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New Mexico Geological Society Spring meeting abstracts—1995

The New Mexico Geological Society annual spring meeting was held at New Mexico Institute of Mining and Technology (Socorro) on April 7, 1995. Following are the abstracts from all sessions given at that meeting.

Geologic controls on Cenozoic basins session

PETROGRAPHIC INVESTIGATION OF THE NACIMIENTO FORMATION, SOUTHERN SAN JUAN BASIN, NORTHWEST NEW MEXICO, by *K. W. Holmes*, and *L. J. Crossey*, Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

The San Juan Basin is a Laramide-age broken foreland basin in northwestern New Mexico. The basin contains sediment deposits that record paleodrainage patterns and source areas located in mountains to the north and northwest, from Late Cretaceous through early Eocene time. Although diverse Paleocene vertebrate fossils found in the Nacimiento Formation have been studied extensively, the corresponding petrology has not been documented. This study examines four localized collection areas in the southwestern and southern perimeter of the San Juan Basin based on the stratigraphic work of Williamson and Lucas (1992), and Williamson (1994).

The depositional environment of the formation has been interpreted as a poorly drained alluvial floodplain (Williamson, 1994). The 43 samples studied range from strongly cemented arkose and lithic arkose channel sandstones, found interbedded with mudstones, siltstones, and thin layers of lignite. Lithics include unaltered plutonic and volcanic fragments, volcanic chert, clay-cemented sedimentary rocks; fine rock fragments are highly altered.

The Kutz Canyon section, representing the most complete vertical section sampled, ranges from bottom to top from zeolite (analcime) and gypsum cements in the "main body" member, to clays and discontinuous calcite in the "unnamed" member, to pedogenic silcretes and related silica-cemented units in the Escavada Member. In the Arrollo Chijuillita Member of the Mesa de Cuba section calcite and clays are the dominant cements, which is distinct from the temporally equivalent "main body" member to the west. X-ray diffraction (XRD) results indicate that smectite and kaolinite are the dominant clays.

The results are consistent with provenance identified by Smith (1988, 1992) and Lucas and Williamson (1992) as drainages extending from surrounding uplifted Precambrian granite and associated strata. These areas include the Four Corners Platform, Brazos–Sangre de Cristo uplift, Nacimiento uplift, and the San Juan uplift, and Tertiary volcanics.

ORIGIN AND DISTRIBUTION OF CALCITE CEMENTATION IN THE ZIA FORMATION, SANTA FE GROUP, ALBUQUERQUE BASIN, by *Joseph Beckner*, Department of Geoscience, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Calcite-cemented zones in the Zia Formation of the lower Santa Fe Group in the western part of the Albuquerque basin exhibit a wide range of morphologies from isolated oval and elongate shapes to laterally extensive sheets (>1 km). Excellent exposures allow detailed examination of geometric relationships between primary textures, cementation, and depositional environment. These relationships will be determined in outcrop as well as petrographically and geochemically. Laterally extensive cemented zones are formed predominately in mixed fluvial-eolian environments during periods of depositional stability and soil formation. The formation of small (0.01–10 M) lenticular, ovoid or elongate (oriented) concretions is controlled by primary permeability in the sands (i.e., they form preferentially in coarser and better sorted layers). These smaller concretions are more common in strictly fluvial or eolian environments (i.e. unmixed environments). The lower part of the Zia (Piedra Parada and Chamisa Mesa Members) is largely eolian in character, and concretionary zones are small lenticular bodies and isolated nodules. The middle Zia (Canada Pillares Member) is of fluvial origin, and concretions are much the same. The upper Zia (unnamed member) has many laterally extensive concretionary zones, as well as many smaller and isolated concretions. Characterization of different concretion types, how they form, and their spatial distribution can be important in recognition of similar rocks where exposure is poor.

PATTERNS OF CEMENTATION ALONG A CENOZOIC NORMAL FAULT: A RECORD OF PALEOFLOW ORIENTATIONS, by *L. B. Goodwin*, and *P. S. Mozley*, Department of Geoscience, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The Sand Hill fault is a steeply dipping normal fault that cuts

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Also in this issue

Coming Soon

Morrison Formation of northwestern New Mexico

Jornada Draw fault in the southern Jornada del Muerto poorly consolidated sediments of the Albuquerque Basin, New Mexico. The fault zone, which varies in width from ~1 to 6 m, is selectively cemented by calcite. The margins of cemented areas are locally characterized by striking patterns of elongate cementation, which have a strong subvertical orientation. We have considered a variety of possible mechanisms for the formation of these elongate cements, including deformation, weathering, rotation of adjacent cemented beds, and precipitation from flowing ground water. All but the latter can be ruled out. In addition, the elongate cements closely resemble elongate concretions that form from flowing ground water in sedimentary rocks. Such concretions are common elsewhere in the Santa Fe Group, particularly in the Zia and Sierra Ladrones Formations. We conclude that the fault-zone cements precipitated from flowing ground water and are elongate parallel to the flow direction at the time of precipitation. Thus, these elongate cements provide an important constraint on models of fluid flow along faults in poorly consolidated sediments—the orientation of outcrop-scale flow.

FAULT-RELATED CONTROLS ON THE PERMEABILITY OF POORLY CONSOLIDATED SANTA FE GROUP UNITS, by *J. M. Sigda*, Hydrology Department, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Fault-related slip deformation and diagenesis alter the permeability of the parent sedimentary basin fill by changing the pore-size distribution and interconnectedness. These alterations allow fault zones to act as either barriers or conduits to ground-water flow. The importance of fault-zone controls on permeability in well-indurated sedimentary rocks is well known in reservoir engineering because faults often seal or compartmentalize hydrocarbon reservoirs. However, fault-zone impacts on the permeability of poorly consolidated sediments typical of aquifers are not well understood. Field measurements of gas permeability at two faulted outcrops of Santa Fe Group sediments indicate that fault-related changes decrease permeability within the fault zone relative to that for the parent basin-fill material. Geostatistical analysis is employed to determine whether the permeability decreases are significantly distinguishable from the naturally occurring permeability heterogeneity of the parent materials. Thin-section petrography is used to examine how the permeability changes are related to a hierarchy of structural deformations and to post-slip diagenetic changes.

PERMEABILITY, POROSITY, AND GRAIN-SIZE DISTRIBUTION OF PLIOCENE AND QUATERNARY SEDIMENTS OF THE ALBUQUERQUE BASIN: OUTCROP STUDIES AND SUBSURFACE INVESTIGATIONS, by *D. M. Detmer*, Department of Geoscience, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Outcrop studies allow valuable observation and measurement of the characteristics of similar deposits occurring in the subsurface, including permeability measurements, relationships among facies, continuity of facies, scale of bedding, and sedimentary structures. Aquifer-related sediments crop out at the surface at a number of locations in the Albuquerque Basin. As part of an investigation of natural and artificial recharge in the basin, 12 outcrops in the municipal area were examined. Three outcrops of upper Santa Fe Group were selected, along with proximal and medial Tijeras Arroyo facies, two recent outcrops in Bear Canyon Arroyo, and distal Embudo fan facies. Late Pleistocene river-terrace deposits, the Los Duranes and Edith Gravel type sections, and young Rio Grande river deposits were also sampled. Permeability of surface exposures were measured with an air-minipermeameter. In contrast to compressed-gas-type permeameters, the air-minipermeameter uses a falling piston to induce air flow. It is highly portable and was designed to measure the range of permeabilities common to poorly to moderately consolidated sandy and silty deposits occurring in the Albuquerque Basin. Permeability was measured in situ, porosity of the deposit was determined, and a soil sample taken from the point of measurement. Grain-size distributions were determined by mechanical sieving. Permeability is correlated with porosity, lithification, and a number of grain-size distribution parameters of the samples. A strong correlation is observed with the log10 of measured permeability and mean particle size. Correlation of permeability with the 10 and 20% passing sieve diameters is also high. A weak correlation is found with porosity and permeability, explained in part by cementation and sorting of the samples. Multiple regression analysis was used to formulate predictive permeability equations based on grain-size distribution parameters. These equations differ from most published permeability equations by excluding a value for porosity, which is difficult to obtain. Samples were divided into the following bedding types: crossbeds, channels, horizontal beds, scour and fill structures, and structureless deposits. Moment measurements were used to calculate sorting coefficients. Log-hyperbolic plots were employed as an effective way to graphically represent and compare grain-size distributions. Compared to the common cumulative percentage plots, log-hyperbolic plots provide high resolution of the finest grains, which are generally less abundant but have a large influence on permeability. Scatter plots and box plots were used to make visual comparisons between bedding types. Kolmogorov–Smirnov tests were used to quantify differences between facies. Comparison of outcrop samples to well core and cuttings allows estimation of the permeability of sediments at depth, based on grain-size distribution. Quantitative analysis of geophysical logs provide a check for

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the effectiveness of the technique. The uncertainty associated with the use of grain-size analysis of well cuttings, subject to rapid vertical facies changes and mixing of material in the well bore, is reduced when used in conjunction with geophysical logs. Geophysical logs and the analysis of core and cuttings may be used to evaluate permeability on a scale that meets or exceeds the resolution of many groundwater models.

HIGH GROUND-WATER NITRATE IN TIJERAS ARROYO, HELLS CANYON, AND ABO ARROYO: EVIDENCE FOR A NATURAL GEOLOGIC ORIGIN, by *Dennis McQuillan,* New Mexico Environment Department, Santa Fe, NM; and *Michael Space,* Dames & Moore, Albuquerque, NM

Nitrate-contaminated ground water has existed in Tijeras arroyo and Hells Canyon, between the mountain front and Rio Grande valley, for about 40 years. The contamination persists in a narrow band underlying each channel, indicating ongoing recharge and contamination. The plumes contain high nitrate (up to 120 mg/L as N) with unusually low chloride (<40 mg/L). Recently, this same type of geochemistry was discovered at the mouth of Abo arroyo. All three watercourses, the "arroyos," drain the Sandia/Manzano Mountain area.

All other nitrate contamination cases in this region have much higher chloride. Sewage cases, two septic-tank areas and a domestic sewage lagoon, have moderate nitrate (up to 30 mg/L as N) and moderate chloride (up to 150 mg/L). Livestock cases, two dairies, a packing plant, and a stockyard, have high nitrate (up to 300 mg/L as N) and high chloride (up to 1,200 mg/L). Mountainview contamination, also with high nitrate and chloride, was probably caused by overfertilization of a vegetable farm.

The high nitrate in the arroyos may be caused by evapotranspiration (ET) of infiltrating rain water in the shallow subsurface followed by ground-water recharge. These stream segments flow mostly during May through September after large precipitation events. Infiltration is so rapid that flows seldom reach the Rio Grande. After storm events, hot summer conditions return to enhance ET. Summer rainfall in northern New Mexico contains an average nitrate-N/chloride ratio of 3.2 by weight. An ET concentration line for rainfall is consistent with the data for the arroyos.

