivers associated with the ancestral Rio Puerco fluvial system (Arroyo Ojito Formation, **To**) and provide geologic constraints on ground-water-flow anisotropy. The **To** dominates the upper Santa Fe Group basin fill. **To** drainages flowed obliquely toward the basin axis where they entered the south-southwest-flowing axial Rio Grande fluvial system (ARG). Basin-margin unconformities generally become gradational toward depocentral areas. Northwestern basin-margin faults may have been active before 19 Ma, resulting in local stripping of formerly widespread Oligocene strata. The lack of middle-member (**To**) deposits on the footwall of the San Ysidro fault indicates that erosion of the northwestern basin margin occurred between late Miocene and Pliocene time. Widespread basinal aggradation diachronously ceased ~2.5–0.8 Ma, probably as a consequence of differential tilting and changing sedimentation rates and patterns within the basin. Conglomeratic deposits were largely restricted to basin margins before Pliocene time. The coarse-grained upper member (**To**) subsequently prograded across much of the western basin. The ARG flowed within 2 km of the Sandia Mountains frontal fault system before Pleistocene time. Piedmont deposits derived from rift-flank uplifts prograded west and buried much of the ARG succession by early Pleistocene time. Between 1.2 and 0.8 Ma, the ARG had migrated toward the basin center when incision began forming the Rio Grande valley.

STRATIGRAPHY OF UNITS Qbt1g–Qbt3 OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF IN THE NORTH-CENTRAL TO NORTHEASTERN PORTION OF LOS ALAMOS NATIONAL LABORATORY, NEW MEXICO, by *Danielle K. Katcher*, dkatcher@lanl.gov, *Alexis Lavine*, *Claudia J. Lewis*, *Jamie N. Gardner*, and *Jennifer E. Wilson*, Environmental Geology and Risk Analysis Group, EES-9, Los Alamos National Laboratory, Los Alamos, NM 87545

We conducted detailed stratigraphic studies as part of a larger geologic mapping project to assess seismic hazards to the north-central to northeast portion of Los Alamos National Laboratory. Units **Qbt1g**–**Qbt3** of the Tshirege Member of the Bandelier Tuff are differentiated by the degree of welding, crystallization, weathering characteristics, and distinctive mineralogy. To better understand lateral variations in stratigraphy, we measured four stratigraphic sections and collected samples for petrographic and X-ray diffraction analysis. Non-welded **Qbt1g** is vitric (50–70% glass). The top of **Qbt1g** is marked by a "vapor-phase notch," above which glass is altered to cristobalite, tridymite, and alkali feldspar in units **Qbt1v** through **Qbt3**. The non-welded unit **Qbt1v-c** ("colonnade") lies directly above the vapor-phase notch and has a distinctive columnar appearance, due to cooling joints and/or tectonic fractures where the unit is indurated by devitrification and vapor-phase alteration minerals. We hypothesize that the main cementing agents in **Qbt1v-c** are cristobalite and Fe-oxide. Devitrification is recognized by axiolitic and minor spherulitic intergrowths of cristobalite and feldspar. Cristobalite content decreases as tridymite content increases in overlying non- to moderately welded unit **Qbt1v-u** ("upper"). **Qbt1v-u** and moderately welded **Qbt2** contain tridymite, alkali feldspar, and lesser cristobalite as crystals in pore spaces, suggesting an increase in vapor-phase alteration. In the western portion of the study area, closer to the source of the Bandelier Tuff, the upper part of **Qbt1v-u** is welded together with unit **Qbt2**. In the eastern portion of the study area, non-welded **Qbt1v-u** is overlain by partially to moderately welded **Qbt2**.

STRUCTURE AND TECTONICS

STRUCTURAL GEOLOGY OF THE NORTH-CENTRAL TO NORTHEASTERN PORTION OF LOS ALAMOS NATIONAL LABORATORY, NEW MEXICO, by *Alexis Lavine*, alavine@lanl.gov, *Claudia J. Lewis*, *Danielle Katcher*, *Jamie N. Gardner*, and *Jennifer Wilson*, Environmental Geology and Risk Analysis Group, EES-9, Los Alamos National Laboratory, Los Alamos, NM 87545

Geologic mapping in the north-central to northeastern portion of Los Alamos National Laboratory revealed small faults and broad zones of deformation that have little potential for seismic surface rupture. The 7.5 km^2 area lies ~1 km east of the Pajarito fault system, ~2.5 km south of the Sawyer Canyon fault, and within a zone of inferred subsurface, pre-Bandelier Tuff faults. Mapped changes in welding and crystallization in the Tshirege Member of the Bandelier Tuff coincide with or parallel stratigraphic contacts, providing large-scale, planar markers for determining structural offset. Fault and fracture zones include: 1) an ~180-m-wide zone of abundant fractures and faults that range in width from 1 to 60 cm, and have a mean strike of N12E ± 26° and mean dip of 87 ± 5º; 2) a 60-m-wide fault zone with ~1.2 m of down-to-the-northwest displacement; 3) a 15–20-cm-wide fault that is oriented N16E, 86E and consists of densely spaced deformation bands; and 4) three small (<1 m of vertical displacement) faults in the western portion of the map area. Fault zones 1 and 2 coincide with a zone of shallower dip that trends N10–15E, and could accommodate up to 8 m of down-to-the-west displacement across ~500 m. No stratigraphic markers are present where fault 3 is exposed; however, 3-D structural analysis suggests that it may be associated with distributed down-to-the-east deformation accommodating 5–6 m of displacement over ~300 m. Changes in dip of Tshirege Member units may result from distributed deformation or deposition over paleotopography.

DEFORMATION BANDS IN NON-WELDED IGNIMBRITES: PETROPHYSICAL CONTROLS ON THEIR OCCURRENCE AND IMPLICATIONS FOR FLUID FLOW, 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, Los Alamos National Laboratory, EES-9, MS D462, Los Alamos, NM 87545

Faults in ignimbrites are of interest for a variety of reasons, including their potential impact on fluid flow and transport through vadose zones in places like Los Alamos, New Mexico, and Busted Butte, Nevada. We have investigated petrophysical controls on deformation in small-displacement faults in these areas. Fractures and deformation bands are found at both sites. The primary controls on which structure forms in an ignimbrite unit are the number and strength of grain contacts in the groundmass, which are inversely proportional to porosity and directly related to degree of welding and postdepositional crystallization. Low-porosity, welded units deform by transgranular fracture; high-porosity, glassy, non-welded units deform by cataclasis and pore collapse within deformation bands. Moderately high porosity, non-welded units with postdepositional crystallization deform by either cataclasis with associated pore collapse, or by fracture, depending on local variations in clast size and nature of crystallization.

