NEW MEXICO GEOLOGICAL SOCIETY
SPRING MEETING

Friday, April 16, 2004
Macey Center
New Mexico Institute of Mining and Technology
Socorro, New Mexico

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NMGS EXECUTIVE COMMITTEE

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2004 SPRING MEETING COMMITTEE

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Pre-Registration Coordinators:	Theresa Lopez
On-Site Registration:	Theresa Lopez
Oral Session Chairs:	Peter Fawcett, Matthew Heizler, David Love, Spencer Lucas, John Sigda

Schedule of Events –NMGS Annual Spring Meeting, April 16, 2004
Registration 7:45 am to Noon, Lower Lobby

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HECKERT, *Andrew, HESTER, P., BERKHOUDT, Rene, MATHIAS, W.*

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BURNEY, *Dave*

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ODETTE, *J., CHAVEZ, W., JR.,*

Abstracts

GROUNDWATER GEOLOGY OF TAOS VALLEY

BENSON, Anthony L. University of New Mexico at Taos; email AnthonyBenson@msn.com

Over 1,000 water wells have been accurately located in Taos Valley and 1:24,000 scale maps have been prepared. Over 100 cross-sections were made to show structural and groundwater features. The largest Late Neogene feature is the Airport arch trending northeast across the Rio Grande rift basin. It is a southwest-plunging surface topographic high extending from the mountain-front to west of the Rio Grande gorge and flanked by gentle cuesta escarpments. The steeper east flank is highly faulted, down-to-the-east, into the El Prado-Taos basin. A series of four or more north-northwest-trending faults can be mapped with a combination of well control and surface fault expression from the Rio Hondo southward to the Picuris Mountains. The Rio Grande gorge follows in part, a north-south fault system, including one fault segment under the gorge bridge. East-trending valleys may reflect east-west fault systems. Blueberry Hill appears to be a fault-bounded horst block. Detailed water table data have been acquired in new subdivisions along the mountain-front at Weimer and Cañon Heights. Groundwater storage in fractures of tight Pennsylvanian rocks near the mountains is more limited than in Neogene clastics filling the rift basin. Many of the faults in Taos County appear to interrupt groundwater flow and compartmentalize the groundwater system. One hundred wells in the Questa area show a high water level north of town rapidly dropping to the Red River and Rio Grande local base levels. Multiple monitoring wells drilled at the Mountain View Grocery gas storage tank leak and the Taos Wastewater Treatment Plant show details of the water table gradient and seasonal and yearly water table variations.

GEOLOGIC ASSESSMENT OF ACID CONSUMPTION FROM LEACHING OF OXIDE COPPER ORES OF THE EXOTIC EL TESORO COPPER DEPOSIT, NORTHERN CHILE

BURNEY, Dave, Dept. of Mineral Engineering, New Mexico Institute of Mining and Technology, Socorro, New Mexico 87801; email: burndw@yahoo.com

Northern Chile hosts some of the world's largest copper ore deposits, including copper oxide systems of exotic derivation. The El Tesoro exotic copper deposit is located in Region II of northern Chile, approximately 160 kilometers NE of the port city of Antofagasta. Estimated reserves comprise 185 million tonnes of ore containing 0.88% Cu as atacamite and chrysocolla. An SX/EW operation, El Tesoro produces 70,000 tons of 99.99% cathode copper annually. With current open pit mining methods and rate, the expected life of the deposit is twenty-one years.

El Tesoro copper oxides are hosted within a sequence of fanglomerates comprising unconsolidated to poorly consolidated gravels and channel sands. These sediments show little or no alteration; copper, iron, and manganese oxides form part of the sediment matrix. The mineralized fanglomerate sequence strikes approximately N50E and dips 15°NW, and extends over an area of 10 km^2. Clasts making up the host gravels and sands are predominantly andesite and granitic rock fragments, including formerly mineralized porphyry clasts that may show pre-erosion alteration consisting of white phyllosilicate and/or chlorite replacement of groundmass and phenocryst sites. Ores are hosted by two tabular mineralized horizons having a combined thickness of about 80 meters, with 10 to 15 meters of essentially barren gravels separating the two mineralized gravel sequences. A regional, basin-bounding fault forms the eastern limit of the gravel sequence; early Eocene age andesite flows occur adjacent to this structure and contain minor copper mineralization. The mineralized gravels are thought to be younger than early Miocene age (no older than about 23.7 Ma), and are definitely older than a 10.2 Ma volcanic ash horizon that overlies the El Tesoro fanglomerate sequence.

Because all copper at El Tesoro is recovered using SX-EW methods, this study was initiated to ascertain the significance of fanglomerate mineralogy with respect to acid consumption, leaching effectiveness, and copper production. Petrographic study of the clasts comprising the ore-host fanglomerates suggests that aluminum, manganese, and iron are likely released during acid leaching of the copper ores. Such release of cations from aluminosilicates results in both increased acid consumption and formation of phyllosilicates within the leach-recovery circuit; however, our study also indicates that moderation of pH during leaching would result in limited dissolution of aluminosilicates and concomitant improvement in copper recovery and acid consumption.