HYDROGEOCHEMICAL COMPUTER MODELING OF PROPOSED ARTIFICIAL RECHARGE OF THE ALBUQUERQUE AQUIFER, by *T. M. Whitworth,* New Mexico Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Recently, the City of Albuquerque began investigating the feasibility of artificial recharge of the Albuquerque aquifer. Artificial recharge by both subsurface injection and surface infiltration is under consideration. Proposed recharge fluids are (1) treated effluent from the Albuquerque wastewater treatment facility and (2) Rio Grande surface water. This study used the hydrogeochemical models PHREEQE and MINTEQA2 to simulate both subsurface injection and surface infiltration. The purpose of the hydrogeochemical modeling was to attempt to answer the following questions: (1) is it likely that minerals will precipitate during artificial recharge and clog the pore space in the aquifer thus limiting the useful life of artificial recharge sites and (2) what will the effect of artificial recharge be on water quality? Changes in water quality can occur from precipitation of minerals, dissolution of minerals, absorption/desorption effects, and mixing of the recharge water with the groundwater. Water quality changes from these mechanisms may be either detrimental or beneficial.

As a basis for comparison, simulations were also performed with data from the successful El Paso artificial recharge project. The results suggest that subsurface injection of Albuquerque treated effluent will be successful and that surface infiltration of Rio Grande surface waters will probably be successful. Simulations of surface infiltration predict a possibly significant amount of mineral precipitation in the vadose zone, which might limit the life of a surface-infiltration facility. The simulations predict no adverse impact upon water quality due to artificial recharge. However, trace-metal distribution, ion exchange, bacteriological content of the waters, or the presence of potential pollutants are not considered by the models. Chemical pilot-testing and kinetics-based computer modeling are recommended to predict the useful life of recharge facilities. Equilibrium-based models, such as used in this study, cannot determine the potential life of a recharge facility.

A CLIMATICALLY DRIVEN FLUVIAL CYCLE HYPOTHESIS FOR THE FILL TERRACES OF THE JEMEZ RIVER, JEMEZ MOUNTAINS, NEW MEXICO, by *J. B. Rogers,* Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

The Jemez River, a tributary of the Rio Grande, heads in the Jemez and Nacimiento Mountains of north-central New Mexico. Near its confluence with the Rio Guadalupe, the Jemez River is a medium- to high-order straight perennial bouldery mountain stream. Qt1 and Qt2 are mid-Pleistocene fill terraces at this locality. Lateral extent, regional correlation based upon ash and elevation above grade, and fossil gastropod assemblages suggest the fills of Qt1 and Qt2 are of climatic origin. The alluvium beneath Qt1 and Qt2 record identical cycles of climatically driven incision, equilibrium, aggradation, equilibrium, and incision. Incision occurs during interglacial-glacial transitions, equilibrium during interglacial and glacial conditions, and aggradation during glacial-interglacial transitions. Evidence for this hypothesis comes from fill stratigraphy, the presence of Lava Creek B ash, paleoecological inferences, and by analogy with the modern floodplain of the Jemez River.

The fluvial stratigraphy of Qt1 and Qt2 fills is similar. Both terrace deposits lie on bedrock. This implies incision prior to alluviation. The basal member of each fill is a 3–4-m-thick axial-river boulder bed in planar contact with bedrock. This layer is a buried strath and represents a time of fluvial equilibrium. Overlying the boulders is a thick (3–10 m) sequence of finer channel gravels, channel sands, and overbank sediments. This layer represents the valley-filling interval. Fossil gastropods found within the overbank fines have living counterparts in the Jemez Mountains today but only at significantly higher (and wetter) elevations. Paleoecologic inferences drawn from these assemblages and from the discovery of Lava Creek B ash in the overbank sediments of Qt1 fill, which at an age of 620 ka falls between marine oxygen isotope stages 16 and 15, support a hypothesis that aggradation occurred during glacial-interglacial transitions. The finer fills are capped by boulder layers similar to those beds found near the bases of the terrace deposits and are interpreted to represent another strath. At present, in the vicinity of the confluence, the Jemez River and its principal tributaries are cutting and depositing similar boulder-capped straths on alluvium. By analogy, the gravel caps of Qt1 and Qt2 formed during interglacial periods. Terrace formation by incision would have followed the interglacial equilibrium period, probably an interglacial-glacial transition, a time when stream power was increasing and sediment supply was relatively low. The strath at the base of the fill terraces, therefore, represents equilibrium conditions that existed during glacial episodes.

This climatically driven fluvial cycle hypothesis may explain the more complex and poorly exposed stratigraphy of younger Qt3 and Qt4 terraces. It does successfully predict the stratigraphy beneath the modern floodplain which, from well logs, includes the presumed Late Wisconsin strath at the fill/bedrock interface and the overlying Late Wisconsin–Holocene transition alluvial fill.

Sedimentology, volcanology, and chronology session

ALLOCHTHONOUS NATURE OF THE LOWER MISSISSIPPIAN WAULSORTIAN MOUNDS IN THE SACRAMENTO MOUNTAINS, NEW MEXICO, by *K. A. Giles,* Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003

Waulsortian mounds comprise a distinctive assemblage of carbonate facies organized into a mounded geometry and apparently confined stratigraphically to the Lower Mississippian (Tournaisian and Lower Visean). The currently accepted model of Waulsortian mound generation entails in situ biohermal buildup in a moderately deep water setting (>100 m). Depositional and deformational features of well-exposed mounds in the Sacramento Mountains, New Mexico, suggest the mounds are allochthonous and were emplaced by downslope movement and subsequent onlapping by flanking, resedimented carbonate debris. Downslope movement of sediment resulted from a combination of gravity-driven sedimentary processes such as translation (glide and slump), debris flow, grain flow, and turbidity current. Characteristics of the Sacramento mounds that favor the allochthonous model are dominance of resedimented material within the core and flank facies, nongradational and noninterfingering transition from core to flanking strata, presence of slump folds and clastic injection dikes at the base of some of the mounds, and a complete absence of framework or sediment-binding organisms.

EARLY PERMIAN TRACKSITE, BASE-LEVEL CHANGES, AND DEPOSITIONAL CYCLICITY OF INTERTONGUED ABO–HUECO STRATA, ROBLEDO MOUNTAINS, NEW MEXICO, by *S. G. Lucas*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; *A. B. Heckert*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131; *O. J. Anderson*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801; and *A. P. Hunt*, Department of Geology, University of Colorado at Denver, P.O. Box 173364, Denver, CO 80217-3364

Lower Permian marine carbonates and calcareous shales of Hueco Formation lithology and red-bed siliciclastics of Abo Formation lithology intertongue extensively over a 120-m-thick interval in the southern Robledo Mountains of Doña Ana County, New Mexico. In the middle of this interval, more than 30 fossil tracksites occur at a single stratigraphic level over an area of at least 20 km^2 and thus define the Robledo Mountains megatracksite. Previous analyses of depositional cyclicity in these strata suggested that the red beds containing the megatracksite are an asymmetrical depositional cycle of marine regression followed by a shorter transgression culminated by marine limestone deposited during maximum transgression. (Other supposed symmetrical cycles of regression-transgression in these strata have not been observed by us in the field). According to previous analyses, most of the red-bed facies accumulated as offlap facies during regression.

These analyses, however, contradict current understanding of coastal depositional systems, which maintain that sediment aggradation takes place during rising base level that typically characterizes transgression, not during the base-level fall and lowstand associated with most regressions. We propose a new model of Abo–Hueco depositional cyclicity consistent with this understanding and supported by detailed and extensive stratigraphic, sedimentologic, and paleontologic data. Our model identifies the base of a red-bed parasequence, such as the megatracksite interval, as an unconformity on top of highstand marine limestone that tops the preceding cycle. Varied facies—shoreface sandstone, tidal-flat sandstone/siltstone and delta cliniforms—immediately overlie this unconformity. They record irregular infilling during early base-level rise (transgression) of the incised topography developed during regression and lowstand. Continued transgression produced laminated and ripple-laminated sandstones/siltstones with tracks on extensive tidal flats developed on a surface of negligible topographic relief. Marked tidal cyclicity controlled tracksite formation and preservation. Continued base-level rise then produced calcareous shales capped by marine limestone that represents the maximum flooding zone. The overlying cycle (parasequence) then began with a marine regression that produced another unconformity surface.

OUTCROP EXPRESSION AND SIGNIFICANCE OF THE TR-4 UNCONFORMITY IN WEST-CENTRAL NEW MEXICO, by *A. B. Heckert*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131; and *S. G. Lucas*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

In west-central New Mexico and east-central Arizona, the TR-4 unconformity is at the base of the Sonsela Member of the Petrified Forest Formation (Chinle Group). Multiple lines of evidence, including tetrapod biochronology and palynostratigraphy, indicate that the TR-4 unconformity approximates the Carnian–Norian boundary. Correlation of measured stratigraphic sections extending from the Petrified Forest National Park (Apache County, Arizona) eastward through the Zuni Mountains (McKinley and Cibola Counties, New Mexico) and continuing to the Lucero uplift (Cibola, Valencia, and Socorro Counties, New Mexico) demonstrate that as much as 100 m of erosional relief was generated from west to east along this transect.

In eastern Arizona, conglomerates and conglomeratic sandstones of the Sonsela Member are underlain by as much as 90 m of mudstone-dominated flood-plain and paleosol deposits of the Blue Mesa Member of the Petrified Forest Formation. To the east, the strata of the Blue Mesa Member are progressively thinner, averaging approximately 35 m throughout the Zuni Mountains. In the Lucero uplift, Blue Mesa Member strata are entirely absent, and the Sonsela rests disconformably on "red beds" of the older Bluewater Creek Formation or its lateral equivalent, the San Pedro Arroyo Formation. Measured sections and field observation in the Zuni Mountains and Lucero uplift show that the Bluewater Creek Formation does not thicken appreciably at the expense of the Blue Mesa Member, maintaining a near-constant thickness of approximately 60 m, and at no place do the two units interfinger or otherwise grade into each other. Similarly, in the southernmost portion of the Lucero uplift, San Pedro Arroyo Formation sediments laterally replace Bluewater Creek Formation strata, again with little if any increase in stratigraphic thickness. We interpret these relationships to indicate that the decreasing thickness of the Blue Mesa Member is related to a period of erosion due to a regional fall in base level, with subsequent infilling of the resulting incised topography with coarse clastics of the Sonsela Member.

IDENTIFICATION OF INDIVIDUAL VOLCANIC CENTERS IN THE EOCENE PALM PARK AND RUBIO PEAK FORMATIONS, SOUTHERN NEW MEXICO, by *R. O. Ramirez, M. S. Broadwell, R. Gallegos, M. Schmucker, M. Haga,* and *N. J. McMillan*, Dept. Geological Sciences, New Mexico State University, Las Cruces, NM, 88003

The Eocene Palm Park and Rubio Peak Formations record a major calc-alkaline magmatic episode throughout southern New Mexico. This volcanism deposited a blanket of volcaniclastic debris, mainly lahars, sandstones, and conglomerates that are intercalated with lava flows and tuffs. Three volcanic centers of this age are defined in south-central New Mexico by the presence of near-vent volcanic facies or hypabyssal intrusions: Rubio Peak lavas in the southern Cooke's Range and in the Goodsight Mountains and the Cleofas intrusion in the Doña Ana Mountains. However, the location of volcanic centers that produced the volcaniclastic rocks is equivocal because of the virtual impossibility of determining paleocurrent directions in lahars. This study compares the major- and trace-element compositions of volcanic clasts in lahars from three sections in the Palm Park and Rubio Peak Formations (southern Cooke's Range, Faulkner Canyon, and the East Selden Hills) with the in situ lavas and intrusions as a method of correlating volcanic aprons with the related volcanic centers.