Clast- and pore-size reduction in deformation bands is significant, producing indurated zones of clay-sized material. Preferential wetting, inferred to promote alteration and cementation, is observed in many deformation bands. Many of these bands are also locally rich in smectite and/or cemented by calcite. We therefore interpret variably altered fault-zone material as evidence of preferential fluid flow through deformation bands in the vadose zone, which we infer to be the result of enhanced unsaturated permeability due to pore-size reduction in deformation bands. This is significant for models of fluid flow and transport, since most assume matrix-dominated flow through non-welded ignimbrites, disregarding potential effects of small-displacement faults.

FIRST YEAR'S DATA FROM TILTMETERS INSTALLED AROUND THE MARGINS OF HISTORIC UPLIFT, CENTERED ABOVE THE SOCORRO MAGMA BODY, RIO GRANDE RIFT, NEW MEXICO, by *David W. Love*, *Bruce Allen*, *Richard Chamberlin*, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *William Haneberg*, Haneberg Geoscience, 4434 SE Land Summit Court, Port Orchard, WA 98366

The elliptical pancake-shaped Socorro magma body is inferred to extend over 3,400 km^2 at a depth of ~19 km with an estimated thickness of 0.1 km: thus yielding a volume of about 340 km^3 (Balch et al., 1997). Since 1909 the rate of historic uplift near the center of the Socorro magma body at San Acacia has been between 1.8 mm/yr and 4 mm/yr (Larsen et al., 1986; Fialko and Simmons, 2001). Using vertical uplift rates from previously published studies, we calculate average tilt rates on the flanks of the uplift to be ~0.12 microradians (µrad) per year (~1° in 145 ka). Above the Socorro magma body, fault blocks of the early Rio Grande rift are numerous, strongly extended, and variably tilted. However, the long axis of the Socorro magma body is approximately coincident with the active axis of the rift as defined by Quaternary grabens that outline the southern end of the Belen Basin and the much narrower graben of the Socorro Basin.

With matching funds from the New Mexico Department of Public Safety, we installed tiltmeters on three margins of the historic uplift. The solar-powered meters are capable of measuring 0.1 µrad differences in tilt for extended periods. We anticipate that monitoring over several years might provide insight into the uplift process and interaction of magmatic stresses with long-term tectonic stresses as defined by upper crustal fault blocks. We selected tiltmeter locations to the north (Sevilleta 1) and south (Tech 1) that were away from Quaternary scarps and within graben blocks in order to minimize rift-related block rotation. The western station (Silver Creek 1), however, is on a large active west-tilting half graben (La Jencia Basin) where tectonic tilt and magmatic tilt should be additive. Available equipment limited the installation to depths of 3–4 m in alluvium.

Dataloggers record tilts, temperatures, and precipitation (only at Silver Creek) every 30 seconds and store averaged data every 20 minutes. The tilt data show diurnal fluctuations in the range of tenths of µrad that apparently are related to Earth tides. Longer-term trends of tens of µrad are contrary to expectations and may be due to several factors, including settling after installation. Surface waves from distant earthquakes as small as magnitude 5.1 temporarily affect the 20-minute averages and show that some tiltmeter rotation matches Rayleigh-wave motions. Temporary reversals in tilt direction follow precipitation events at Silver Creek. Sevilleta 1 continued to tilt southeast throughout the year. Tech 1 tilted northwest until the end of October, when it began to tilt northeast. Silver Creek 1 tilted southeast from March until August, then tilted briefly to the southwest and northeast, and tilted west and northwest in November and December.

HYDROGEOLOGY

SIMULATION OF PRE-DEVELOPMENT GROUND-WATER FLOW IN THE BASIN-FILL AQUIFER OF THE TULAROSA BASIN, SOUTH-CENTRAL NEW MEXICO, by *G. F. Huff*, gfhuff@usgs.gov, U.S. Geological Survey, New Mexico State University, Dept. 3ARP, Las Cruces, NM 88003

The U.S. Geological Survey in cooperation with the city of Alamogordo, New Mexico, and Holloman Air Force Base investigated the hydrology of the basin-fill aquifer in the Tularosa Basin through construction and calibration of a steady-state three-dimensional ground-water-flow model using the U.S. Geological Survey finite-difference modular ground-water-flow computer software MODFLOW-96. The model was calibrated by matching simulated water levels to available pre-development ground-water-level measurements. The distribution of pre-development water-level data restricts the well-calibrated area of the model to the eastern side of the Tularosa Basin. The root mean square error of the model in the well-calibrated area was 6.3 m.

Estimates made through model calibration indicate that an amount equal to approximately 143,000 m^3 per day (42,300 acre-ft per yr) of recharge enters the basin-fill aquifer from sub-basins that rim the Tularosa Basin. An amount equal to approximately 4–5% of annual precipitation in most sub-basins is simulated to enter the basin-fill aquifer as recharge. Approximately 88% of recharge left the basin-fill aquifer as simulated evapotranspiration under pre-development conditions. The remaining 12% was simulated to discharge either at land surface through springs or across the southern model boundary as ground water flow into the Hueco Bolson. Generalized directions of simulated pre-development ground water flow are dominantly west to southwest away from recharge areas in the Sacramento Mountains.

GROUND WATER GEOLOGY OF TAOS VALLEY, by *Tony Benson*, AnthonyBenson @msn.com, and *Elsbeth Atencio*, University of New Mexico, Taos, NM 87571

Water well drillers' logs (after accurately locating the wells with GPS equipment) were used to map the ground water table and subsurface structure. Basalt and clastic interbeds allow drillers' ample descriptions to be correlated from the Rio Grande gorge to the town of Taos.

The main feature herein, called the Airport arch, is a northeast-trending uplift with surface expression. Numerous normal faults have been mapped, especially on the east flank of the arch. Four north-trending faults seen at the surface in Los Cordovas can be traced northward and southward in the subsurface. Other faults have been mapped on the Hondo Mesa and Blueberry Hill. Faults appear to interfere with the lateral flow of ground water westerly toward the Rio Grande gorge.

Ground water recharge from streams near the mountain front shows seasonal drops in water level and an overall drop during the last 8 yrs of drought. Communities near the mountain front have seen water levels drop in response to the drought, whereas wells farther out in the valley have seen little effect.