COMPARATIVE STRATIGRAPHY OF THE DAKOTA SANDSTONE ACROSS THE PICURIS–PECOS FAULT SYSTEM SOUTH OF LAMY, NEW MEXICO: DEFINITIVE EVIDENCE OF LARAMIDE STRIKE-SLIP

CATHER, Steven M., New Mexico Bureau of Geology, New Mexico Tech, Socorro, NM 87801; and LUCAS, Spencer G., New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104; email: steve@gis.nmt.edu

The Picuris–Pecos fault of northern New Mexico is the largest known fault in the Rocky Mountain region with 37 km of dextral strike separation of Proterozoic lithotypes. The timing of dextral slip is disputed. The Picuris-Pecos fault system continues southward from Lamy, New Mexico, as a complex zone of faults that cuts strata of Mesozoic age and is intruded by the unfaulted, 27 Ma Galisteo dike. On the San Cristobal Ranch, ~20 km south of Lamy, a ~2 km dextral step in the fault system is characterized by numerous, steep NNE-striking faults that exhibit normal separation and form an en echelon array (A. Lisenbee, 2000, NMBMMR OF-GM-39). Many of the fault blocks in this en echelon array include outcrops of the Dakota Sandstone (Upper Cretaceous, ~95 Ma), thus affording a unique opportunity to stratigraphically evaluate Laramide strike-slip across much of the Picuris–Pecos fault system.

On the San Cristobal Ranch, eight detailed measured stratigraphic sections (separated from each other by 0.1 to 2.0 km) of the Oak Canyon and Cubero Members of the Dakota Sandstone display significant stratigraphic differences between adjacent fault blocks. Comparison to six control sections (separated from each other by 0.6 to 3.5 km) measured in unfaulted areas west of the Picuris–Pecos fault system (two sections near Lamy; four near Galisteo Dam) indicates the across-fault stratigraphic differences observed on the San Cristobal Ranch are too great to be attributed simply to lateral facies variation, but instead require strike-slip juxtaposition of dissimilar Dakota Sandstone sections. The role of strike-slip juxtaposition is indisputably displayed on two faults in the Hub Canyon area of the San Cristobal Ranch that exhibit only minor (<2 m) dip separation but divide markedly different, well-exposed Dakota Sandstone sections. We estimate the minimum dextral Laramide slip on the Picuris–Pecos fault to be several kilometers; the upper slip limit has not yet been determined.

Limited kinematic data for minor faults within blocks bounded by the en echelon fault system on the San Cristobal Ranch show mostly fault-normal (approximately E-W) extension, similar to Laramide fault-normal shortening or extension observed elsewhere on nearby segments of the Picuris-Pecos fault system (Erslev, 2001, GSA Bulletin). Reconciliation of stratigraphic evidence for significant strike-slip *between* fault blocks with minor-fault evidence for fault-normal deformation *within* fault blocks indicates that Laramide dextral-oblique deformation was partitioned into discrete strike- and dip-slip components. Slip partitioning occurs in numerous, modern zones of oblique deformation, but is best documented for the San Andreas system of California. The widespread importance of slip partitioning indicates that components of strike-slip in orogenic regions cannot be reliably assessed by minor-fault analysis.

INCISION AND AGGRADATION IN THE RIO GRANDE RIFT: UPS AND DOWNS OF AN AXIAL RIVER

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A summary review of previous and ongoing research in the Rio Grande rift constrains the timing, character, and patterns of aggradation and incision of basin-fill in this tectonically active region. Regional incision of the synorogenic Santa Fe Group marks a transition from widespread aggradation, which dominated much of the SE Basin and Range, to incision associated with the Rio Grande Valley. The transition from aggradation to incision is generally well understood south of the Española basin. To the north, it is complicated by extensive volcanic activity, the character of strain accommodation zones developed between basins, and higher relief and greater precipitation in upland drainages. Distinct geomorphic surfaces associated with local depositional tops of the Santa Fe Group provide a record of tectonic and climatic controls on landscape development. Older geomorphic surfaces and associated deposits are preserved along basin margins, typically in updip positions of tilted basin floors. Younger surfaces conservatively constrain the beginning of regional entrenchment to between 0.7-1.2 Ma. Widespread and nearly synchronous incision of basin fill by the ancestral Rio Grande occurred during a time of increased magnitude of climatic oscillations.

Extensive Mio-Pliocene erosion surfaces provide paleogeomorphic clues as to the interactions between sediment supply and tectonics. Widespread erosional surfaces, recognized along the margins of the Española, Albuquerque, and Socorro basins, formed between about 7-5 Ma, and mark a transition from earlier internal drainage and fairly rapid sediment accumulation, to a later time of drainage integration and slower accumulation of coarser-grained sediment. The angularity of Mio-Pliocene unconformities indicates that erosion occurred slightly after (or possibly during) deformation. The weakly deformed character of overlying sediments suggests that Plio-Pleistocene aggradation continued during times of lower tectonic activity. The reduction in sedimentation rates and transition from internal drainage to fluvially integrated drainage supports an overall reduction in tectonic activity, which would allow upstream basins to fill and integrate southward.

HYDROTHERMAL ALTERATION ASSOCIATED WITH A POSSIBLE COPPER-MOLYBDENUM PORPHYRY SYSTEM, WEBSTER PASS AREA, PARK AND SUMMIT COUNTIES, COLORADO.

CROOK, Josh, Dept. of Mineral Engineering, New Mexico Institute of Mining and Technology, Socorro, NM 87801.

Recent drilling near Webster Pass, Colorado, revealed the presence of a mineralized porphyry system. The prospect is located 8 km east of the Montezuma District, known historically for its silver-base metal deposits. The area lies along the eastern edge of the Colorado Mineral Belt, known for several large Climax-type porphyry molybdenum deposits. Four diamond core holes at Webster Pass have yielded approximately 2670 meters of core for study. This core was selectively sampled, and 60 thin sections and polished ore mounts were produced.