All of the samples are predictably similar in composition, having been generated in the same tectonic environment. The largest differences in composition are related to the extent of weathering and alteration: total volatile content ranges from 1% to 8%, with large variations in K_2O, Na_2O, Sr, and Ba. Although it is difficult to assess the geochemical impact of weathering, this study uses the high field-strength elements, such as Y, Zr, Sc, and TiO_2 because they are more reliable petrogenetic indicators in weathered samples.

Based on the concentrations of these elements, the three volcaniclastic sections appear to have originated from three separate vents. The Cooke's Range clasts exhibit only very weak elemental correlations, even for samples with low total volatile content, suggesting that the magmas evolved through open-system processes. In contrast, the East Selden Hills and Faulkner Canyon samples show correlations between Sc, Zr, and Y. The East Selden Hills samples have higher Sc and Y than the Faulkner Canyon section, suggesting that they evolved from distinct parental magmas with different concentrations of these elements.

Lavas from the Cooke's Range and Goodsight Mountains have higher Y and Zr than any of the suites of clasts, precluding them as volcanic centers for the lahars. However, the Cleofas intrusion is similar in composition to clasts from the East Selden Hills and Faulkner Canyon and is probably the volcanic center for one or both of these lahar suites. Unfortunately, data from the Cleofas intrusion do not exhibit the detail necessary to discriminate between the East Selden Hills and Faulkner Canyon suites.

AN OVERVIEW OF PORPHYRY COPPER DEPOSITS IN NEW MEXICO AND ADJACENT REGIONS, by *D. Hack*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801 and New Mexico Institute of Mining and Technology, Department of Mineral and Environmental Engineering, Socorro, NM 87801; *V. T. McLemore*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801; and *W. X. Chavez, Jr.*, New Mexico Institute of Mining and Technology, Department of Mineral and Environmental Engineering, Socorro, NM 87801

Economic benefits derived from porphyry copper deposits in southwest New Mexico, southeast Arizona, and northern Sonora, Mexico have become a major impact in the social and economic lives of these regions in the 20th Century. In 1993, Arizona accounted for more than 64% of U.S. copper production, producing 1,277,312 short tons (st) of contained copper, and New Mexico produced 255,072 st. A porphyry copper deposit is an economic occurrence of veinlet-controlled and disseminated copper mineralization in rock, typically a monzonite, diorite, or granite porphyry, that has been altered and subsequently enriched by hypogene and/or supergene processes and is amenable to low-cost, bulk mining methods. In the southwest U.S, as many as 50 major porphyry-style occurrences are known from a large northwest-trending belt defined on the northwest and southeast by Mineral Park, Arizona and La Caridad, Mexico, respectively, and on the west and east by Ajo, Arizona and Copper Flat, New Mexico, respectively. Many of the deposits formed during the Late Cretaceous–early Tertiary Laramide orogeny, a time of intrusive and tectonic activity spanning approximately 55 to 75 million years ago (m.y.a.). Patterns can be seen in the distribution of ages: the oldest deposits (greater than 70 m.y.a.), such as Copper Flat, New Mexico and Mineral Park, Arizona occur on the northwest and eastern fringes of the belt; the mid-age deposits (60–70 m.y.a.), such as Christmas and Silver Bell, Arizona occur in the central band of the belt; and the youngest deposits (55–60 m.y.a.), such as La Caridad, Mexico and Tyrone, New Mexico, in the southeast corner of the belt. The only major pre-Laramide deposit, the Jurassic Bisbee, Arizona porphyry, also occurs in this area. A consistency is found in the rocks hosting the deposits, most of which occur in Laramide intrusions. Typical lithologic varieties are the granite porphyry at Pinto Valley (Castle Dome), Arizona and the quartz monzonite porphyry at Morenci, Arizona. Many of these plutons invaded Precambrian metamorphic rocks, such as the Pinal Schist (Globe–Miami district), and Paleozoic carbonates. These carbonates, metasomatized by the Laramide intrusions, may constitute porphyry-related skarn deposits, economically important chiefly because porphyries with carbonate wallrocks typically have higher hypogene copper grades than those without wallrocks. Skarn-hosted mineralization has been an important constituent of the orebody at Santa Rita, New Mexico, which produced an average grade of 0.94% Cu in its first 50 years of production. In addition, the interest in nonporphyry-related skarns of the southwest U.S. has been considerable, as in the Pinos Altos, New Mexico and Bismark, Mexico properties. Further exploration in the southwest U.S. and adjacent Mexico may center on these porphyry- and nonporphyry-related high-grade skarns.

SEDIMENTOLOGIC AND TEMPORAL RELATIONSHIPS BETWEEN VOLCANIC AND VOLCANICLASTIC ROCKS OF THE KERES GROUP, JEMEZ MOUNTAINS, NEW MEXICO, by *Alexis Lavine*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Miocene (Keres Group) volcanism in the Jemez Mountains of north-central New Mexico displayed a wide range of eruptive activity and accompanied growth of the Rio Grande rift. Volcaniclastic sediments derived from these volcanoes record portions of the volcanic record (especially explosive volcanism) that are often not preserved elsewhere, as well as yielding information about sedimentologic processes that were active on the flanks of Keres Group composite volcanoes. Because much of the Keres Group volcanic record is still preserved, an examination of clast types within volcaniclastic sedimentary deposits yields information about the linkage between type of volcanic activity (production of autoclastic flow breccias, domes, flows, explosions) and by what processes volcanic fragments arrived in the sedimentary record. Volcaniclastic sediments were deposited by debris flow, hyperconcentrated flow, and normal stream flow and are interbedded with pyroclastic deposits (both primary and reworked) and flows.

Keres Group volcaniclastic sediments were deposited on the slopes of breccia-dominated andesitic cones in complex channels and in volcaniclastic aprons between and surrounding Keres Group composite volcanoes. Block-and-ash-flow deposits, andesite flows, andesite and dacite flow breccias, and dacitic ash-fall deposits are interbedded with volcaniclastic sediments, indicating deposition proximal to volcanic centers. Sediments representative of discrete eruptions include reworked pyroclastic deposits (including dacitic ash and pumice and hyperconcentrated-flow deposits of andesitic ash), debris-flow deposits containing "hot" (radially jointed) clasts, and some monolithologic debris-flow deposits. Heterolithologic debris-flow and stream-flow deposits do not represent discrete volcanic eruptions. Comparison of the stratigraphy of volcaniclastic deposits in stratigraphic sections indicates that clast compositions vary locally; however, several units correlate over distances of 5–6 km.

Clasts in debris-flow deposits are derived from primary fragmental volcanic rocks and are dominated by andesite (derived from cone-forming breccias and flows), glassy aphyric andesite/dacite (derived from dome growth), porphyritic dacite (derived from flow breccias), and andesitic/dacitic scoria and dacitic pumice (derived from pyroclastic eruptions). Clasts of glassy aphyric andesite/dacite are found throughout the volcaniclastic sediments and represent growth of a large dome or several smaller domes of similar composition, which has/have either been completely eroded or buried. Radially jointed, glassy aphyric andesite/dacite clasts are found in debris flows in the eastern part of the field area, indicating at least one probable source in this vicinity. No similar primary volanic units have been recognized in the Jemez Mountains.

Pyroclastic deposits interbedded with volcaniclastic sediments include primary and reworked dacitic and andesitic ash and pumice. No rhyolitic pyroclastic deposits are interbedded with volcaniclastic sediments; rather, in some areas, they occur as thick, discrete units above or below volcaniclastic sediments, indicating a lull in explosive rhyolitic volcanism during much of the time of volcaniclastic sedimentation, or removal of rhyolitic pyroclastics to more distal locations during deposition of most other volcaniclastic sediments.

SECONDARY CRYSTALLIZATION IN THE TSHIREGE MEMBER OF THE BANDELIER TUFF, by *M. Horn*, Dept. of Geology, UT Arlington, Arlington, TX 76019

The Tshirege member (Qbt) of the Bandelier Tuff is the youngest (ca. 1.0 Ma) large-volume volcanic rock in the Jemez Mountains of northern New Mexico. Complete exposures reveal that Qbt was deposited from multiple pyroclastic flows fed by tephra fountains associated with the collapse of the Valles caldera. Analytical data show Qbt as a porphyritic, dominantly high silica rhyolite with phenocrystic sanidine (Or45–Or50) and low quartz.

In all exposures visited, Qbt consists of a lower vitric zone (glassy pumice and shards) overlain by a secondarily crystallized (sillar) zone of silicate minerals in place of glass. Powder XRD, electron microprobe, and SEM analyses indicate the sillar assemblage comprises mainly micron-size crystals of an alkali feldspar (ca. Or50), tridymite, cristobalite and a scapolite (tentatively identified as marialite).

The presence of marialite has two implications. The first is that marialite crystallized instead of sodic feldspar in the sillar assemblage due to the high chlorine content (ca. 2,000 ppm) of the melt. Another is that marialite may be common as a sillar mineral in chlorine-rich rhyolitic ignimbrites. Indeed, the mineral is reported to occur in the Bishop Tuff (California) and is perhaps present in the Rhyolite Canyon Tuff (Arizona).

Field and experimental observations have further implications for secondary mineral paragenesis. First, the preponderance of delicate, but intact, crystallized pumice suggests negligible post- to syn-crystallization strain. That is, secondary crystallization is post-depositional, and the deposit suffered no appreciable compaction or welding after crystallization. Second, a thick (~2.0 m) unconsolidated vitric zone, devoid of secondary minerals, overlies the sillar zone in an exposure in the town of Los Alamos. This field relation suggests that precipitation of "vapor-phase" minerals by upward-percolating gases is minimal at that exposure and perhaps throughout Qbt. Finally, experiments show the time scale for crystallization of a cooling silicate melt is roughly the same as for heat conduction in a porous silicate medium. Therefore, under plausible cooling conditions, the amorphous component (pumice and shards) in hotter parts of the deposit possibly crystallized without reaching the glassy state. If so, use of the term 'devitrification' is inappropriate in this case.