INFLUENCE OF INFILTRATION AND EVAPORATION ON THE HYDROLOGIC BUDGET AT THE LAS VEGAS NATIONAL WILDLIFE REFUGE, NEW MEXICO, by *Thomas Evans* and *Jennifer Lindline*, Environmental Geology Program, New Mexico Highlands University, Las Vegas, NM 87701

An integrated hydrogeological study was conducted to characterize the soil types and to assess the influence of infiltration and evaporation on the hydrologic budget for a small pond at the Las Vegas National Wildlife Refuge in northeastern New Mexico. Fieldwork was conducted in September 2002 at Melton Pond, a representative pond (0.029 mi^2) within the refuge surface water system. Soil sampling and infiltration testing was completed during a time when the pond had been dry for several months. Ten soil samples were collected and separated into clay, sand, and silt fractions for classification. The soils underlying Melton Pond consist predominantly of clay with minor sandy clay and clay loam. A double ringed infiltration system was used to measure infiltration rates. Infiltration rates varied from 20.0 to 144.0 mm/hr averaging 55.2 mm/hr. Air temperature, wind speed, and relative humidity data over a 15-yr period were obtained from the Las Vegas Municipal Airport and used to calculate evaporation rates. Results indicate that evaporation varies from 0.45 (November) to 2.26 (June) acre-ft per month totaling 15.36 acre-ft per year. Since Melton Pond holds 58 acre-ft of water, the results suggest that a significant amount of water is lost to infiltration throughout the year. This result is supported by the observed ground water seeps in the Gallinas River Canyon that are recharged by pond leakage. Since the hydrogeologic characteristics of Melton Pond are representative of conditions throughout the Las Vegas region, the significant surface water losses to ground water leakage need to be accounted for as the municipality considers the benefits of an acequia-lining plan.

SOILS AND CO_2

SOIL GAS CO_2 EMISSIONS OVER THE BRAVO DOME FIELD IN THE AMISTAD AREA OF NEW MEXICO, by *Kristie McLin*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The Bravo Dome field, located in Union and Harding Counties, New Mexico, is a large underground carbon dioxide reserve that is one of the largest CO_2 accumulations in North America. This field provides jobs for about 100 people, as well as $1.8 million in tax revenues and royalties for the state annually. The carbon dioxide is primarily used to enhance recovery in the oil fields of southeast New Mexico and western Texas. Although the region's economy relies heavily upon the production of carbon dioxide, residents living on the eastern boundary of the field have expressed concern about the health effects associated with possibly elevated levels of carbon dioxide. In July and August of 2002, a field survey was conducted to investigate the possible natural leakage of carbon dioxide from the Bravo Dome field on ranches near the town of Amistad where health related complaints were reported to the states environmental and health departments. Atmospheric carbon dioxide concentrations were continuously monitored using a Drager CO_2 analyzer. Soil carbon dioxide concentrations were measured in several locations as well. Ambient atmosphere contains approximately 0.036% (by volume) CO_2, and measured atmospheric CO_2 concentrations in the study area remained consistently at 0.03%. Soil carbon dioxide concentrations ranged from 0.47% in sparsely vegetated areas to 1.0% in densely vegetated lawns. These measurements did not significantly differ from background measurements taken approximately 20 mi north of the CO_2 field. No elevated CO_2 concentrations were found in houses, near pipelines or the compressor plant. At Mammoth Mountain, California, soil CO_2 concentrations are significantly larger (>30% by volume), yet CO_2 related illnesses are rarely reported. We found no evidence for the presence of elevated CO_2 levels, and alternative explanations must be found to account for the illnesses experienced in the Amistad area.

POSTER SESSIONS, AFTERNOON PALEONTOLOGY

EDOPOID POSTCRANIA FROM THE RED TANKS MEMBER OF THE BURSUM FORMATION, LUCERO UPLIFT, CENTRAL NEW MEXICO, by *Susan K. Harris* and *Spencer G. Lucas*, New Mexico Museum of Natural History, 1801 Mountain Rd., NW, Albuquerque, NM 87104

Partially articulated material that represents the anterior dorsal vertebral column and most of the pectoral girdle of a large, primitive temnospondyl was collected at NMMNH locality 4509 in the Upper Pennsylvanian (upper Virgilian) Red Tanks Member of the Bursum Formation. This locality is in the uppermost part of the Red Tanks Member in a bed of grayish-green shale and reduced mudstone, probably of paludal or lacustrine origin, approximately 1.6 m below the base of the overlying Abo Formation. Closely associated material includes a segment of articulated caudal central elements, the complete left radius, and the proximal left ulna, as well as numerous rib fragments.

Whereas the morphology of the intercentra and pleuracentra is typically rhachitomous, the widely expanded ventral plate of the clavicle and its narrow, rodlike dorsal process distinguish this specimen from all euskelians (higher temnospondyls), such as *Eryops*. Other notable features of the pectoral girdle include the remarkably deep, dorsoventrally oriented glenoid fossa and the narrow, triangular coracoid plate, which bears a central longitudinal ridge with a large supracoracoid foramen positioned midway along its length.

Temnospondyl taxonomy is dependent, to a large extent, on cranial and mandibular characters. Thus, a generic or family level diagnosis of the Red Tanks material cannot be confirmed. However, the apparently primitive condition of the clavicular ventral plate and dorsal process suggests assignment of this specimen to the basal temnospondyl superfamily Edopoidea.

SPHENACODONTINE PELYCOSAURS FROM THE UPPER PENNSYLVANIAN (UPPER VIRGILIAN) RED TANKS MEMBER OF THE BURSUM FORMATION, by *Susan K. Harris*, *Spencer G. Lucas,* New Mexico Museum of Natural History, 1801 Mountain Rd., NW, Albuquerque, NM 87104; *Michael J. Orchard*, Geological Survey of Canada, Vancouver, B. C. V6B 5J3 Canada; and *Karl Krainer*, Institute for Geology and Paleontology, University of Innsbruck, Innrain 52, A-6020 Innsbruck, Austria

In 1980, Fracasso (Journal of Paleontology 54: 1237–1244) assigned localities yielding *Sphenacodon* material from megasequence one at El Cobre Canyon in the Cutler Formation of north-central New Mexico a Missourian age, thereby extending the stratigraphic range of *Sphenacodon* well below the Wolfcampian. However, later authors determined these localities to be within Wolfcampian age sediments of megasequence two. Diagnostic neural spines from the upper part of the Red Tanks Member of the Bursum Formation in the Lucero uplift of central New Mexico represent the oldest definitive record of the subfamily Sphenacodontinae. Their age is late Virgilian based on streptognathid conodonts collected from the middle third of the member that display primitive characters of the species complex that includes the index of the Virgilian–Wolfcampian boundary, *Streptognathodus isolatus*. No stratigraphic breaks occur in the upper third of the Red Tanks, strongly suggesting that the entire member, at least up to the base of the overlying Abo Formation, is of Carboniferous age.

As many as seven localities in the Red Tanks Member yielded elongate, anteroposteriorly expanded, laterally compressed neural spines diagnostic of the genus *Sphenacodon*. Three of these sites, in the Carrizo Arroyo South section, are approximately 34 m below the base of the Abo in beds of limestone conglomerate, whereas four additional sites in the Major Ranch area are within the uppermost 13 m of the member, and occur in beds of grayish-green shale and reduced mudstone.

Four partially articulated vertebrae were found preserved in a matrix of limestone-pebble conglomerate 8 m below the base of the Abo in the Red Tanks section, in close association with a bed containing large numbers of the bivalve *Permophorus*. The slender, elongate neural spines are characterized by a circular cross section and an absence of anterior and posterior grooves, features diagnostic of the primitive species *Dimetrodon milleri*, otherwise known only from the Lower Permian (middle Wolfcampian) Archer City Formation (ex Putnam Formation) in Archer County, Texas.