Preliminary petrologic study suggests that Precambrian amphibolite, schist, and gneiss of the Idaho Springs Formation host the porphyry system at Webster Pass. The porphyry intrusions vary from monzodiorite to diorite. Two intrusion-related breccias were also observed. Observations suggest that porphyry mineralization is structurally controlled, and is associated with hydrothermal alteration zones.

Hydrothermal alteration varies from propylitic to intermediate argillic, and alteration zones are not concentric due to local structural control. Hydrothermal alteration assemblages include chlorite plus biotite with fresh orthoclase in propylitic-altered rocks; quartz, white phyllosilicates, including muscovite, and pyrite in phyllic-altered rocks; and illite, smectite, and kaolinite in intermediate argillic-altered rocks.

The most important economic minerals observed are molybdenite and chalcopyrite. These occur as molybdenite veinlets, chalcopyrite veinlets, and minor sphalerite and galena in pyrite. Paragenesis of ore minerals appears to follow the pattern: pyrite → chalcopyrite ± sphalerite ± galena ± pyrite ± trace of bornite → molybdenite.

MISSING ARC-VOLCANIC INPUT TO UPPER CRETACEOUS FORELAND BASIN DEPOSITS OF THE MEXCALA FORMATION, SOUTHERN MEXICO

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During the Jurassic through early Tertiary, the western margin of North America was a convergent plate boundary with the Farallon plate subducting below the North American Plate (Sevier-Laramide orogeny). Convergence is well evidenced in the western United States by arc volcanism, the fold and thrust belt, and foreland basin development (Western Interior Seaway). Infilling of the foreland from the fold and thrust belt to the west included numerous volcanic ash beds. In contrast to the western U.S. record, evidence for arc volcanism and the proximity of the arc to southern Mexico is not well understood due to limited stratigraphic, biostratigraphic, structural studies and due to overprinting by post-Laramide deformation. One method used to address the proximity of arc volcanism to the Mexican craton is petrographic provenance studies of Cretaceous foreland basin sandstones.

This study focuses on part of the Upper Cretaceous (Cenomanian-Campanian) turbiditic sandstones of the Mexcala Formation in southern Mexico (Guerrero state). Initial field observations from turbidite paleoflow indicators suggest northwest to westward transport directions. Preliminary petrographic results indicate abundant sandstone grains from plutonic and metamorphic sources (deformed quartz, white mica, biotite, epidote). However, little or no volcanically derived grains (pyroxenes, amphiboles, alkali plagioclase, volcanic lithics) have been observed. This apparent absence of volcanic input may be interpreted as the result of three possible scenarios: 1) the volcanic arc was too far removed from the foreland basin study area; 2) some physical barrier prevented detrital volcanic influx (i.e., fold and thrust belt or fault blocking); or 3) an absence of volcanic activity/erosion during the studied time interval.

If these preliminary results are verified, further petrographic research should be conducted throughout the entire 2600 m-thick Mexcala Formation. Addition research in coeval foreland basin deposits to the east and west will better constrain tectonic models involving volcanic arc development adjacent to the southern Mexico continental margin.

GEOMORPHIC S7ETTING OF ARCHAEOLOGICAL SITES AND TIMING OF RECENT EOLIAN EVENTS ON THE PAJARITO PLATEAU, NEW MEXICO

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Five Coalition Period to Classic Period Ancestral Puebloan sites were investigated on Pajarito Plateau mesa tops north of Los Alamos Canyon and in the Cañada del Buey watershed. Stratigraphic relationships, thickness of deposits burying sites, and soil characteristics provide a context for determining the relative age of sites and recent geomorphic history. Puebloan sites are partially buried, primarily by eolian deposits, and are underlain by 0-1.5 m of Pleistocene and Holocene deposits overlying the Bandelier Tuff. Pre-Puebloan deposits include a sequence of discontinuous, truncated soils that are inferred to represent episodic eolian deposition and soil formation followed by erosion in the mid Pleistocene, late Pleistocene, early Holocene, and mid Holocene. Puebloan sites include three Coalition Period roomblocks or multicomponent sites, a Classic Period field house, and a Classic Period grid garden site. The roomblock sites are buried by colluvium, derived in part from erosion of the roomblocks, and eolian sediment. It is inferred that 15 to 20 cm of eolian deposition occurred sometime after the Middle Coalition Period but prior to the Classic Period; *ca*. 1250 to 1325 AD. A more recent eolian event occurred after abandonment of the early Classic Period sites, resulting in deposition of an additional 5 to 10 cm of eolian sediment in the last 600 years. After abandonment, the roomblocks acted as effective traps of eolian sediment, enhancing local deposition rates and site preservation. Animal burrowing also appears more active in the roomblocks, which may also help enhance local colluvial transport rates.