MONTE LARGO SHEAR ZONE, MANZANO MOUNTAINS, NEW MEXICO: TECTONIC SIGNIFICANCE AND ARGON GEOCHRONOLOGY, by *J. R. Marcoline, Steven Ralser,* and *M. T. Heizler,* Department of Geoscience, New Mexico Institute of Mining and Technology, Socorro, NM 87801, and New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

The Monte Largo shear zone (MLSZ) located in the Manzano Mountains, central New Mexico, has been recognized as a northeast-trending ductile shear zone separating the greenschist-grade Bluesprings schist from the overlying amphibolite-grade Sevilleta metarhyolite. Detailed mapping in the Capilla Peak area shows that the simple boundary recognized in Monte Largo Canyon is complicated by repetition of units, interlayered quartzites, and extensive strain partitioning. The MLSZ is expressed as a series of discrete shear zones occurring in the Bluesprings schist and along lithologic contacts. Kinematic indicators (e.g. asymmetric porphyroclasts, shear bands) within the MLSZ record an east-side-up sense of shear, whereas kinematic indicators in the surrounding rock have a consistent west-side-up sense of shear suggesting that the MLSZ formed in a different deformational regime. $^{40}Ar/^{39}Ar$ analysis of nine amphiboles from amphibolites within the Sevilleta metarhyolite show complex age spectra. The complexities in the age spectra may reflect retrograde actinolite growth of the hornblendes. The age spectra from these separates yield both 1.4 and 1.6–1.7 Ga apparent ages, possibly dating the original amphibolite-grade metamorphic event (ca. 1.6–1.7 Ga) and the retrograde (ca. 1.4 Ga) event. A biotite and muscovite from the area yield plateau ages ~1,400 Ma, suggesting that the region cooled below ~300°C at this time.

Taken together, the observed field relations, kinematic indicators, and $^{40}Ar/^{39}Ar$ age spectra may indicate amphibolite-grade metamorphism and associated west-side-up shear occurred at ~1.6–1.7 Ga. The actinolite growth may be associated with the documented 1.4 Ga metamorphism in this area. The timing of east-side-up deformation within the MLSZ remains uncertain.

Cenozoic basins and water studies session

PALEOGEOGRAPHIC, VOLCANOLOGIC, AND TECTONIC SIGNIFICANCE OF THE UPPER ABIQUIU FORMATION AT ARROYO DEL COBRE, NEW MEXICO, by *G. A. Smith,* Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Detailed study of the sedimentology and petrography of the upper member of the Abiquiu Formation at Arroyo del Cobre, west of Abiquiu, revealed three stratigraphic intervals reflecting distinctive provenance and depositional processes. Interval I consists of fluvial sandstone and siltstone derived from erosion of volcanic rocks in the San Juan Mountains and Precambrian rocks of the Tusas Mountains north of Abiquiu. Interval II consists primarily of pumiceous debris-flow deposits derived from erosion of the 26.5 Ma Amalia Tuff erupted in the Latir volcanic field northeast of Taos. This interval also contains detritus indicative of San Juan and Tusas Mountains provenance, suggesting drainage, at times catastrophic, from the north across the distal outflow sheet of the Amalia Tuff, which was dispersed at least 60 km westward from its source at the Questa caldera. Volcanism-induced sedimentation following eruption of the Amalia Tuff affected a larger area than previously recognized. Interval III is characterized by fluvial facies, notably finer grained than those of interval I, with petrographic characteristics consistent with derivation entirely from the Latir volcanic field. This study suggests that the petrosomes defined by Ingersoll and Cavazza (1991; SEPM Spec. Pub. 45) and the paleogeographic reconstruction of Ingersoll et al. (1990, GSA Bull.) require revision. Interval I of the upper Abiquiu Formation is a variant of the Esquibel petrosome (derived from the San Juan Mountains) that contains significant (≥25%) basement-derived detritus revealing the significance of relief in the Tusas Mountains. It is not clear whether this provenance represents remnant relief of the Laramide Brazos uplift or is related to early-rift tilting. Interval II is a mixture of the Esquibel and Cordito (derived from the Latir volcanic field) petrosomes. The presence of the Cordito petrosome in the Abiquiu Formation was not incorporated into the Ingersoll et al. (1990) paleogeographic synthesis. The dominance of Latir-derived sediment in interval III along the far western margin of the Rio Grande rift suggests that eastward tilting of the San Luis Basin in the late Oligocene (~26 Ma) was small compared to the volume of sediment supplied from the Latir volcanic field, so that a westward paleoslope was maintained across most of the basin and into the Abiquiu embayment. Southward dispersal of this sediment at Arroyo del Cobre suggests, however, that rift-bounding faults were active and influenced drainage patterns. The Arroyo del Cobre outcrops will be examined during the 1995 NMGS Fall Field Conference.

ARSENIC ENRICHMENT DURING POTASSIUM METASOMATISM AND HYDROTHERMAL PROCESSES IN THE SOCORRO, NM, AREA—IMPLICATIONS FOR TRACING GROUND-WATER FLOW, by *N. W. Dunbar, C. E. Chapin,* and *D. J. Ennis,* New Mexico Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801 (nelia@nmt.edu)

The As content of rocks in a large area around Socorro, New Mexico, is elevated as compared to normal crustal rocks. A set of more than 100 samples analysed for As reveals a large area with an average level of As abundance of 5–10 ppm in silicic and mafic rocks as compared to 1–2 ppm in the same rock units farther from the Socorro area. This area of As enrichment coincides with the area of marked K enrichment in rocks by the process of K-metasomatism, which is interpreted to be the result of alteration by alkaline-saline brines that were associated with a playa system in the Socorro area from approximately 15 to 7 Ma. Superimposed on this low level of As enrichment due to K-metasomatism are localized areas of very high As enrichment (up to 220 ppm As in whole rock). These areas coincide with localities of hydrothermal mineralization, either Mn or precious metals; samples also show strong enrichments of other element such as Sb, Pb, and Zn. The local enrichment of this set of elements suggests that the high level of As enrichment is related to a high-temperature fluid associated with a magmatically related hydrothermal system.

Chemical analysis of mineral separates from altered rocks indicates that the As content of bulk rock is, in general, higher than that in quartz, potassic feldspar, and/or clay minerals. Arsenic is therefore interpreted to be largely adsorbed to mineral phases in the rock, rather than being bound into a mineral structure, and the higher As content of bulk rock as compared to quartz/feldspar/clay mineral separates suggest that the As is preferentially adsorbed onto mafic oxide phases. The adsorbed state of the As would allow mobilization of As by a secondary fluid phase passing through an altered rock. The high As content (47 ppb) of the warm springs at Socorro is an example of ground-water leaching As as it circulates through K-metasomatized and hydrothermally altered rocks.

Arsenic may provide a natural tracer of use in both surface and ground-water hydrology. The As content of the Rio Grande and its tributaries in northern New Mexico is low (averaging 2 ppb). But, dissolved As in the Rio Grande increases as the river flows along the eastern edge of the Datil–Mogollon volcanic field (averages from 4 to 5.3 ppb). The high As values, plus the lack of perennial tributaries in this reach, suggest that the Rio Grande must be substantially augmented by ground water. Arsenic concentrations in the Snake River are elevated in a similar fashion where the Snake flows through rhyolitic terrains in southwestern Idaho. In contrast, arsenic concentrations in the Colorado River remain at low levels where the Colorado flows through rhyolitic and K-metasomatised rocks between Las Vegas, Nevada, and Yuma, Arizona, because of the lack of ground-water input in this reach.

The sorption properties of As onto Fe and Mn oxide phases in oxidizing surface waters provide a mechanism for removing dissolved As from river water. The dissolved As in large rivers seldom exceeds 6 ppb, and dissolved As decreases after passing through a rhyolitic terrain. Dissolved As contents of small tributary streams, however, may be very high, such as Jemez Creek (28–66 ppb), which drains the Jemez volcanic field. A plume of higher temperature and high As ground water extends southward from the Jemez Mountains to beyond Albuquerque and helps to delineate ground-water flow and mixing paths in the northern Albuquerque Basin.

PRELIMINARY HYDROGEOTHERMAL STUDIES ACROSS THE PECOS RIVER VALLEY IN SOUTHEASTERN NEW MEXICO, by *Marshall Reiter,* New Mexico Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *D. L. Jordan,* D. B. Stephens and Associates, 6020 Academy Blvd. NE, Albuquerque, NM 87109

Heat-flow data derived from subsurface temperatures and rock thermal conductivity can often provide valuable information about the ground-water flow within a region. In the present study bottom-hole temperature data (BHT data) are generally used to make a preliminary study of the subsurface thermal regime along an east-west profile in southeastern New Mexico. Although BHT data are notoriously suspect, these data may be used to detect hydrologically induced anomalies if sufficient data are available over the entire sediment depth of a ground-water basin. Because deep BHT data are typically a good deal less perturbed than are shallow BHT data, the deep BHT values can often provide a heat-flow datum for the region that allows shallower, hydrologically induced heat-flow anomalies to be recognized. Vertical temperature gradients in the earth are typically several orders of magnitude greater than are horizontal temperature gradients, and therefore vertical ground-water advection is generally responsible for anomalous heat flows. If anomaly dependence on depth is recognized, an estimate of the depth of vertical ground-water flow can be made.

These concepts are applied to the southern Roswell artesian basin in southeastern New Mexico. A number of interpretations from the heat-flow data are consistent with suggestions made in previous studies; e.g. a broad upward cross-formational flow discharging to the Pecos River, downward ground-water flow in areas of the High Plains, and a region near the Mescalero Ridge where no observable vertical ground-water flow appears. A very local anomaly in the western part of the study area seems to result from upward ground-water flow along the front of a buried Precambrian horst recently discovered by explorative drilling. The depth of flow in these cases is thought to be from 3,000 ft and perhaps as deep as 5,000 ft.

PRELIMINARY RESULTS OF MODELING THE SHALLOW AQUIFER, MORTANDAD CANYON, LOS ALAMOS NATIONAL LABORATORY, NEW MEXICO, by *W. J. Stone,* DOE Oversight Program, Ground Water Protection & Remediation Bureau, New Mexico Environment Department, Santa Fe NM

Mortandad Canyon receives effluent from Los Alamos National Laboratory's liquid radioactive-waste treatment facility at Technical Area 50 (TA-50). As the stream does not normally leave the canyon, the fate of the effluent is a concern. Although the hydrology of Mortandad Canyon has been fairly well studied, including some modeling, it is still not completely understood. Thus, a modeling project was undertaken. The first phase, reported here, consisted of a steady-state simulation of the shallow aquifer in one dimension for pre-TA-50 conditions. The model focused on the alluvium between wells MCO-1 and MCO-8, which was discretized as 1 layer, 1 column (scaled for valley cross-sectional dimensions) and 30 rows. MODFLOW utilizing the recharge, evapotranspiration (ET), and streamflow routing packages, was the code used. With ET maximized and no leakage to the underlying tuff allowed, the model showed that the stream flowed the entire length of the canyon. As this does not normally occur in nature and ET was maximized to a reasonable value for the vegetation present, the volume of water the model showed to be leaving the system via streamflow (0.185 cfs) must be dispersed either by leakage or underflowing ground water. Since no underflow has been detected in previous studies, the excess water must be lost through downward leakage. This project showed the need for additional data on various parameters: runoff or interflow from slopes to the canyon floor; distribution, ET rate, and extinction depth for vegetation types; and hydraulic conductivity of the alluvium. The next phase of the project, involving a fully three-dimensional simulation of the system, should eliminate the constraints placed on this model by using a single layer and column.