Pelycosaurian abundance and diversity are typically low in Desmoinesian and Missourian strata of the Pennsylvanian. Although faunal proportions of ophiacodontids and varanopsids increase significantly during the Virgilian, the Red Tanks material represents the only pre-Wolfcampian record of the progressive sphenacodontine genera *Sphenacodon* and *Dimetrodon*.

A TIME-AVERAGED TETRAPOD BONEBED: TAPHONOMY OF THE EARLY PERMIAN CARDILLO QUARRY, CHAMA BASIN, NORTH-CENTRAL NEW MEXICO, by *K. E. Zeigler*, *S. G. Lucas*, *A. B. Heckert*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104; A. *C. Henrici* and *D. S. Berman*, Carnegie Museum of Natural History, 4400 Forbes Ave., Pittsburgh, PA 15213

The Early Permian Cardillo Quarry is located near Arroyo del Agua, in the Chama Basin in north-central New Mexico. The quarry is stratigraphically low in the Cutler Formation and is Wolfcampian in age. During excavations in 1979, 1980, and 2002, the remains of the labyrinthodont amphibian *Eryops*, the diadectamorph *Diadectes*, a captorhinid, a varanopseid pelycosaur, and the pelycosaurs *Sphenacodon* and *Ophiacodon* were recovered from this locality. Numerically, the pelycosaurs dominate the bonebed. Taphonomic data collected during the 2002 excavations reveal that the Cardillo Quarry fossil assemblage is an attritional accumulation. The bones lie within a series of three distinct, pedogenically modified conglomerates that also include calcrete nodules, chert, quartzite, and other siliceous pebbles. The skeletal material is mostly disarticulated, though a partially articulated pelycosaur skeleton has been recovered from the overbank sediments above the uppermost conglomerate. Isolated skeletal elements and bone fragments are in various stages of weathering and show differing degrees of abrasion. The assemblage does not appear to have been hydraulically sorted because all three Voorhies groups are well represented. The Cardillo Quarry assemblage was formed by a series of crevasse splays, and the formation of each splay deposit followed the same sequence of events. First, basement material (siliceous pebbles) was incorporated into lag deposits in a stream, together with individual bones and bone fragments from upstream. This lag of pebbles and bones was then reworked onto the floodplain by crevasse splays during flooding of the stream, and probably incorporated additional bone material that was lying on the floodplain. The mixture of bones and pebbles was subsequently buried under fine silts during overbank deposition and pedogenically modified. Thus, the Cardillo Quarry is a classic example of a time-averaged vertebrate fossil assemblage.

NONMARINE BIVALVES (*UNIONOIDA: ANTHRACOSIIDAE*) FROM THE LOWER PERMIAN CUTLER FORMATION OF NORTH-CENTRAL NEW MEXICO, by *L. F. Rinehart*, *S. G. Lucas*, *A. B. Heckert*, *K. E. Zeigler*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104; *D. S. Berman*, and *A. Henrici*, Carnegie Museum of Natural History, 4400 Forbes Ave., Pittsburgh, PA 15213

The Welles Quarry (NMMNH locality 4825) is one of several pond/crevasse splay deposits in the Cutler Formation exposures near Loma Salazar in the Arroyo del Agua collecting area, Rio Arriba County, New Mexico. The quarry yields fish, amphibian, reptile, invertebrate, and plant fossils of Wolfcampian age. We describe a rich deposit of thin-shelled, freshwater bivalves from the quarry. The clams are preserved as external and (rarely) internal casts with a few shell fragments in laminar, gray and dark-red, micaceous muddy shale. Typical presentation is with the paired valves wide open (~180°), the hinge intact, and exterior surfaces facing up. Fish scales, coprolites, and disarticulated bones are common in the clam-bearing facies.

The clams are equivalved, inequilateral, and elongate oval in shape. Ligaments are external and opistodetic, hinges are straight and edentate, and adductor muscle scars are absent or not preserved. Length ranges from ~1 to ~23 mm. Umbones are slightly inflated and located at ~0.25 of length from the anterior end. Ornamentation consists only of concentric growth ridges. Two variants, one with a rounded posterior end, and the other more blunt, may represent sexual dimorphs. Allometric height-to-length ratio (= 0.45) and overall morphology are identical to the Guadalupian–Lopingian age anthracosiid, *Palaeanodonta parallela*, known from the Lower Beaufort Series of the Karroo Basin in South Africa, and the Tatarian of Russia. However, because of the large temporal and geographic range differences between *P. parallela* and the Welles Quarry specimens, we provisionally assign the clams to *Palaeanodonta* cf. *P. parallela*. This is the first report of *Palaeanodonta* from the Permian of North America, and a substantial extension of its stratigraphic range from the middle Permian to nearly the base of the Permian.

REVISED FAUNAL LIST AND SIGNIFICANCE OF THE UPPER TRIASSIC (REVUELTIAN: EARLY-MID NORIAN) SNYDER QUARRY, NORTH-CENTRAL NEW MEXICO, by *A. B. Heckert*, *K. E. Zeigler*, *S. G. Lucas*, *A. P. Hunt*, and *L. F. Rinehart*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

The Snyder Quarry, in the Painted Desert Member of the Petrified Forest Formation in north-central New Mexico, is one of the richest and most diverse Upper Triassic bonebeds discovered in the past 50 yrs. This bonebed formed, at least in part, as a result of a catastrophic paleowildfire that we also implicate in the formation of the well-known Canjilon Quarry and the recently discovered Hayden Quarry.

The Snyder Quarry yields a diverse array of vertebrates and a more depauperate invertebrate assemblage. Invertebrates include a new decapod crustacean, a conchostracan, and an allochthonous assemblage of the unionid bivalve "*Antediplodon*." Phytosaurs that we assign to *Pseudopalatus buceros* dominate the vertebrate assemblage (minimum number of individuals [MNI] = 11). Aetosaurs present in the quarry include *Typothorax coccinarum* and *Desmatosuchus chamaensis*, both represented by diverse osteoderms (scutes) and some other postcrania representing as many as five different individuals. A striking feature of the Snyder Quarry is the relative abundance of theropod dinosaurs (MNI = 4), most of which appear to be coelophysoids congeneric with *Eucoelophysis*, previously known only from the type locality near Orphan Mesa to the east. Other vertebrates are considerably rarer, and include semionotid and redfieldiid fish, metoposaurid amphibians, a procolophonid reptile, a probable lepidosauromorph reptile, and possibly a xenacanth shark. Recently we determined that rauisuchian archosaurs (*Postosuchus*-grade) are also a rare component of the fauna.