WATER QUALITY ASSESSMENT ALONG GALLINAS CREEK SURFACE WATER AND GROUNDWATER PATHWAYS, LAS VEGAS, NEW MEXICO

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We report preliminary results of a pilot study that compared the chemistry of surface water and ground water within the Gallinas Watershed. Gallinas Creek originates in the southern Sangre de Cristo Mountains and flows southeast towards the high plains desert community of Las Vegas, New Mexico. A large percentage of flow is diverted to the Storrie Lake Water Project and divided among multiple users, including the city of Las Vegas, Las Vegas National Wildlife Refuge, and farmers and ranchers. We studied changes in water quality within different regions of the diverted water system. Samples were collected at four primary locations: the surface water source (Upper Gallinas River), diverted surface water (McCallister Lake), ground water seeps (springs along Gallinas Canyon) and ground water receptor (Lower Gallinas River). This study hypothesized that as water infiltrates through the subsurface, the area's highly alkaline soils and the shallow bedrock aquifer contribute dissolved constituents to ground water. To test this hypothesis, surface water and ground water samples from Gallinas Creek sources were collected and analyzed for various water parameters. Our results indicate that Ca, Mg, Na, Si, Cl, SO_4, and $CaCO_3$ concentrations are 1.6 to 7.2 times higher in ground water. Likewise, hardness, alkalinity, conductivity, and total dissolved solids are also appreciably higher (increased by factor of 1.4 to 2.0). These results suggest that soils and bedrock are leaching dissolved constituents to ground water. McCallister Lake exhibits elevated Ca (402 mg/L), Na (1165 mg/L), Cl (678 mg/L), SO_4 (3525 mg/L), and electrical conductivity (11,200 micromohs/cm) concentrations that suggest high evaporation is enriching dissolved salt concentrations. Continued drought conditions will enhance evaporation rates and lead to increasing accumulation of dissolved salts and minerals potentially threatening the vitality of the lake ecosystem.

HOLOCENE MILLENNIAL-SCALE CLIMATE VARIABILITY IN WESTERN NORTH AMERICA

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Several high-resolution paleoclimatic records spanning the Holocene indicate near-synchronous millennial-scale climate variability through much of western North America. These records are taken from a variety of environments including a subalpine setting in Yellowstone National Park, an alpine setting in New Mexico and an arid playa system in the Chihuahuan Desert of northern Mexico. High montane lakes and bogs from the Sangre de Cristo Mountains of northern New Mexico record a series of glacial and periglacial events (colder, effectively wetter climates) that alternate with warmer, drier climates. This record spans the late Pleistocene and the Holocene. Forest fire-related sedimentation and alluvial activity from northeast Yellowstone National Park also shows a clear response to millennial-scale climate change during the Holocene. Pulses of fire-related debris flow activity occur during warmer, drier periods that are more prone to droughts. These alternate with cooler, effectively wetter conditions producing more river discharge and promote terrace formation through lateral migration of channels. Pluvial lake highstands in northern Mexico documented by constructional beach ridges and freshwater lacustrine fauna occur during cooler and wetter climate conditions and alternate with warmer and drier playa conditions.

Most of the cooler wetter events in each of these records are spaced approximately 1000 to 2000 years apart and correlate in time with each other. They appear to reflect widespread temperature anomalies and to a lesser extent, precipitation anomalies. These cool events also correlate with episodes of widespread cooling in the North Atlantic Ocean suggesting that millennial-scale climate changes are at least hemispheric in extent during much of the Holocene.

PROBING THE SECRETS OF RODINIA: PIECES OF THE SUPERCONTINENT PUZZLE EXTRACTED FROM ^{40}AR/^{39}AR GEOCHRONOLOGY OF DETRITAL MUSCOVITES

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Despite study by several investigators many features of the Precambrian supercontinent Rodinia remain enigmatic. ^{40}Ar/^{39}Ar geochronology of detrital muscovites from Mesoproterozoic sedimentary rocks across the southwest United States is employed in an attempt to refine models for continental alignment within Rodina, determine stratigraphic age and provenance. Specifically, detrital muscovite age data are reported from the Apache group in southeast Arizona, the De Baca group in New Mexico and the Unkar group in the Grand Canyon. Significant provenance variations are observed and new constraints on the age and correlations can be deduced. Approximately 310 single muscovite ages from the Pioneer shale unit of the Apache group yield a strongly bimodal age population with peaks at about 1.4 Ga and 1.65 Ga. This result is consistent with a U/Pb zircon age of 1.33 Ga from a volcanic unit within the Pioneer and the age populations support a southwestern Laurentia source. Stratigraphically higher in the Apache group, the Dripping Springs formation has a more diverse age population that ranges between 1.20 to 1.60 Ga. The youngest apparent ages indicate that the Dripping Springs formation is no older than 1.2 Ga and challenges correlations of the overlying Mescal limestone with the well dated 1254 Ma (U/Pb zircon) Bass formation in Grand Canyon. The De Baca Group is constraint to be older than about 1.1 Ga based on an inferred 1.1 Ga age for crosscutting diabase. The detrital muscovites from a shale horizon have a dominant age population at about 1.4 Ga with smaller peaks 1.6 Ga and 1.2 Ga. The 1.4 Ga and 1.7 Ga ages are likely locally derived from Meso and Paleoproterozoic crust to the north. The younger 1.2 Ga dates may suggest a depositional age that is less then 1.2 Ga. Muscovite from a quartzite unit in close proximity to the diabase has ages between about 0.5 to 1.6 Ga. The youngest crystals have presumably under gone post-deposition argon loss and/or represent growth of new fine-grained mica at this time. Ages between 1.1 and 1.2 Ga may be provenance ages, but factors such as reheating associated with sill emplacement and post-deposition alteration may have caused argon loss. We cannot be specific about the depositional age of this unit. Two formations from the Unkar group from the Grand Canyon were investigated. A sandstone layer within the Hotauta conglomerate below a 1.254 Ga ash horizon yields dominantly 1.65 Ga muscovite with a single grain yielding a 1.4 Ga apparent age. These ages are common for the underlying basement, presumably locally derived and consistent with the Hotauta being older than 1.25 Ga. Higher in the Unkar section, several samples of the Dox Formation were sampled. Over 500 crystals display an age range from about 1.14 to 1.25 Ga with no 1.4 Ga or 1.65 Ga detritus. 1.11 Ga dikes and sills cut the Dox and therefore the depositional age of the Dox is constrained to be 1.11 to 1.14 Ga. This result indicates a Grenville source area for the Dox that presently crops out in SW Texas. Evidently large river systems carried detritus from an eroding Grenville highland several hundred kilometers to the Grand Canyon area.