THE EFFECT OF PARTICLE-SIZE DISTRIBUTION ON THE BASE-METAL GEOCHEMISTRY OF STREAM SEDIMENTS FROM THE UPPER PECOS RIVER, NEW MEXICO, by *T. C. Pease, V. T. McLemore, L. A. Brandvold,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801; and *A. M. Hossain,* Mathematics Department, New Mexico Institute of Mining and Technology, Socorro, NM 87801

As part of an ongoing study of base-metal concentrations in upper Pecos River stream sediments, 33 samples were collected in May 1994 during high-flow spring runoff. Analysis by flame atomic absorption (FAAS) and x-ray fluorescence (XRF) of the whole (excluding >2 mm), large (<2 mm and >63 microns), and small (<63 microns) sediment fractions has shown elevated levels of Zn, Pb, and Cu at sites immediately below the Pecos mine waste dump and below the tailings pile in Alamitos Canyon. In addition, elevated levels of Zn are found near the Lisboa Springs Fish Hatchery, 18 km below the Pecos mine. These data also show that metal concentrations are greater in the smallest size fraction. Particle-size analysis of all samples has shown that the smallest size fraction (<63 microns) typically represents only 10% of the whole sample. Neutron activation analyses were performed on 22 samples for a suite of elements, including Sb, As, Au, Se, and Cd. These metals were typically low except for elevated concentrations immediately below the Pecos mine. Six samples were sieved into six size fractions (1–2 mm, 0.5–1 mm, 0.25–0.5 mm, 0.125–0.25 mm, 63 microns–0.125 mm, and <63 microns) and analyzed by FAAS for Cu, Pb, Zn, Cd, Fe, Mg, and Mn. In three samples exhibiting low total metal values (Windy Bridge, Above Hatchery, Villanueva), the metal concentrations (Cu, Pb, Zn, Cd) increase with decrease in particle-size fraction. In the sample collected at the site labeled ☞

Above Hatchery, Zn concentrations are high (740 ppm) in the <0.063 mm size fraction. This suggests that precipitates and suspended sediment are transported from the Pecos mine waste dump and are being deposited at the diversion dam above the hatchery (site AH). The suspended sediment, elevated in Zn, may be entering the hatchery during turbulent flows and could be contributing to periodic fish kills. In three samples with elevated metal values (Below Willow Creek, Above Pecos Village, Below Pecos Village), the highest metal concentrations (Cu, Pb, Zn, Cd) typically correspond to the largest (0.5–1mm, 1–2mm) and smallest (0.063–0.125mm, <0.063mm) size fractions and further suggest that the metals are traveling as precipitates, suspended material, and as larger grains weathered from the mine waste dump and tailings pile.

GEOCHEMISTRY OF CARLSBAD CAVERN POOL WATERS, by *J. R. Forbes*, Daniel B. Stephens & Associates, 6020 Academy NE, #100, Albuquerque, NM 87109

Carlsbad Cavern contains dozens of pools of standing water that lie at depths ranging from 500 ft to 1,100 ft below the land surface. The pools are recharged by drip water that enters through the cave ceiling, and water is lost from the pools by a combination of evaporation from the pool surface, leakage from the bottom, and overflow from the edges. Flowing streams are not present in the cave, except following intense precipitation events.

The chemistry of the pools is determined by the chemical composition of the infiltrating drip water, as well as the geochemical and physical processes operating in the cave, such as mineral precipitation/dissolution and evaporation/condensation. The mean residence time of water in the pools determines the relative importance of these processes in altering pool-water chemistry.

Water samples from 10 pools throughout Carlsbad Cavern have been collected and analyzed on a quarterly basis for pH, temperature, electrical conductivity, alkalinity, and the concentrations of major and trace inorganic solutes. The temperature, relative humidity, and carbon dioxide concentration of the cave air adjacent to each of the pools were also measured.

Different pools were found to vary markedly in chemical composition from one another. The waters range from very fresh (TDS≈300 mg/L) to saline (TDS≈10,000 mg/L). The salinity of the pool waters does not correlate with depth beneath the land surface, and the pool at the lowest elevation in the cave (Lake of the Clouds) is among the pools containing the lowest concentrations of dissolved solutes. The most dilute pool waters are of the calcium-magnesium-bicarbonate type, whereas the most saline pool (Iron Pool) contains a magnesium-sulfate water.

The geochemical equilibrium speciation model PCWATEQ was used to determine the chemical species present in the pool waters, as well as the saturation status of various cave minerals. The model simulations indicate that most pools are saturated or supersaturated with respect to calcite, and a few pools are also saturated with gypsum or hydromagnesite.

The chloride concentration in most of the pool waters is very low, generally less than 5 mg/L. Using a mass-balance approach in which chloride is assumed to be a conservative tracer derived from precipitation, and assuming a chloride concentration of 0.4 mg/L in meteoric precipitation, the pool-water chloride concentrations suggest that ground-water recharge to the pools is on the order of 10% of total precipitation, with the remainder lost to evaporation in the overlying vadose zone. The chloride and bromide concentrations in one pool and those in the nearby drip water that recharges the pool are nearly identical, indicating little evaporative concentration of solutes in the pool.

In order to assess the leakage rate of water from the pools, an ongoing tracer study was initiated whereby a known quantity of sodium bromide was introduced into the pools to achieve an initial bromide concentration of approximately 10 ppm. The pools are being sampled periodically to determine the rate of decline of the bromide concentration due to loss of water (and bromide) through leakage and/or overflow. The initial results of the tracer test show relatively constant bromide concentrations over the six weeks following tracer introduction. This suggests that the pools were not leaking at a significant rate during this time period. The low dissolved-solute concentrations observed in most of the pools, coupled with the apparent long residence time for the bromide tracer, indicate that the pools are recharged periodically by infrequent precipitation events separated by long quiescent periods of slow evaporation with minimal leakage.

The carbon dioxide concentration of the cave atmosphere above the pools ranges from that of fresh outside air (350 ppm) to approximately 5 times greater (1,750 ppm). The lowest carbon dioxide concentrations are observed during the winter months when cold dense outside air sinks into the natural entrance, thereby freshening the cave atmosphere. The partial pressures of carbon dioxide in the pool waters themselves are 2 to 10 times greater than those of the cave atmosphere, indicating that the pools represent a continuous source of CO_2 to the cave air.

RECOVERY OF GARNET AND SPHALERITE FROM HANOVER MILL TAILINGS, GRANT COUNTY, NEW MEXICO, by *Ulvi Cetin*, Minerals and Environmental Engineering Department, New Mexico Institute of Mining and Technology, Campus Station, Socorro, NM 87801

The Hanover mill tailings were produced by Empire Zinc mine at Hanover, Grant County, New Mexico. Empire Zinc mine had been in production from the early 1900s through early 1970s except for some periods when the demand for zinc was low. The ore minerals were smithsonite, sphalerite, and galena, and the gangue minerals were garnet, pyroxene, calcite, and magnetite.

Hanover mill tailings are located east of Silver City, southwest New Mexico, along Hanover Creek and consist of five ponds. Four small ponds are located on the west side of Bull Hill, and the main pond is on the east side. Tailings contained in four small ponds will be removed from the banks of the creek, placed in the main pond, and stabilized. In this study, possible recovery methods for garnet and sphalerite from these tailings ponds have been investigated in order to offset the cost of remediation. Total material to be removed is about 160,000 tonnes with 20% to 40% garnet (mainly andradite and small amounts of grossular) in different size fractions. The tailings contain approximately 4.3% zinc, mainly in oxidized form. Iron, lead, and cadmium sulfides and oxides are also present, in addition to zinc.

The major end uses for garnet are abrasive (sand blasting, water-jet cutting, and polishing) and filtration-media applications. Garnet does not contain free silica, and the heavy-metal content is much less than copper and iron blast-furnace slags used as abrasives. It is cheaper than diamond and aluminum oxide compounds used for coated abrasives, and it can be recycled up to 5 times in sand blasting and water-jet cutting applications. Because of the above advantages over its competitors, the demand for garnet has increased in recent years.

The recovery methods investigated in this study were desliming, grinding, sulfide and oxide minerals flotation, gravity concentration, and magnetic and electrostatic separation. A garnet concentrate has been obtained with approximately 45% recovery by gravity concentration during preliminary tests. Before gravity concentration, sulfide and oxide bulk flotation concentrates were produced in order to remove lead, zinc, and iron minerals from the gravity circuit feed and to improve the garnet grade. A sphalerite concentrate, with 50+% zinc, was obtained with approximately 26% zinc recovery after selective flotation from the bulk sulfide concentrate. Both flotation and gravity-separation processes need to be further optimized.

Another objective of this study was to reduce the heavy-metal concentration in the reprocessed material. Coarse gravity tailings and the concentrates satisfy the above purpose, and they can be classified as nonhazardous material.

The garnet concentrate contains approximately 400 ppm lead, 1.20% zinc, 5.50% iron, and 29 ppm cadmium. Its specific gravity is 3.53 g/cm^3. The concentrate passes the EPA Toxicity Characteristic Leaching Procedure (TCLP) test; however, it contains 6.70% acid-soluble matter (mostly calcite), which can be further reduced by recleaning and optimization of the gravity circuit feed.

Paleontology session

"COELOPHYSIS," RIOARRIBASAURUS, AND THE STRATIGRAPHY AND BIOCHRONOLOGY OF THE UPPER CHINLE GROUP IN NORTH-CENTRAL NEW MEXICO, by *A. G. Heckert*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131; *S. G. Lucas*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; *R. M. Sullivan*, State Museum of Pennsylvania, P.O. Box 1026, Harrisburg, PA 17108; and *A. P. Hunt*, Department of Geology, University of Colorado at Denver, P.O. Box 173364, Denver, CO 80217-3364

We demonstrate by a combination of measured stratigraphic sections and paleontologic, topographic, and historical evidence that the original *Coelophysis* fossils collected by David Baldwin in 1881 and named by E.D. Cope in 1887 were almost certainly collected from what is now known as the Painted Desert Member of the Petrified Forest Formation (Chinle Group). In contrast, the Whitaker quarry at Ghost Ranch, which has produced dozens of skeletons of the theropod dinosaur *Rioarribasaurus*, is located within the overlying Rock Point Formation (Chinle Group). Furthermore, our results support the hypothesis that *"Coelophysis"* and *Rioarribasaurus* are two distinct, valid taxa, and as such indicate the first clearly superposed Chinle dinosaur taxa.

The topotypic material of *"Coelophysis"* was collected from a low-lying, easily accessible suite of bentonitic mudstones and very thin sandstones and conglomerates cropping out as low badlands approximately 2.5 km SSE of Ghost Ranch in a horizon correlative to the Canjilon phytosaur quarry. Tetrapod fossils from the Canjilon quarry, particularly the phytosaur *Pseudopalatus* and the aetosaur *Typothorax*, support an early-mid Norian age for the Painted Desert Member of the Petrified Forest Formation in this region. The Whitaker quarry is topographically and stratigraphically higher in a series of interbedded, nonbentonitic sandstones and siltstones that we assign to the Rock Point Formation. Vertebrate fossils, particularly the phytosaur *Redondasaurus*, from the Rock Point and correlative units indicate that this unit is of latest Norian or Rhaetian age. This marks the only known occurrence of two unambiguously superposed dinosaur genera in the Chinle Group, re-emphasizing that dinosaurs remain remarkably poor for use in correlation within the Chinle because of their great rarity.