The tetrapod fauna of the Snyder Quarry is a "typical" Revueltian assemblage, including the index taxa *P. buceros* and *T. coccinarum*. The assemblage is particularly important for many reasons, including: (1) its exceptionally good preservation of many of the vertebrates, (2) it is the type locality of *D. chamaensis*, (3) it has the highest concentration of pre-Apachean (latest Triassic) ceratosaurian dinosaurs known, and (4) the extraordinarily rich concentration of phytosaur skulls and postcrania. *D. chamaensis* appears to be an anagenetic descendant of the more common *D. haplocerus*, known from older Chinle strata across the southwestern United States. Dinosaurs are exceedingly rare in the Chinle Group (except at the Ghost Ranch *Coelophysis* Quarry), and the presence of multiple individuals of a single species at the Snyder Quarry is a significant discovery. Indeed, *Eucoelophysis* is one of the oldest known coelophysids, and its presence marks the first appearance of a body form that would be successful until the end of the Early Jurassic (with the extinction of *Syntarsus*). The abundance of phytosaurs at the Snyder Quarry, although somewhat "typical" of Chinle localities, is still significant because the catastrophic nature of the assemblage has helped us document sexual dimorphism in the phytosaur *Pseudopalatus* (best shown at the nearby Canjilon Quarry) and will facilitate studies of the ontogeny and variation of this genus.

HOW BIG WAS A PHYTOSAUR? MASS ESTIMATES OF AN EXTINCT CLADE OF LATE TRIASSIC ARCHOSAURS BASED ON NEW MEXICAN FOSSILS AND MODERN CROCODILES, by *A. B. Heckert*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104; *G. Hurlburt*, Biology Department, California State University, Bakersfield, 9001 Stockdale Highway, Bakersfield, CA 93309; *J. O. Farlow*, Department of Geosciences, Indiana-Purdue University, 2101 Coliseum Boulevard East, Fort Wayne, IN 46805; and *K. E. Zeigler*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

Phytosaurs were the largest and most common semi-aquatic predators of the Late Triassic. Although their skulls are relatively common in the fossil record, articulated, or even associated skeletons are extremely rare, so it has always been difficult to gauge just how large (mass or length) an individual phytosaur may have been. Body mass in particular is an important physiological variable, often used for scaling of organs, biomass determination, biomechanics, and locomotion. We take advantage of phytosaurs' general similarity to extant crocodilians to attempt to reconstruct body mass and length based on measurements of the skulls and limbs of phytosaurs from the Upper Triassic Snyder and Canjilon Quarries in north-central New Mexico. These quarries, in the Painted Desert Member of the Petrified Forest Formation (Revueltian: early-mid Norian) preserve catastrophic death assemblages that appear to represent well discrete populations of phytosaur populations. We also utilize a snout-vent measurement based on an articulated skeleton from the Canjilon Quarry to compare the accuracy of different equations based on discrete limb elements. Body mass estimates for Snyder Quarry phytosaurs range between 25 and 500 kg, with most specimens yielding estimates of approximately 200–350 kg. The Canjilon Quarry sample includes fewer juveniles and more robust adults, including one individual that may have weighed as much as 535 kg. From equations based on nine extant crocodilian genera, these Revueltian phytosaurs appear to have approached 4.5 m total body length for an ~400 kg phytosaur. The prevalence of subadult to adult phytosaurs in both quarries based on body mass estimates corroborates qualitative estimates of the population structure based on skull sizes alone, thereby reinforcing the hypothesis that both quarries are catastrophic assemblages.

NEW TETRAPOD TRACKSITE, UPPER TRIASSIC SLOAN CANYON FORMATION, UNION COUNTY, NEW MEXICO, by *A. P. Hunt*, *S. G. Lucas*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104; and *M. G. Lockley*, Geology Department, University of Colorado at Denver, Denver, CO 80217

The vast majority of tetrapod tracks in the Upper Triassic Chinle Group of the western United States occur in the Rock Point sequence, which is of Apachean (late Norian–Rhaetian) age. These tracks are important for several reasons, including: (1) they represent the most diverse Late Triassic tetrapod track assemblages in western North America; (2) they provide evidence of faunas that are poorly represented by body fossils; and (3) they provide a basis for correlation with the tetrapod faunas of the Late Triassic of eastern North America, which are predominantly represented by ichnofaunas.

The Apachean Sloan Canyon Formation of northeastern New Mexico contains a number of significant tetrapod ichnofaunas, including Peacock Canyon and Sloan Canyon. A newly discovered tetrapod tracksite is present in the floor of Sloan Creek in Union County, New Mexico (sec. 15 T5N R35E). The tracksite is in the middle part of the Sloan Canyon Formation and covers a minimum area of 2,000 m^2. Sediments at the tracksite represent playa sandflat and playa margin deposits.

At Sloan Creek, tracks occur at eight distinct stratigraphic levels in a 1.5-m-thick interval of red and green mottled, fine-grained sandstone and siltstone. The most common tracks are identified as *Pseudotetrasauropus* (prosauropod dinosaur) and occur at five levels. Less common, each only occurring at a single level, are tracks assigned to *Brachychirotherium* (aetosaur?), *Grallator* (theropod dinosaur), and *Tetrasauropus* (sauropod dinosaur?). The Sloan Creek site differs from Sloan Canyon in lacking large tridactyl theropod tracks and from Peacock Canyon in lacking *Rhynchosauroides*, *Kouphichnium*, and putative therapsid tracks.

A NEW LOCALITY FOR MIDDLE JURASSIC FISH FROM THE TODILTO FORMATION, NORTH-CENTRAL NEW MEXICO, by *A. P. Hunt*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104; and *A. Downs*, Ruth Hall Museum of Paleontology, Ghost Ranch Conference Center, HC 77, Box 1, Abiquiu, NM 87510

The Middle Jurassic (Callovian) Todilto Formation crops out throughout much of northwestern and east-central New Mexico and southwestern Colorado. The Todilto represents a vast, paralic salina. In the central part of the basin of deposition the Todilto is composed of a lower Luciano Mesa Member that is dominated by laminated limestone and an upper Tonque Arroyo Member that is composed of gypsum.

The Luciano Mesa Member locally contains a depauperate fauna. Holostean fish are known from several localities in New Mexico including: (1) Bull Canyon, west of Santa Rosa; (2) Warm Springs, north of San Ysidro; (3) Lamy; (4) Montezuma; (5) Suwanee near Grants; (6) La Liendre near Las Vegas; (7) Echo Amphitheater, south of Chama; and (8) probably near Acoma. Despite the number of localities only the Bull Canyon area has produced significant numbers of specimens.

We have located a new locality for holostean fish from the Luciano Mesa Member adjacent to Ghost Ranch in Rio Arriba County. Fish fossils occur 2.1 m above the lower contact with the Entrada Formation. The fish occur in a 10-cm-thick bed of limestone that forms a slope break. The matrix is a varved, organic-rich limestone. Beds above and below the fish level exhibit microfolding ("crinkly" bedding), which is characteristic of parts of the Luciano Mesa Member. The Luciano Mesa Member is 4.55 m thick at this location.