HYDROGEOLOGIC STUDY OF THE COALBED METHANE RESOURCE IN THE RATON BASIN, NM

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Coalbed methane is a newly emerging resource for the Raton Basin in New Mexico. In recent years a stronger emphasis has been placed on understanding the hydrogeology related to coalbed methane production because of the inextricable relationship of water and gas in such reservoirs. The purpose of this study was to investigate how hydrogeology influences coalbed methane potential in the study area. Surface and subsurface water chemistry, potentiometric surface, and permeability data were analyzed. Water balances were performed for two watersheds in the study area given historical rainfall records, stream flow measurements, groundwater well levels, and evapotranspiration estimates. Well logs and production data were also examined. The results indicate that the subsurface aquifer system in which the coalbeds are located is under-pressured. It is confined by an amalgamation of low permeability lithologies overlying and intermixing with the coalbeds. Matrix permeability shows no apparent distinction between lithologies in the aquifer. However, hydraulic conductivity tests inclusive of fracture permeability show correlation to lithology, with mudstones having the highest conductivity, followed by coals, and then sandstones. Increased water production in wells proximal to igneous intrusives supports the notion of increased connectivity due to fracturing around such features. These findings, when compared to coalbed methane production data, suggest a possible connection between hydrogeology and coalbed methane potential.

OLDEST RECORD OF *DIPLOCAULUS* CRANIAL MATERIAL FROM THE LOWER ABO FORMATION (EARLY WOLFCAMPIAN) AND ITS FAUNAL DISTRIBUTION IN NEW MEXICO

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A right tabular horn (Carnegie Museum of Natural History 38011) from the lowermost Abo Formation (lower Wolfcampian) northeast of Socorro in the Joyita uplift of south-central New Mexico represents the oldest record of cranial material diagnostic of the nectridean genus *Diplocaulus*. Additional *Diplocaulus* material from this locality includes indeterminate, densely concreted cranial bones, as well as five isolated presacral vertebrae.

The most extensive records of *Diplocaulus* are from the Leonardian Clear Fork Group of Texas, whereas upper Wolfcampian-lower Leonardian strata of the Wichita Group and Wellington Formation of Texas and Oklahoma, respectively, yield moderately abundant material. However, only two localities outside of New Mexico produce *Diplocaulus* fossils older than early Wolfcampian, the Virgilian Upper Conemaugh Group site at Pitcairn near Pittsburgh, Pennsylvania and the early Missourian Mcleansboro Formation in the Lower Conemaugh Group near Danville, Illinois. Together, these Late Pennsylvanian localities have only yielded a small number of isolated vertebrae and an incomplete lower jaw.

In contrast, the combination of *Diplocaulus* fossils from the Joyita Hills and isolated vertebrae from three additional lower Abo localities (Jemez Springs, Caballo and Los Pinos mountains), as well as vertebral material from the Pecos River Valley in the Sangre de Cristo Formation, demonstrate a relative abundance of the genus *Diplocaulus* in the lower Wolfcampian red-bed vertebrate fossil assemblages of New Mexico. *Diplocaulus* body fossils are absent from upper Virgilian and lower Wolfcampian tetrapod assemblages of New Mexico deposited in mixed marine-nonmarine strata, indicative of a more coastal environment, where paleoniscoid material is abundant (Red Tanks and Laborcita members of the Bursum Formation). This pattern of distribution of *Diplocaulus* is consistent with the contention of previous workers that paleoniscoid fish and *Diplocaulus*, though not mutually exclusive, are characterized by an inverse relationship of abundance depending on paleoenvironmental conditions. Thus, in wetter, mesic conditions, paleoniscoid fish are more abundant, whereas *Diplocaulus* dominates in seasonal environments subject to brief periods of partial drying, during which it may have survived, not by aestivation in a strict sense, but in a state of torpor.

THE KRZYZANOWSKI BONEBED: AN UPPER TRIASSIC (ADAMANIAN: LATEST CARNIAN) VERTEBRATE FAUNA, AND ITS IMPLICATIONS FOR MICROVERTEBRATE STUDIES

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The Krzyzanowski bonebed (NMMNH locality 3764) is an extremely rich vertebrate locality in Upper Triassic Chinle Group strata in the Blue Hills near St. Johns in east-central Arizona. The fauna of the Blue Hills includes the aetosaur *Stagonolepis* and the phytosaur *Rutiodon*, both index fossils of the Adamanian (latest Carnian) land-vertebrate faunachron. The bone-bearing horizon is low in the Blue Mesa Member of the Petrified Forest Formation and consists of an intraformational conglomerate that rapidly (<10 cm) fines upward into a bentonitic mudstone. The entire bonebed appears to be pedogenically modified, as the strata are color-mottled, and the bones are frequently encrusted with an iron-rich concretionary coating. Fossils from the Krzyzanowski bonebed consist of disarticulated, but associated (often jumbled) bones of small tetrapods and fish, and the largest elements recovered thus far are less than 20 cm maximum dimension. To date, the macrovertebrate fauna consists of actinopterygian and coelacanth fish, extremely fragmentary metoposaurid amphibians (confined to the base of the bonebed), phytosaurs, at least one sphenosuchian, several fish, probable theropods, and a possible ornithischian. Among the most important of these are a fish with an elongate, edentulous rostrum, and a tiny dentary bearing teeth that closely resemble those of Triassic ornithischians. Microvertebrates previously reported from the quarry include actinopterygian fish, at least two archosauriforms, probable theropods, an ornithischian dinosaur, and another probable herbivorous dinosaur. We have also recovered several new records, including possible prosauropods, the ornithischian *Tecovasaurus* or a closely allied form, and additional theropods, sphenosuchians, and archosauromorphs.