A SAUROPOD FROM MARINE SHALES IN SHIPROCK, NEW MEXICO, by *C. H. Whittle*, General Delivery, Shiprock, NM 87420

Rocks referable to the lower Mancos Shale, Upper Cretaceous, are exposed throughout the town of Shiprock, New Mexico. These deposits typically yield marine invertebrates, most notably *Inoceramus*. Two large bone fragments were found in a wash that passes under NM–666. A 17-cm-long distal tibia fragment with a weathered articular surface has been identified. The second fragment, >20 kg, has been identified as a sauropod femur cross section. It is uncertain whether these specimens represent the same animal.

The femur fragment and the proximal end of the tibia fragment are well preserved, and the condition of the fractures indicate that other pieces should be nearby. Searches in the stream bed have not uncovered the missing pieces but spring floods may. Both fragments have attached matrix. A preliminary search failed to locate the lens from which the bones eroded. In consulting with Spencer Lucas, New Mexico Museum of Natural History and Science, we decided that the bones were probably driven to the wash and dumped. No further field work is planned.

ADDITIONS TO THE VERTEBRATE FAUNA FROM THE UPPER CRETACEOUS (LOWER CAMPANIAN) ALLISON MEMBER, MENEFEE FORMATION, SOUTHEASTERN SAN JUAN BASIN, NEW MEXICO, by *T. E. Williamson* and *P. L. Sealey*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

The Upper Cretaceous (upper Santonian–middle Campanian) Menefee Formation has a poorly known vertebrate record consisting of indeterminate hadrosaur, "carnosaur," ankylosaur, trionychid and baenid turtle, crocodylia, and amiid fish. New discoveries of vertebrate fossils from New Mexico Museum of Natural History localities L-3033 and L-3034 from the Allison Member, Menefee Formation (lower Campanian) of the southeastern San Juan Basin furnish important additions to this fauna. New vertebrate fossils include a partial skeleton of a pachyrhinosaurine ceratopsid, a tooth of a velociraptorine dromaeosaurid (cf. *Saurornitholestes*), a partial skull and associated lower jaws of the alligatoroid *Brachychampsa*, carapace fragments of trionychid chelonians, and carapace and plastron fragments of baenid chelonians.

The ceratopsid partial skeleton includes parts of the skull and mandible, several vertebrae, several ribs, a partial ilium, and a femur. The skull and mandible elements include a nearly complete left squamosal, a left dentary, and a complete predentary. This is among the oldest ceratopsians from North America and the first occurrence of a pachyrhinosaurine ceratopsid from the southern Rocky Mountain region. The new specimen of the rare alligatoroid cf. *Brachychampsa* is a new species and represents the fourth and oldest reported skull of a Cretaceous alligatoroid.

North American terrestrial vertebrate faunas of early Campanian age are generally poorly known. Results of a preliminary investigation of the vertebrate paleontology of the Allison Member, Menefee Formation suggest that it may yield a significant vertebrate fauna of early Campanian age.

A NEW LATE CRETACEOUS DECAPOD CRUSTACEAN ASSEMBLAGE FROM CARTHAGE, NEW MEXICO, by *E. K. Toolson* and *B. S. Kues*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131-1116

Abundant and diverse decapod crustaceans occur in upper Turonian shallow-marine sandstones of the Fite Ranch Sandstone Member, Tres Hermanos Formation, near Carthage, Socorro County. Present collections comprise more than 400 identified specimens, including about 90 carapaces, representing 10 species, of which 9 are believed to be new. Decapod assemblages of this magnitude are very uncommon in the Late Cretaceous of North America, and the Fite Ranch collections vastly augment previously known Late Cretaceous decapods from New Mexico (limited to 6 specimens, 3 species).

Brachyuran (6 species; 32% of specimens), anomuran (3 species; 67% of specimens), and palinuran (1 species; 1% of specimens) decapods are present in the Fite Ranch assemblage. Of the brachyurans (true crabs), *Pseudonecrocarcinus ovalis* (Stenzel) (44 carapaces), *Raninella* n. sp. (36 carapaces), *Necrocarcinus* (*Necrocarcinus*) n. sp. (2 carapaces), *N.* (*Cenomanocarcinus*) n. sp. (2 carapaces), *Tetracarcinus* n. sp. (5 carapaces), and *Xanthias*? n. sp. (42 chelipeds) have been identified thus far. Anomurans (mostly mud shrimp) include two new species of *Protocallianassa* (known from more than 200 cheliped elements, several abdomens, and one poorly preserved cephalothorax) and *Paguristes* n. sp. (27 cheliped elements). Palinurans (lobsters) are rare (5 cheliped elements), and all appear to be *Archaeocarabus*? n. sp. These decapods may be considered a *Protocallianassa–Pseudonecrocarcinus–Raninella* assemblage, after its dominant constituents, which total more than 75% of the specimens.

The discovery of this decapod assemblage in the Fite Ranch Member is important for several reasons: (1) it is by far the most diverse and abundant Late Cretaceous decapod assemblage known from the southern Western Interior; (2) most of the species appear to be new, and thus will add significantly to knowledge of North American Late Cretaceous decapod diversity; (3) the occurrence of these genera in upper Turonian strata in central New Mexico represents stratigraphic and geographic range extensions for most of them; and (4) several of the species are represented by numerous specimens, allowing study of intraspecific variability; this abundance is unusual for a group (Late Cretaceous decapods) in which many of the described North American species are known from but a single specimen.

Although abundant, these decapod remains are typically small (less than 15 mm) and easily overlooked, which probably explains why they have not been reported previously. They occur in a transgressive, nearshore sandstone body, together with large numbers of more conspicuous shallow-marine molluscs, including the bivalves *Lopha belliplicata novamexicana, Pinna petrina, Inoceramus dimidius* and *Homomya* sp. and the ammonite *Coilopoceras colletti.* Careful examination of similar depositional environments in other parts of the New Mexico Late Cretaceous sequence may well reveal additional decapod assemblages.

LATE MIOCENE AND PLIOCENE (HEMPHILLIAN AND BLANCAN) VERTEBRATE FOSSILS FROM THE GILA GROUP, SOUTHWESTERN NEW MEXICO, by *G. S. Morgan* and *P. L. Sealey*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

Vertebrate fossils collected from the upper part of the Gila Group (="Gila Conglomerate") in the Mangas graben in southwestern New Mexico help to constrain the age of this problematic geologic unit. The sediments of the Gila Group in the Mangas graben range in age from early Miocene to early Pleistocene, based on radioisotopically dated basalt flows and volcanic ashes, as well as vertebrate fossils of at least five different ages. Basalt flows dated at between 21 and 19 Ma intertongue with basal Gila Group sediments northeast of the Mangas graben and in the Duncan Basin on the New Mexico–Arizona border. The oldest vertebrate fossil known from the Gila Group in New Mexico is an oreodont similar to *Promerycochoerus carrikeri,* derived from a sandstone low in the Gila Group in the Black Range in western Sierra County. This oreodont is typical of the early Miocene (late Arikareean, about 20 Ma). A skull of the rhinoceros, *Teleoceras fossiger,* from a conglomerate on Dry Creek in southern Catron County is indicative of a late Miocene age (late Clarendonian or early Hemphillian, 10–7 Ma).

A tuffaceous siltstone exposed along the North Fork of Walnut Canyon southeast of Cliff in northern Grant County has produced a rich concentration of mammal fossils. The co-occurrence of the horses *Astrohippus stocki* and *Dinohippus mexicanus* in this fauna indicates a latest Miocene or earliest Pliocene age (latest Hemphillian 5.5–4.5 Ma). Other members of the Walnut Canyon fauna include the rabbit *Hypolagus*, a small rodent, the fox *Vulpes stenognathus,* the camels *Hemiauchenia* and *Megatylopus,* and an antilocaprid. The San Juan Rak Camel Quarries from the Chamita Formation in northern New Mexico and the Coffee Ranch local fauna in the Texas Panhandle are also late Hemphillian in age; however, both of these faunas contain the less-advanced horses *Astrohippus ansae* and *Dinohippus interpolatus* and are overlain by volcanic ashes dated at about 5.5 Ma. *A. stocki* and *D. mexicanus* were described from the Yepómera Fauna in Chihuahua in northern Mexico. *A. stocki* is also known from the Redington Fauna in the Quibiris Formation in the San Pedro Valley of southeastern Arizona. The Yepómera, Redington, and Walnut Canyon faunas are all latest Hemphillian in age, between 5.5 and 4.5 Ma.

Badlands northwest of Buckhorn in northern Grant County have yielded a diverse vertebrate fauna of early late Pliocene age (medial Blancan, 3.5–2.5 Ma). The fossils occur in at least three different stratigraphic units within a 25-m-thick interval in the upper part of the Gila Group. A greenish-gray clayey sand near the top of the local section has produced a partial skeleton and several fragmentary limb bones of a flamingo (*Phoenicopterus*), as well as bones of several smaller birds. An unconsolidated sand near the bottom of this interval contains numerous microvertebrates, including rodents, birds, snakes, fish, and abundant frogs. Larger mammals occur primarily in reddish silty and clayey beds above this sand. A medial Blancan age is indicated by the association of the small three-toed horse *Nannippus peninsulatus* (=*N. phlegon*), the larger horse *Equus* (*Dolichohippus*) *simplicidens,* and the primitive muskrat *Pliopotamys* sp. The Buckhorn fauna also includes the ground squirrel *Spermophilus,* the rabbit *Hypolagus,* the badger *Taxidea,* the large short-faced bear *Arctodus,* a medium-sized felid, the peccary *Platygonus vetus,* the camels *Camelops* and *Hemiauchenia* cf. *H. blancoensis,* and an unidentified proboscidean. Correlative medial Blancan faunas include Palomas Creek and Cuchillo Negro Creek from the Palomas Formation in the Rio Grande valley in south-central New Mexico and the Benson fauna from the St. David Formation in the San Pedro Valley, southeastern Arizona.

MIDDLE MIOCENE (LATE BARSTOVIAN/EARLY CLARENDONIAN) VERTEBRATE FOSSILS AND ICHNOFOSSILS FROM THE "MIDDLE RED MEMBER," ZIA FORMATION, CEJA DEL RIO PUERCO, SANDOVAL COUNTY, NEW MEXICO, by *T. E. Williamson*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; and *G. S. Morgan*, Department of Earth and Planetary Science, University of New Mexico, Albuquerque, NM 87131

A small vertebrate fauna was collected from exposures of the "middle red member," Zia Formation along the Ceja del Rio Puerco, west of Rio Rancho, Sandoval County, New Mexico. This fauna includes the proboscidean *Gomphotherium,* the small protolabidine camel *Michenia,* a large aepycameline giraffe-camel, a small mustelid, a small canid, a small equid, an indeterminate rhinocerotid, and the beaver *Eucastor.* Co-occurrence of *Gomphotherium, Michenia,* and *Eucastor* indicate a middle Miocene (late Barstovian/early Clarendonian) age for this fauna.