This locality has not been excavated. Surface collection has yielded two specimens that are reposited at the Ruth Hall Museum of Paleontology at Ghost Ranch. Both specimens are laterally compressed, and the cranial and other areas are covered by matrix. However, based on the morphology of the tail and dorsal fin and the fact that only three species of holostean fish are known from the Todilto, we are confident in assigning these specimens to *Todiltia schoewei*. This locality has great potential to be a significant source of Jurassic fossil fish specimens.

A LARGE HADROSAUR TRACK FROM THE FRUITLAND FORMATION (LATE CRETACEOUS: CAMPANIAN), NORTHWESTERN NEW MEXICO, by *A. P. Hunt*, *S. G. Lucas*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104; and *M. G. Lockley*, Geology Department, University of Colorado at Denver, Denver, CO 80217

The Late Cretaceous (Campanian) Fruitland Formation is widely exposed within the San Juan Basin of northwestern New Mexico and represents deltaic and paludal environments. The Fruitland contains an extensive vertebrate fauna, but there is only one previous report of tetrapod tracks.

The new track is in the collections of New Mexico Museum of Natural History and Science (NMMNH P-7145). This track is preserved in a carbonaceous siltstone from the upper part of the formation. It is a tridactyl pedal track with a maximum length (through the central digit impression) of 800 mm and a maximum width of 870 mm. There is a small, rounded heel impression. The track consists of three, broad digit impressions with blunt tips. The side digit impressions are 750 and 630 mm long.

The majority of North American ichnofaunas from the Late Cretaceous are dominated by ornithopod tracks. NMMNH P-7145 is similar to an ornithopod track in (1) being wider than long, (2) having wide divarification of the digit impressions, (3) the length of the middle digit impression not being substantially greater than the side digit impressions, (4) possessing broad digit impressions, and (5) the tips of the digit impressions being blunt. Hadrosaurs are the only large Campanian ornithopods known from New Mexico, and so NMMNH P-7145 presumably represents a hadrosaur. The Fruitland Formation contains the lambeosaurine *Parasaurolophus cyrtocristatus* and indeterminate hadrosaurines. However, the conservative postcrania of hadrosaurs does not allow the identification of tracks below the family level.

NONMARINE INVERTEBRATES FROM THE LATE TRIASSIC SNYDER QUARRY, CHINLE GROUP, CHAMA BASIN, NEW MEXICO, by *S. G. Lucas*, *K. E. Zeigler*, *A. B. Heckert*, and *L. F. Rinehart*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

Near Ghost Ranch in Rio Arriba County, New Mexico, NMMNH locality 3845 (the Snyder quarry) is stratigraphically high in the Petrified Forest Formation of the Chinle Group and of Revueltian (Norian) age. Besides an extensive fossil bone assemblage, which apparently formed in response to a catastrophic wildfire, the quarry yields a small array of nonmarine invertebrates from mudstones and conglomerates a few meters above the principal bone bed. A single, incomplete conchostracan from the mudstone has fine growth lines, a carapace length of ~5 mm and can be tentatively assigned to the polymorphic genus *Lioestheria*. It indicates the presence of a shallow, ephemeral pond of probable high alkalinity soon after Snyder bonebed accumulation. Mudstone above the main bone bed also yielded a 48-mm-long by 19-mm-wide decapod specimen that is wide bodied and short tailed, unlike other known Triassic crustaceans. This animal represents the first decapod body fossil from the Triassic of New Mexico and is the oldest eubrachyuran crab.

The most abundant invertebrates from the Snyder Quarry are unionid bivalves that form an allochthonous assemblage in conglomerate above the main bone bed. These unionids are elongate to ovate in outline, thin shelled, and have abrupt anterior ends, about 19 radiating umbonal ridges and radiating riblets on the beak. Metrics (in mm, N = 16) are length = 25–58, height = 10–29 (length/height ~2), and beak length = 7–16. They are best assigned to *Antediplodon terraerubrae* (Meek, 1875) *sensu* Good, 1998, though we recognize that application of the name *Antediplodon* Marshall, 1929 to Triassic unionids is problematic. *A. terraerubrae* is a common Revueltian unionid from Chinle Group strata in New Mexico, Arizona, and Utah.

DINOSAUR FOOTPRINTS FROM THE LOWER CRETACEOUS ANAPRA SANDSTONE AT CERRO DE CRISTO REY, DOÑA ANA COUNTY, NEW MEXICO, by *E. Kappus*, Department of Geological Sciences, University of Texas at El Paso, El Paso, TX 79968; *S. G. Lucas*, *A. B. Heckert*, and *A. P. Hunt*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

Dinosaur tracks and swimming traces have been discovered at three localities in the latest Albian "Anapra Sandstone" (= Sarten Member of the Mojado Formation, Bisbee Group) at Cerro de Cristo Rey in Sunland Park, New Mexico, southernmost Doña Ana County. At one locality, NMMNH locality #5293, many underprints (over 400) of the ichnogenus *Caririchnium* (an ornithopod dinosaur) are preserved in concave relief on top of a hematized, bioturbated sandstone bed in the lower part of the Anapra, ~9 m above its basal contact with the underlying Mesilla Valley Shale. The exposure is approximately 400 m^2, although ~150 m^2 is partially covered by erosional debris. These tracks are tridactyl, relatively large (up to 65 cm footprint length), have wide, blunt toes, and a square bilobate heel, all of which are characteristic of the ichnogenus *Caririchnium.*

The second and third localities are two quarries adjacent to each other and are designated NMMNH localities #5291 and #5292. These are linear quarries exposing two track-bearing beds 9 m apart stratigraphically in the upper third of the Anapra Sandstone. The lower bed of this second locality also preserves large *Caririchnium* tracks in concave relief with small manus impressions. Also preserved are large (40–60 cm footprint length) tracks of the ichnogenus *Magnoavipes* (a theropod dinosaur), characterized by extremely thin, pointed toes. These theropod tracks are preserved in convex epirelief in a hematized, bioturbated sandstone as well. The upper bed of these two localities preserves *Caririchnium* tracks in convex hyporelief as well as numerous swimming traces—possibly from reptilians. These are scratch marks and other parallel, linear grooves. These two upper Anapra track beds can be traced over a total strike of ~750 m and as many as 350 distinct footprints are exposed, including at least 12 pairs of swimming traces.

The Anapra Sandstone is of latest Albian age (*Plesioturrillites brazoensis* ammonite zone), so the Cerro de Cristo Rey tracks are slightly younger than the well-known late Albian tracksites of northeastern New Mexico, which are in strata equivalent to the *Mortoniceras equidistans* ammonite zone, or slightly younger. At Cerro de Cristo Rey, the dominance of ornithopod tracks and absence of sauropod tracks fits regional patterns of late Albian–Cenomanian track distribution consistent with North American extirpation of sauropods before late Albian time. The deltaic/coastal plain depositional setting of the Anapra Sandstone is also remarkably similar to the track-bearing late Albian–Cenomanian sandstones of northeast New Mexico, Oklahoma, and southeast Colorado, which also have a tetrapod footprint ichnofacies dominated by ornithopod (*Caririchnium*) tracks.