There are two particularly important aspects of the Krzyzanowski bonebed: (1) the extreme richness of the deposit; and (2) its preservation of small vertebrates, some of which were previously known only from microvertebrate remains. The richness of this deposit cannot be overstated—one small (<5 kg) jacket has yielded over 100 identifiable fossil elements, including parts of at least five skulls. This particular jacket is probably abnormally rich, but there are still hundreds, if not thousands, of bones in the eight other jackets awaiting preparation.

The macrovertebrate fauna of the Krzyzanowski bonebed includes diverse taxa that possess teeth and other elements previously only known from screen washing. The bonebed therefore is potentially a “Rosetta stone” where isolated teeth from microvertebrate faunas can be matched to more readily identifiable skulls and lower jaws. Thus, the bonebed not only provides a glimpse into a Late Triassic ecosystem, but could lend insight into ecosystems represented by more fragmentary fossils elsewhere.

THE MICROVERTEBRATE FAUNA OF THE UPPER TRIASSIC SNYDER QUARRY, FROM THE PAINTED DESERT MEMBER OF THE PETRIFIED FOREST FORMATION (REVUELTIAN), NORTH-CENTRAL NEW MEXICO

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The Snyder quarry is a well-documented assemblage of Late Triassic invertebrates and vertebrates from the Painted Desert Member of the Upper Triassic Petrified Forest Formation in the Chama basin, north-central New Mexico. The presence of Revueltian index taxa, including the aetosaurs *Typothorax coccinarum* and *Desmatosuchus chamaensis* and the phytosaur *Pseudopalatus* demonstrate that the Snyder quarry is of Revueltian (early-mid Norian) age. Screen washing the matrix of the primary bonebed at the Snyder quarry yields a moderately diverse assemblage of microvertebrates, some of which were not represented in the macrovertebrate fauna. Microvertebrate fossils from the Snyder quarry are mostly scales and bone fragments, with isolated teeth no more common than isolated vertebrae. New records include a tooth of the hybodontoid shark *Lonchidion* and numerous scales of a palaeoniscid fish tentatively assigned to aff. *Turseodus*. Not surprisingly, the microvertebrate assemblage differs somewhat from the known macrovertebrate assemblage, and includes many more fossils of bony fish. Indeed, osteichthyans dominate the microvertebrate fauna, and include semionotids, redfieldiids, palaeoniscoids, and indeterminate actinopterygians. Osteichthyans are largely represented by scales, with the exception of the indeterminate actinopterygians, which are represented by fragments of dentigerous toothplates, fossils previously assigned to colobodontids. The microvertebrate tetrapod fauna represented by teeth includes metoposaurid amphibians, juvenile(?) phytosaurs(?), probable dinosaurs, aetosaurs and other diverse, unidentified archosauromorphs. Many of the vertebrae appear to pertain to small archosauromorphs. The microvertebrate assemblage is unusual in that vertebrae and other non-cranial elements greatly outnumber intact teeth. We interpret this as additional support for the hypothesis of a catastrophic origin for the Snyder quarry vertebrate assemblage, as more typical Chinle Group microvertebrate assemblages are attritional deposits in which teeth greatly outnumber vertebrae.

THE VERTEBRATE FAUNA OF THE UPPER CRETACEOUS (EARLY CAMPANIAN) MENEFEE FORMATION, NORTHWESTERN NEW MEXICO

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The Upper Cretaceous (Santonian-Campanian) Menefee Formation is by far the most extensively exposed nonmarine Upper Cretaceous lithostratigraphic unit in New Mexico. However, the Campanian-Maastrichtian Fruitland/Kirtland formations are more fossiliferous, and these units yield the vast majority of Upper Cretaceous tetrapod fossils known from New Mexico. Even the Moreno Hill Formation in western New Mexico, a partial stratigraphic equivalent of the Menefee, yields a more diverse fauna than the Menefee. We report here several new fossils from the Menefee Formation in the southeastern corner of the San Juan Basin. The Cleary Coal Member yields a vertebrate fauna of indeterminate amiids, lepisosteids, trionychid and baenid turtles, hadrosaurs, ankylosaurs, and an indeterminate tyrannosaur. Most of these records are based on extremely fragmentary material that is not diagnostic below the family level. New vertebrate records from the Allison Member include a fin spine fragment of a hybodont shark, possibly *Lissodus* or *Lonchidion*, lepisosteid fish, the trionychid turtle *Adocus*, a pelomedusid turtle, and an indeterminate ornithopod. Additionally, we tentatively identify one of the known hadrosaurs from the Allison Member as a lambeosaurine, the first such record from the Menefee. The rest of the vertebrate fauna known from the Allison Member of the Menefee Formation includes the baenid *Baena nodosa*, indeterminate trionychids, the alligator *Brachychampsa montana* (=*B. sealeyi*) and other, indeterminate crocodilians, the centrosaurine informally known as the "Menefee ceratopsian," indeterminate hadrosaurids, and the dromaeosaur *Saurornitholestes* sp. Another new record, from the Menefee Formation undivided, is of the solemydid turtle cf. *Naomichelys*. Presently vertebrate trace fossils from the Menefee Formation are limited to coprolites, which are relatively rare. Based on litho- and biostratigraphy, the Clearly Coal Member is probably late to latest Santonian in age, and the overlying Allison Member is of early Campanian age. Tetrapod faunas of late Santonian to early Campanian age are rare in western North America, so the Menefee Formation holds the potential to fill this important gap in the Upper Cretaceous tetrapod record.