In addition to vertebrate fossils, several mammal and one avian trackway are also present in the study area. New Mexico Museum of Natural History locality L-2930 yields multiple trackways preserved as positives in a well-indurated, coarse-grained, cross-bedded sandstone. Tracks are preserved on multiple bedding planes. Most trackways are preserved on a single, 2-m^2 slab. These include several trackways that consist of didactyl prints with symmetrical, wedge-shaped hoof impressions. Manus prints are larger than the pes prints. These are referred to the ichnogenus *Gambapes* and can be attributed to a small camel. Two trackways consist of digitigrade footprints with four digits on both the manus and pes. The digital pads are subequal in size and lack claw impressions. The pes prints partly overlap the larger prints of the manus. These tracks are referred to the ichnogenus *Bestiopeda.* Previously, *Bestiopeda* have been attributed to feloids because of the lack of claw impressions. *Nimravides,* a large machairodontine felid known from early Clarendonian deposits of North America, is a possible trackmaker. A single avian trackway consisting of small tridactyl prints are referred to *Avipedes.*

PLEISTOCENE (RANCHOLABREAN) VERTEBRATE FOSSILS FROM SAND AND GRAVEL PITS NEAR ROSWELL, CHAVES COUNTY, NEW MEXICO, by *G. S. Morgan* and *S. G. Lucas*, New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

Fossil vertebrates occur in Quaternary alluvium exposed in commercial sand and gravel pits in the Pecos River valley about 10 km northeast of Roswell, Chaves County, southeastern New Mexico. Fossils were collected from 11 gravel pits in sec. 35 T8S R25E and secs. 3 and 10 T9S R25E. The fossils are derived from a 5-m-thick interval of poorly consolidated, coarse-grained sandstones and conglomerates that probably represent axial gravels of the ancestral Pecos River. The fossil assemblage consists primarily of isolated teeth and bones of large mammals and shell fragments of a small land tortoise. Middle to late Pleistocene vertebrate faunas of the Rancholabrean North American Land Mammal Age are known from more than 70 sites throughout New Mexico, but Rancholabrean fossils have not been reported previously from Chaves County.

The vertebrate fauna is composed of six species, the living desert tortoise *Gopherus agassizii* and five extinct species of mammals. The desert tortoise, identified from isolated shell fragments and a complete humerus, no longer inhabits New Mexico, although it is known from at least seven other Pleistocene localities in the southern half of the state. This species currently is restricted to the Mojave Desert in southeastern California, southernmost Nevada and Utah, and the Sonoran Desert in western Arizona and northern Sonora in Mexico. The presence of *G. agassizii* in southern New Mexico suggests this region experienced milder winters during certain intervals of the Pleistocene. A partial dentary with three teeth and an isolated P2 are referred to the horse *Equus occidentalis*. Several isolated teeth belong to a smaller undetermined species of *Equus*. The large camel, *Camelops hesternus*, is identified in the Roswell gravel pits from a mandible. An isolated lower molar pertains to a species of *Bison*, either *B. latifrons* or *B. antiquus*. The lack of a horn core precludes a more precise identification. The presence of *Bison* in the Roswell fauna is of particular importance because it is the defining genus for the Rancholabrean. The Columbian mammoth, *Mammuthus columbi*, is represented by one complete M3 and about ten partial molars, several of which reportedly came from a skull that was destroyed during mining operations. The Roswell mammoth is very large and advanced. The M3 has 18–20 plates with thin, highly crenulated enamel and its crown height is greater than 250 mm. *M. columbi* is widespread in Rancholabrean faunas throughout New Mexico where it is known from more than 30 localities.

The fossil mammals from the Roswell gravel pits constitute an assemblage very similar to the Rancholabrean mammal fauna from the Edith Formation in the vicinity of Albuquerque in Bernalillo County. Four of the five mammals from the Roswell sites also occur in the Albuquerque gravel pits, including *Equus occidentalis, Camelops hesternus, Bison* sp., and *Mammuthus columbi*. Two other extinct mammals, Harlan's ground sloth, *Paramylodon harlani*, and the giant short-faced bear, *Arctodus simus*, are known from the Albuquerque gravel pits but are not present in the Roswell fauna. The recent discovery of several Bison postcranial elements from a gravel pit near Socorro and the mandible of an American mastodon, *Mammut americanum*, from axial river gravels of the Rio Grande near Lemitar, both in Socorro County, suggest that Rancholabrean mammals should be expected in similar deposits elsewhere in New Mexico.

Poster session

QUATERNARY GEOLOGIC FRAMEWORK OF THE SANDIA MOUNTAINS PIEDMONT, NEW MEXICO, by *S. D. Connell*, and *S. G. Wells*, Department of Earth Sciences, University of California, Riverside, CA 92521

Detailed quaternary geologic mapping of the Sandia Mountains piedmont, from Las Huertas Creek to Embudito Canyon, provides evidence on the tectonic evolution of the Albuquerque Basin during the Quaternary. These results represent both a refinement and a northward extension of earlier work by Lambert (1968). The piedmont can be divided into two significantly different geomorphic regions, separated by the intersection of the Rincon, Placitas, and Valley View fault segments. This intersection also forms the western margin of a right-step in the Albuquerque Basin. To the north, the piedmont is dominated by laterally extensive, generally northwestward-sloping, gravel-mantled pediment surfaces and strath terraces, associated with major drainages, that originate at the mountain front. To the south, the piedmont is dominated by westward-sloping alluvial fans that interfinger with fluvial gravels of the Rio Grande.

No numerical age-control was established; however, relative age estimates of geomorphic surfaces were made on the basis of soil-profile development, landscape position, and surface morphology. Pediment surfaces (up to 73 m above local base level) of the pediment-dominated region range in age from early to late Pleistocene, suggesting that this part of the basin has undergone only minor subsidence since the early Pleistocene. In contrast, alluvial fans to the south are generally much younger, with age estimates ranging from middle Pleistocene through Holocene. The depositional nature of this portion of the piedmont suggests that this area has undergone more rapid and long-term subsidence, punctuated by a maximum basin aggradation event during the middle Pleistocene. A period of pedimentation following this aggradational event implies that basin subsidence decreased. The boundary between pediment-dominated and fan-dominated piedmont coincides with a right step in the Albuquerque Basin, suggesting basinward, footwall transfer of strain from the Placitas and San Francisco faults during the Quaternary. Faulting observed along the base of Rincon Ridge and within the basin supports ongoing basin subsidence. The lack of Holocene faulting to the north and east of the Rincon fault segment, near del Agua Canyon, suggests that strain may be transferred to buried structures within the basin.

TECTONIC CONTROLS ON THE DISTRIBUTION OF HYDROSTRATIGRAPHIC AND LITHOFACIES SUBDIVISIONS OF THE MIDDLE AND UPPER SANTA FE GROUP IN THE NORTHERN ALBUQUERQUE BASIN, by *J. W. Hawley*, New Mexico Bureau of Mines & Mineral Resources, 2808 Central SE, Albuquerque, NM 87106

Internal structure of the northern Albuquerque Basin is characterized by a deep, asymmetrical (half-graben) basin that is tilted eastward and flanked by relatively shallow structural benches (central North Graben block and North Albuquerque and Laguna benches, to the east and west, respectively) that step up to bordering uplifts (Sandia to the east and Colorado Plateau to the west). Structural interpretations based on seismic surveys and deep test drilling throughout the basin indicate that most of the major basin-bounding and intrabasin faults have curved surfaces of normal displacement that flatten markedly with depth (listric-fault geometry) and appear to "detach at the base of the brittle crust" (Russell and Snelson, 1994, GSA Special Paper 291, p. 105). Dips of these "master" faults are as low as 15 to 20° at depths of 30,000 to 35,000 ft (about 10 km) below sea level.

The primary master-fault component is designated the Rio Grande fault (May and Russell, 1994, GSA Special Paper 291, pp. 113–123), which has more than 30,000 ft (10 km) of vertical offset. Analyses of geophysical and sample logs from deep water wells (up to 1,000 m) in the east Albuquerque area indicate that this fault approaches the surface along a narrow zone under the east edge of the Rio Grande valley near I–25. A secondary (Sandia) component of the master fault system continues eastward and approaches the modern land surface just west of the Sandia Mountain front near Tramway Blvd.; however, neither component appears to have been active in the late Quaternary. On a basinwide scale, the updip segments of the hanging-wall block (Laguna bench, west of the Albuquerque volcanoes) has a hinged (inner-basin) margin that flexes down to the east and is cut by relatively steep and shallowly penetrating faults. As the basin pulled apart, clockwise (eastward) rotation of the hanging-wall block produced the very deep and complexly faulted North Graben block. The Albuquerque structural bench forms the footwall block of the Rio Grande (primary) master fault and the hanging-wall of the Sandia (secondary) master fault. This bench tilted slightly eastward during the latest Miocene to late Pliocene interval (7–2 Ma?), rotating clockwise away from the deep-basin axis. Tectonic unloading of the Sandia Mountain (footwall) block along the eastern basin margin probably started in the middle Miocene and is reflected in the high topographic relief of that "rift shoulder uplift" (May et al., 1994, GSA Special Paper 291, pp. 125–134).

The role that geologic structure (basin tectonism) has played in controlling the position of the ancestral Rio Grande is clearly illustrated in the four basin-wide hydrogeologic cross sections that were displayed in the poster session. Stratigraphic and structural interpretations are based on analyses of geophysical logs, samples, and other subsurface data from 35 deep wells drilled in the area (Hawley and Haase, 1992, NMBMMR Open-file Rept. 387; and Haneberg and Hawley, NMBMMR Open-file Rept. 402, in prep.). The asymmetrical half-graben morphology described in the Albuquerque Basin is characteristic of most basins of the Rio Grande rift (Mack and Seager, 1990, GSA Bulletin, v. 102, pp. 45–53; Cather et al., 1994, GSA Special Paper 291, pp. 157–170). This style of large-scale structural deformation directly influences the distribution patterns of the major environments of deposition observed in basin-fill sequences (e.g. piedmont-slope alluvial, and basin-floor playa-lake or fluvial braid-plain deposits). The thickest documented sections of ancestral Rio Grande facies of the upper Santa Fe Group are preserved as a stacked sequence of braided river-

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channel deposits that is as much as 300 m thick and 3 mi (5 km) wide beneath the eastern "Heights" of metropolitan Albuquerque. The observed eastern limit of the fluvial facies throughout the northeastern Albuquerque Basin is only about 3 mi west of the Sandia Mountain front. This sequence, which ranges in age from about 1 to 5 Ma, is characterized by extensive beds of sand and pebble gravel and relatively small amounts of silt and clay. Clasts are primarily derived from upstream (northern New Mexico) source areas.