NEW MEXICO'S MOST COMPLETE SKULL OF THE CRETACEOUS DINOSAUR *PENTACERATOPS* (ORNITHISCHIA: CERATOPSIDAE)—INSIGHTS INTO THE CRANIAL ANATOMY OF THE GENUS, by *P. K. Reser*, *A. B. Heckert*, and *S. G. Lucas*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

In 1978 the Museum of Northern Arizona (MNA) excavated a remarkably complete skull and jaws of the ceratopsian dinosaur *Pentaceratops sternbergii* from the Fruitland Formation in northwestern New Mexico. This specimen, MNA Pl. 1747, was on display in the NMMNH's Cretaceous Seacoast hall for a decade, exhibited much as it was found—crushed and slightly disarticulated. Before the specimen was returned to MNA, we made a mold and cast the disarticulated elements and assembled them in a new, three-dimensional resin cast mount now on display in the NMMNH's remodeled Cretaceous hall. This mount preserves the specimen as it was found but, unlike the previous exhibit, is now free-standing so that the skull can be examined from all angles. By doing this we avoided the pitfalls associated with reconstruction or "correcting" deformation. The restoration allows us to re-evaluate much of the cranial anatomy of *Pentaceratops*. The skull was almost entirely complete, lacking only the nasal horn. One significant result of this project revealed that the marginal epoccipitals cannot be placed on the frill with confidence, even though this is one of the best-preserved frills of *Pentaceratops* known. The XI epoccipitals, however, between the parietals at the posterior edge of the frill, are well preserved and confirm previous diagnoses of the genus. Another significant finding is that frill length is approximately 200% of "face" length. That is, a preorbital length of 740 mm on the NMMNH cast compares with a "frill length" (measured from the anterior margin of the orbit to the posterior edge of the parietal) of 1,480 mm, for a total skull length approaching 2.2 m. This suggests that the specimen of *Pentaceratops* from the San Juan Basin on display at the Sam Noble Museum of Natural History in Norman, Oklahoma (OMNH 10165), although incomplete, is reconstructed correctly with a total skull length of approximately 3 m. Other useful comparative measurements made on the cast of the MNA specimen include occipital condyle diameter (78 mm), squamosal length (1,140 mm), and dimensions of the sheared supratemporal fenestra on both the right (660 mm long, 600 mm wide) and better-preserved left (370 mm long, 26 mm wide) side. This is a relatively rare fossil of *Pentaceratops* that includes lower jaws, and the left lower jaw is approximately 790 mm long as preserved.

TURONIAN AMMONITES FROM THE UPPER CRETACEOUS D-CROSS MEMBER OF THE MANCOS SHALE, D-CROSS MOUNTAIN, CATRON AND SOCORRO COUNTIES, NEW MEXICO, by *P. L. Sealey* and *S. G. Lucas*, New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

The zones of *Prionocyclus wyomingensis*, *Scaphites ferronensis*, and *Prionocyclus novimexicanus* are present in the D-Cross Member of the Mancos Shale at D-Cross Mountain. The ammonite fauna includes *Coilopoceras inflatum* Cobban and Hook, *Prionocyclus wyomingensis* Meek, *Scaphites* *ferronensis* Cobban, and *Prionocyclus novimexicanus* (Marcou). *C. inflatum* is abundant and is found at or near the base of the D-Cross Member at D-Cross Mountain. All specimens collected are the robust form of *C. inflatum*. *P. wyomingensis*, although not common, is found in association with *C. inflatum*. Thus far, only one specimen of *S. ferronensis* has been found at D-Cross Mountain. This is the first report of *Scaphites* occurring at D-Cross Mountain. *P. novimexicanus* is common and is found in the lower part of the section at D-Cross Mountain, in contrast to Cebollita Mesa and Puertecito, New Mexico, where it is found throughout most of the section of the D-Cross.

The collignoniceratid zone of *P. wyomingensis* also occurs in the D-Cross Member at Cebollita Mesa, in the Juana Lopez Member of the Mancos Shale northeast of Thoreau, New Mexico, and in the type section of the Juana Lopez Member northwest of Cerrillos, New Mexico. The occurrence of the standard zone of *S. ferronensis* at D-Cross Mountain indicates correlation of the lower part of the D-Cross there with the lower part of the D-Cross at Cebollita Mesa, the lowest part of the D-Cross at Puertecito, and the upper part of the Juana Lopez Member of the Mancos Shale at the type section. The collignoniceratid zone of *P. novimexicanus* also occurs in New Mexico in the D-Cross Member at Carthage, Riley, Puertecito, Cebollita Mesa and in the Juana Lopez Member at the type and reference sections. The *P. wyomingensis* and *S. ferronensis* zones are of late middle Turonian age, and the *P. novimexicanus* zone is of late Turonian age.

ARCHAEOLOGY

A COMPARISON OF TEMPER MATERIAL IN SANTA FE BLACK-ON-WHITE AND CORRUGATED POTTERY SHERDS WITH LOCAL GEOLOGY FORMATIONS AT TECOLOTE PUEBLO (LA 296), by *T. Hardesty*, *R. Mishler*, Southwest Studies Program, New Mexico Highlands University, P.O. Box 9000, Las Vegas, NM 87701; and *J. Lindline*, Environmental Geology Program, New Mexico Highlands University, P.O. Box 9000, Las Vegas, NM 87701

A petrographic analysis of Santa Fe black-on-white pottery sherds, corrugated pottery sherds, and local geologic materials at Tecolote Pueblo (LA 296) in northeastern New Mexico was conducted to determine provenience of manufacture of the pottery. This study focused on the temper portions of the sherds and the non-clay portions of the geologic formations, those fractions measuring > 0.10 mm in diameter. Temper minerals included quartz, plagioclase feldspar, potassium feldspar, biotite, muscovite, calcite, hornblende, epidote, and pyroxene. Temper material also included a variety of lithic fragments including granite, siltstone, aphyric basalt, and hornblende- and augite-porphyritic basalt. Distinguishing optical and crystallographic properties of minerals and lithic fragments were noted, such as grain size, grain shape, and twinning. Point count analysis was also conducted on each sample to calculate modal percentages of the geologic constituents within each sample group. Qualitative and quantitative analyses have revealed similar geologic materials within all three groups and similar ranges of amounts of each temper material within the pottery samples. The data indicate that the Santa Fe black-on-white and corrugated pottery sherds are distinguished only by temper size. The Santa Fe black-on-white pottery sherds have a smaller temper size (averaging 0.15 mm in diameter) than the corrugated sherds (ranging between 0.50 and 0.25 mm in diameter). Both pottery groups are constructed of material similar in composition to local geological sources, suggesting that they both were locally produced. The data are still undergoing analyses for statistical significance. Completion of the study is anticipated by May 2003.