DISTRIBUTION OF THE ENIGMATIC REPTILE *TRILOPHOSAURUS*, AN UNUSUAL ARCHOSAUROMORPH FROM THE UPPER TRIASSIC CHINLE GROUP, SOUTHWESTERN USA

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Two species of the unusual archosauromorph *Trilophosaurus*, *T. buettneri* Case and *T. jacobsi* Murry, are known from diverse localities in the Upper Triassic Chinle Group of Texas, New Mexico and Arizona. The tricuspid teeth from which *Trilophosaurus* derives its name are identifiable to the species level, so fragmentary tooth-bearing fossils, and even isolated teeth, have biostratigraphic utility. *T. buettneri* is the better-known taxon, but is restricted to a handful of localities stratigraphically low in the Chinle Group of Texas and Arizona. Until recently, *T. jacobsi* was poorly known, leading some workers to speculate that it was actually a procolophonid ("*Chinleogomphius*"). However, we have recovered fossils from an extremely rich bonebed that demonstrate that *T. jacobsi* is congeneric with *T. buettneri*. Teeth of *T. jacobsi* are readily distinguished from those of *T. buettneri* by their tall, faceted central cusp, low, transversely elongate lingual cusp, and the presence of cingulae along their anterior and posterior margins. *T. jacobsi* occurs in lower Chinle Group strata in Texas, New Mexico, and Arizona, and we document the first occurrence of *T. jacobsi* in New Mexico here, as isolated tooth fragments are readily identified from the Sixmile Spring locality (NMMNH locality 2739) in the Bluewater Creek Formation in west-central New Mexico. The two taxa are only known to co-occur at the upper Kalgary locality (NMMNH locality 1430) in the lower Tecovas Formation in West Texas—otherwise *T. buettneri* always occurs in stratigraphically lower strata than *T. jacobsi*. The first occurrence datum (FAD) of *T. buettneri* in Texas corresponds to that of Otischalkian index taxa such as the phytosaur *Paleorhinus* and the aetosaur *Longosuchus*, and implies an Otischalkian age for most *T. buettneri* occurrences. The FAD of *T. jacobsi* is often at or near the FAD of Adamanian index taxa such as the phytosaur *Rutiodon* and the aetosaur *Stagonolepis*, indicating that *T. jacobsi* is a possible index fossil of the Adamanian. *T. jacobsi* is probably an anagenetic descendant of *T. buettneri*, as it comes from generally younger strata and appears to be more derived. *Trilophosaurus* is endemic to southwestern North America, and may represent a relatively rare occurrence of an arboreal herbivore.

40,000 FOSSILS ONLINE: THE NEW MEXICO MUSEUM OF NATURAL HISTORY AND SCIENCE'S DIGITAL DATABASE AS A TOOL FOR GEOSCIENTISTS AND EDUCATORS

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As a result of a collaborative effort with the U.S. Bureau of Land Management (BLM), the entire catalogued paleontological collection of the New Mexico Museum of Natural History and Science (NMMNH), including 35,512 fossils from New Mexico, is now online and available to the general public, avocational paleontologist, researcher, and geoscience educator. We do not provide sensitive geographic locality data or some other details, but all aspects of the taxonomy, stratigraphy, and chronology of the specimens are viewable at http://164.64.119.14/nmmnh/web/default.html. The collection encompasses fossils from 5585 localities (5063 in New Mexico) ranging in age from Cambrian to Holocene. Fossils from every county in New Mexico are included in the collections. The online database is searchable by a variety of taxonomic, stratigraphic, chronologic, and geographic criteria, utilizing a "drill-down" approach that takes advantage of the hierarchical nature of these data to search for specimens or localities at several discrete levels. Taxonomic categories are principally Linnean ranks (class, order, family, genus). Stratigraphic criteria include group, formation, and member. Chronologic criteria are era, period, epoch, stage, and land vertebrate biochron (=land mammal "age"). Geographic criteria are country, state, county, and 7.5-minute topographic quadrangle. Complex (Boolean) searches are not presently a feature of the online database. However, chronologic, stratigraphic, and geographic searches will yield complete faunal lists by locality. Additionally, more than 1000 of the specimens in the database are illustrated digitally, and a jpg-file image of the fossil will appear if it is selected. We envision a wide range of research and outreach opportunities based on this database. For example, geologic mappers can readily learn the number and age of all NMMNH localities on a 7.5-minute topographic quadrangle. Similarly, educators can compile questions about fossil faunas from particular areas, times, or stratigraphic units from New Mexico or elsewhere.