Active eastward rotation of the (hanging-wall) "North Graben and Albuquerque Bench" blocks along the Rio Grande–Sandia master fault zone positioned the ancient fluvial system near the eastern edge of the half-graben and above the western margin of the Sandia Mountain (footwall) block during much of Pliocene time (2–5 Ma?). The uppermost 200 to 300 ft (60 to 100 m) of the 1,000-ft (300-m) stacked-channel sequence contains pumiceous fragments of volcanic rocks derived from late-stage eruptions of the Jemez caldera that culminated with the catastrophic emplacement of the Bandelier Tuff about 1.1 and 1.6 Ma ago (Goff et al., 1989, NMBMMR Memoir 46, pp. 381–434). During that interval, the ancestral Rio Grande rapidly shifted westward toward the position of its present valley, and concurrently, the apron of coalescent-fan deposits forming the Sandia piedmont slope prograded westward across the old fluvial plain. This sequence marks the final stages of basin filling (Santa Fe Group deposition) and is almost identical to the sequences described in the southern Rio Grande rift by Mack and Seager (1990). Blair and Bilodeau (1988, Geology, v. 16, pp. 517–520) observe this depositional style along the episodically active margins of asymmetrical basins in several structural settings. They propose that initial or renewed tectonic activity maintains the fluvial (axial stream) depositional environment in the deepest half-graben zone adjacent to the footwall (e.g. Sandia) block. Rapid basinward shift in the locus fluvial deposition and progradation of the piedmont alluvial apron over the former basin-floor surface only occurs "during tectonically quiescent phases" when mountainward rotation of the hanging-wall block has essentially ceased.

^{40}Ar/^{39}Ar thermochronology of low-temperature shear zones, Manzano Mountains, central New Mexico, by *Steven Ralser,* Department of Geoscience, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *M. T. Heizler,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Discrete, low-temperature shear zones, occur throughout the Precambrian Manzano Mountains of central New Mexico and provide an excellent site for determining the timing of deformation and the argon systematics from deformed versus undeformed minerals.

Shear zones from within and around the 1,427-Ma Priest pluton occur on a scale from a few centimeters to several meters wide and display microstructures indicating deformation at green-schist facies conditions. Temporally the shear zones postdate both the regional amphibolite metamorphism and the metamorphism associated with plutonism at ca. 1,400 Ma but are not yet linked to any know Precambrian deformational or thermal event.

A combination of single-crystal and bulk-sample furnace step-heating experiments were performed on mainly muscovite from deformed and undeformed samples within and surrounding the Priest pluton, with some additional hornblende, biotite, and K-feldspar analyses from the region. Muscovites from undeformed samples yield flat age spectra with plateau ages of 1,390±3, 1,395±2, and 1,39±5 Ma. This age may represent the time that the pluton and country rock cooled through ~350–400 °C. Single-crystal muscovites from shear zones within the pluton reveal age gradients from ~1.1–1.4 Ga but yield terminal ages of 1,360–1,400 Ma. A clear relationship exists between the degree of deformation and the younging of the total gas age and the development of the age gradient.

The single-crystal muscovite (~1 mm) analyses suggest that the age gradients are not related to a mixture of young and old crystal populations but rather reflect the intracrystalline ^{40}Ar distribution. The muscovite age gradients extrapolate to ~1,100–1,200 Ma and may represent the timing of deformation. These shear zones may therefore reflect the effects of Grenville orogenesis. However, it can not be unambiguously determined if the consequences of the Grenville orogeny in New Mexico were uplift and erosion (cooling), a discrete thermal pulse (reheating), or if the shear zones actually record Grenville-age deformation. The muscovites also reveal apparent ages less than 1 Ga for the initial 5% of argon released, and this is consistent with a regional thermal event of 200–250 °C at ca. 850 Ma recorded by K-feldspars from the region.

Vertebrate paleontology and biochronology of the Santa Rosa Formation, Santa Fe County, north-central New Mexico, by *A. P. Hunt,* Department of Geology, University of Colorado at Denver, Campus Box 173364, Denver, CO 80217-3364; *A. B. Heckert* and *S. G. Lucas,* New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104

The Upper Triassic (late Carnian) Santa Rosa Formation consists of three members in Santa Fe County (in ascending order): Tecolotito, Los Esteros, and Tres Lagunas. The Los Esteros and Tres Lagunas members contain stratigraphically distinct vertebrate fossil assemblages (faunas). The Los Esteros fauna includes *Arganodus dorotheae,* cf. *Turseodus* sp., indeterminate redfieldiid, *Buettneria perfecta, Apachesaurus gregorii, Trilophosaurus* sp., *Angistorhinus* sp., *Rutiodon* sp., *Desmatosuchus haplocerus, Stagonolepis wellesi,* two new aetosaurs, *Chatterjeea elegans,* indeterminate poposaurid/rauisuchid, *Parrischia mccreai,* cf. *Spinosuchus* sp., indeterminate theropod, new ornithischian, cf. *Ischigualastia* sp., and an indeterminate cynodont. The Tres Lagunas fauna includes *Apachesaurus gregorii,* a *Pseudopalatus*-like phytosaur, and a new aetosaur. The presence of the phytosaur *Rutiodon* and the aetosaurs *Stagonolepis* and *Desmatosuchus* indicates that the Los Esteros fauna is Adamanian (late Carnian: late Tuvalian) age. The presence of these taxa in the overlying Garita Creek Formation indicates that the Tres Lagunas fauna is also of Adamanian age. There is no evidence as to the age of the Tecolotito Member, and it could be of Otischalkian and/or Adamanian age.

Vertebrate taphofacies of the Upper Triassic (Rhaetian) Redonda Formation, east-central New Mexico, by *A. P. Hunt,* Department of Geology, University of Colorado at Denver, Campus Box 173364, Denver, CO 80217-3364; *A. B. Heckert, S. G. Lucas,* and *P. L. Sealey,* New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; and *M. G. Lockley,* Department of Geology, University of Colorado at Denver, Campus Box 173364, Denver, CO 80217-3364

The Upper Triassic (Rhaetian) Redonda Formation is widely exposed in east-central New Mexico, but vertebrate body and ichnofossils are restricted to Quay County. The Redonda in this area represents a lacustrine-margin sequence. Six taphofacies can be recognized: (1) nearshore lacustrine taphofacies—tabular sandstones and mudstones formed near the lacustrine margin preserve complete and disarticulated fish; (2) carbonate lacustrine-margin taphofacies—vertebrate tracks are preserved on the undersides of ledge-forming calcarenites that formed on lacustrine shorelines; the ichnofauna includes *Brachychirotherium, Grallator, Pseudotetrasauropus, Tetrasauropus,* and *Rhynchosauroides,* the latter two of which are reported for the first time; (3) beach conglomerate taphofacies—conglomerates formed in high-energy shallow water or on beaches are predominantly composed of fish scales and other ichthyoliths but also contain abundant phytosaur teeth and rarer rauisuchian and aetosaur material; (4) fluvial channels taphofacies—intraformational conglomerates and lenticular sandstones, representing fluvial channel deposits, contain fragmentary and abraded bones; locally, small channels are full of well-preserved bones that are dominantly phytosaurian but also include ?poposaur and aetosaur specimens; (5) floodplain taphofacies—isolated phytosaur postcrania and skulls are found in mudrocks formed in proximal floodplain environments; and (6) paleosol

Summary of charges for natural resources other than oil and gas on New Mexico State Lands as of January 1, 1995

Compiled by *Jami Bailey*, State Land Office, Oil, Gas and Minerals Division, Box 1148, Santa Fe, NM 87504-1148 (505/827-5745)
and by *James M. Barker*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801 (505/835-5114)

Type of lease	Length of lease	Filing fees	Annual rental	Royalty rate	Advance royalty	Acquisition method	Minimum bond
General mining	Primary—3 yr Secondary—2 yr Tertiary—5 yr Quaternary—5 yr Lease may be extended by production	$30.00	Primary (1–3 yr) @ $0.25/acre Secondary (4–5 yr) @ $2.50/acre Tertiary (6–10 yr) @ $3.00/acre Quaternary (11–15 yr) @ $10.00/acre Rental fixed at production	2% of gross sales price of materials; 5% on other minerals	0–10 yr—no advance royalty; Quaternary yrs: 11th yr @ $10/acre 12th yr @ $20/acre 13th yr @ $30/acre 14th yr @ $40/acre 15th yr @ $50/acre Advance royalty of two years credited to production royalty	Competitive bid only, sealed or oral (Moratorium on over-the counter leasing)	Performance bond—$2,000; at time mining commences—additional $5,000/lease
Potash	Primary—10 yr Five years in special cases Lease may be extended by production	$30.00	Negotiable, $100 minimum	Sliding-scale royalty depends on ore grade, ranges from 2–5% of gross sales price	None on older leases; negotiable	Application for lands shown to be open on the tract books	Performance bond for nonproducing—$5,000/lease Performance bond for producing—$10,000/lease (or $20,000 for multiple leases)
Salt	Primary—10 yr Lease may be extended by production	$30.00	$40 for each 40-acre legal subdivision	Not less than 10% of gross sales price at place of extraction	None	Application for lands shown to be open on the tract books	Performance bond—$500/lease (or $1,000 for multiple leases)
Coal	Primary—5 yr Secondary—5 yr Lease may be extended by production	$100.00	$5.00/acre or $500 minimum	Surface mining: 12.5% of gross value at point of sale, or at market value in the area Underground mining: 8%	1% of recoverable reserves	Competitive bid only, sealed or oral	Performance bond $15/acre Damage bond $20,000/lease, $50,000 for multiple leases (EMNRD bond filed may satisfy requirements)
Geothermal	Primary—5 yr Secondary—5 yr Lease may be extended by production	$30.00	1st–5th yr @ $1.00/acre 5th–10th yr @ $5.00/acre	See statutes* 10% gross value Byproduct: 5% gross value Power plant: 8% net revenue Recreation: 2–10% gross value Space heating: 2–10% gross value Health: 2–10% gross value	None	Competitive bid only, sealed or oral	Performance bond for nonproducing—$2,000/lease Performance bond for producing—$5,000/lease
Sand & gravel	Primary—1–5 yr (subject to change)	$50.00	Minimum $40 for each 40-acre legal subdivision or any fraction thereof	See schedule in Rule 5* Range: minimum $0.55–$1.45/yd³	Negotiable	Application for lands shown to be open on tract books; 40-acre restriction	Damage bond—$5,000/lease, $10,000 for multiple leases Performance bond—$2,000/lease
Caliche	15-day permit	$30.00	None	See schedule in Rule 5* Range: minimum $0.55–$1.45/yd³	None	Application for lands shown to be open on tract books; 40-acre restriction	Damage bond—$5,000/lease, $10,000 for multiple leases Performance bond—$2,000/lease May tender advance royalty in lieu of performance bond

Data source: State Land Office, Oil, Gas and Minerals Division. *For information, contact the State Land Office, Oil, Gas and Minerals Division.

taphofacies—accumulations of small tetrapods occur in mottled mudrocks containing calcareous concretions that represent paleosols. The Redonda Formation contains a greater range of vertebrate taphofacies than other formations in the Chinle Group of the western United States because of its extensive lacustrine, as well as fluvial, facies. □