CLAYS THAT WORK: COMPOSITIONAL ANALYSIS OF TRADITIONAL PUEBLO CERAMIC SLIPS, by *C. Porreca*, Department of Earth and Planetary Sciences and Department of Anthropology University of New Mexico, Albuquerque, New Mexico; Mailing Address: 611 Lead Ave SW #517, Albuquerque, NM 87102, 505-243-5965 (H)

This research explores what mineralogical differences in clays account for their performances as slip clays in the production of Native American traditional ceramics. Slips are thin suspensions of clay in water applied to the entire surface of a clay vessel before firing and serve as an adhesive base for painted designs. Organic paints adhere to some of these clay slips during firing, but not to others. The clays for this study are derived from fluvial mudstones in the Eocene Diamond Tail Formation in the Galisteo Basin, north-central New Mexico. Random samples were collected within massive, bioturbated, floodplain mudstone facies where the clay mineralogy can vary significantly over short distances. Although there are multiple variables to be considered, this research focuses on evaluating what mineralogical differences in the clays could account for their function as slips and how the mineralogical differences relate to their geological origin. Mineralogical variability can result from primary depositional variations and/or effects of Eocene floodplain weathering. X-ray diffraction was used to assess the chemical composition of the clay samples and to interpret the possible causes of the performance differences. Preliminary results suggest that slip clays containing a larger smectite to illite ratio retain an organic paint better than those clays with relatively less smectite.

CAVES AND KARST

AMERICA'S NATIONAL CAVE AND KARST RESEARCH INSTITUTE 2003—THE GEARING UP PHASE, by *L. D. Hose*, LHose@cemrc.org, *Z. C. Bailey*, National Cave and Karst Research Institute, 1400 University Dr., Carlsbad, NM 88220; *L. Land*, New Mexico Bureau of Geology and Mineral Resources, CEMRC, 1400 University Dr., Carlsbad, NM 88220; and *P. Boston* Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

America's National Cave and Karst Research Institute, established by the U.S. Congress as a National Park Service entity, began its "gearing up phase" in December 2002 following a 2.5 yr development stage. Permanent director Louise Hose has established an institute office in Carlsbad, New Mexico. Interim director, Zelda Bailey, continues to work on development issues from the Denver National Park Service office during this transition time.

The director's current efforts include initial operational setup, recruiting staff positions (we anticipate a science coordinator and an administrator this year), designing a permanent building, and developing a grant process. The institute operates under a mandate to raise one-half of its funds from non-federal sources, thus fundraising and marketing constitute major demands. We currently operate under a funding match from the state of New Mexico, which supports collaborative efforts by New Mexico Bureau of Geology and Mineral Resources, Carlsbad Office, hydrogeologist Lewis Land and New Mexico Institute of Mining and Technology (NMT) geomicrobiologist Penny Boston.

Land is currently preparing a manuscript on variations in ground water discharge from gypsum sinkholes at Bottomless Lakes State Park, New Mexico. An Oklahoma Geological Survey circular titled "Evaporite Karst: Engineering and Environmental Problems in the United States" will be published this fall.

New Mexico Institute of Mining and Technology created a Cave and Karst Studies Program to provide strong intellectual and educational foundations for the institute and wider speleological community, including vigorous fundraising activities designed to enhance the NMT program and support the institute's needs. Five new cave and karst graduate students will be admitted in fall 2003 under Boston's direction.

CAVE AND KARST STUDIES AT THE BEGINNING OF THE 21ST CENTURY: THE NEW MEXICO CONNECTION, by *Louise D. Hose*, LHose@cemrc.org, National Cave and Karst Research Institute, 1400 University Dr., Carlsbad, NM 88220

Once mostly dismissed as the homes of unpleasant guano deposits, curious but economically worthless mineral displays, and eccentric adventurers, caves and the karst landscapes containing them have come into the scientific research mainstream during the last decade. First-tier journals recently published both refereed papers and summary articles about speleological research. Numerous television documentaries have focused the American public on cave resources, touting cancer-fighting microbes and Martian ecosystem analogues. State surveys increasingly look to speleologists and cavers for help solving water contamination and geoengineering problems.

Work in New Mexico has frequently led the changing respectability toward speleology and karst research. The discovery of Lechuguilla Cave (Carlsbad Caverns National Park), the world's most spectacular cave-find in the second half of the 20th century, ignited the public and scientific interest in caves. Recognition of enormous biomass below the surface of the earth and the accompanying explosive interest in geomicrobiology has led geologists to look to caves as windows to this fascinating, potentially valuable world. Lechuguilla Cave has served as the most significant, natural geomicrobiology laboratory.

Changing demographics have forced attention toward karst. Karst and pseudokarst lands, such as the Appalachia, Ozarks, and New Mexico, constitute some of the most impoverished and sparsely populated regions of the country. This relationship is a natural consequence of two common characteristics of karst.....poor soil and few surface streams. Today, industry and suburbia invade karstlands, and humans increasingly impact formerly rural karst regions.

Americans can no longer ignore the 20% of our country and New Mexico underlain by karst.

ORIGIN OF HYDROMAGNESITE CAVE BALLOONS: CLUES FROM HIGH-RESOLUTION TRANSMISSION ELECTRON MICROSCOPY, by *P. P. Provencio*, Sandia National Laboratories, Albuquerque, New Mexico 87185; and *V. J. Polyak*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Hydromagnesite, a platy hydrated magnesium carbonate mineral commonly forming sticky pastes (moonmilk) in dolostone-hosted caves, is the primary component of a rare speleothem type referred to as a cave balloon. Hydromagnesite cave balloons form from moonmilk and have an interior filled with gas, likely carbon dioxide, air, or oxygen. A carbon dioxide interior would be counter-productive to carbonate mineral growth. Hydromagnesite moonmilk may be closely associated with microbial activity, helping to explain the source for a gas-filled balloon interior. To further understand the origin of this rare and fascinating speleothem, we conducted a cross-section examination of a hydromagnesite balloon wall using high-resolution transmission electron microscopy (HRTEM). HRTEM reveals fibrous amorphous-like material between the hydromagnesite plates. Elemental analysis reveals that this material contains silicon. It is known that magnesium silicates such as trioctahedral smectite form in magnesium-rich cave environments. In addition, in laboratories hydromagnesite has been used as a template for the synthesis of smectite. We believe that the amorphous-like material between the hydromagnesite platelets may be a hydrated magnesium silicate-like trioctahedral smectite. Such a material could contribute to the formation of hydromagnesite balloons in two ways: (1) the material could act as a lubricating medium allowing the platelets to move with expansion and contraction of the balloon, and (2) the material could provide a shield for the hydromagnesite from the possibly corrosive nature of the balloon's interior environment.

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