EXPLOITATION OF PRECAMBRIAN FAULT NETWORKS BY YOUNGER OROGENESIS: A TEST USING AR-AR ANALYSES OF K-FELDSPARS

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Our working hypothesis is that Ancestral Rocky Mountain (320-290 Ma) and Laramide (70-50 Ma) faults in New Mexico and Colorado reactivated zones of crustal weakness that formed during the Precambrian. We are testing this with $^{40}Ar/^{39}Ar$ K-feldspar thermochronology analyses. In Arizona, the Grand Canyon Supergroup sedimentary package is well exposed and provides an unambiguous example of development of a Laramide monocline due to reverse slip reactivation of a Neoproterozoic normal fault. However, because there are limited Precambrian sediments exposed or remaining in the more deeply exhumed Rocky Mountains it is difficult to directly observe reactivation of Precambrian structures. Because $^{40}Ar/^{39}Ar$ K-feldspar age data record the time when rocks cooled from about 300 to 150°C it is the only available thermochronometric system that allows quantitative evaluation of Neoproterozoic or Ancestral Rocky Mountain basement exhumation histories. The basement of New Mexico and Colorado is defined by a complex polygonal network of ~10 km scale blocks that were differentially exhumed between ~1.4 Ga to 0.5 Ga. Emerging K-feldspar data show that different blocks had distinct and variable cooling histories. Thermal histories of Precambrian basement rocks across specific Phanerozoic structures are revealing divergent exhumation histories that began during the culmination of the Grenville orogeny at about 1.1 Ga. These data support our hypothesis that many young fault systems are reactivating older structural weaknesses. Thermal history analysis also records a period of regional cooling (exhumation) between 850 to 750 Ma that coincides with the onset of Neoproterozoic rifting of the Rodinia supercontinent. Additionally, in Colorado the K-feldspar data appear to record cooling related to basement removal during the Ancestral Rocky Mountain orogeny. Continued work across distinct faults, with different orientations (NW versus NS) may reveal which segments of the Paleozoic to Laramide fault network were active at different times in the Proterozoic and hence may help decipher the geometry and kinematics of intracratonic Proterozoic fault systems.

GEOARCHAEOLOGY AND PALEOENVIRONMENTS OF THE FIRST PEOPLING OF THE LLANO ESTACADO

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The Llano Estacado (or Southern High Plains) of northwestern Texas and eastern New Mexico has one of the highest concentrations of the oldest ("Paleoindian" 11,500-8000 ^{14}C years B.P.) archaeological sites in North America, including such well-known localities as Lubbock Lake, Clovis, Plainview, and Midland. Research on these Paleoindian localities began in the 1930s and resulted in some f the earliest stratigraphic and chronologic sequences for the Paleoindian occupation of North America. Geologic studies were an integral part of the work at the outset.

Most of the intensely investigated Paleoindian sites are in the three settings where archaeological sites are preserved in well-stratified contexts: draws, playas, and dunes. The draws are now-dry tributary valleys of the Colorado and Brazos Rivers, which contained flowing streams, ponds or marshes during Paleoindian times. The playas are small, shallow basins numbering in the thousands which dot the High Plains landscape and once contained permanent lakes. The dunes include extensive sand dune fields that were initiated during the Paleoindian occupation, and small dunes that fringe some playas.

Geoarchaeological research in the broader context of late-Quaternary stratigraphy, soils, landscape evolution, and paleontology provide important clues to the changing environments of Paleoindian hunter-gatherers. The first (Clovis 11,500-11,000 ^{14}C years B.P.) occupants of the area found abundant water in draws and playas, and game, including a variety of now-extinct fauna such as mammoth, camel, horse, and bison. Later (11,000-10,000 ^{14}C years B.P.) inhabitants likewise lived among a diverse array of resources, perhaps reflected in the large number of sites and wide array of artifact styles for this period (Folsom, Midland, Plainview, Milnesand). The time is also characterized by extinction of most megafauna, and increasing aridity with a declining water table. Late Paleoindian times (10,000-8000 ^{14}C years B.P.), characterized by Firstview and related unfluted lanceolate projectile points witnessed further aridity and declining water in draws and playas along with formation of dunes on uplands. Site frequencies also decline. This environmental and archaeological trend culminates in the prolonged aridity of the early-middle Holocene "Altithermal."

A PRELIMINARY ASSESSMENT OF THE TENDENCY OF SALINE GROUND WATER FROM SELECTED AQUIFERS IN NEW MEXICO TO FORM SCALE DEPOSITS DURING REVERSE OSMOSIS DESALINATION

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The Holocene climate of the southwestern United States is characterized by periods of moderate to severe drought. Maintaining economic activity and quality of life in prolonged drought periods will demand use of non-traditional water resources including saline ground water. Current options for desalination of water include "reverse" osmosis (RO) techniques that reject dissolved salts at, while allowing water to pass through, the surface of a semi-permeable membrane. Salts can accumulate over time on the membrane surface, resulting in clogging and decreased efficiency of the RO process. Common clogging salts include $CaCO_3$, $CaSO_4 \cdot 2H_2O$, and amorphous SiO_2. Clogging salts are collectively referred to as scale deposits. The suitability of saline water for RO treatment is governed, in part, by the tendency of input water to form scale deposits during the RO process. Geochemical modeling that simulates the evaporation of water can be used to determine the tendency of saline waters to form scale deposits during RO.

Simulated evaporation was performed using published U.S. Geological Survey analyses of saline water from selected aquifers in New Mexico. Properties characteristic of selected aquifers include the relatively strong tendency of saline water from the Yeso aquifer to form $CaSO_4 \cdot 2H_2O$ scale deposits and the relatively strong tendency of saline water from the Rio Grande alluvial aquifer to form amorphous SiO_2 scale deposits. Scale-forming tendencies can have a relatively uniform spatial distribution, as exemplified in a limited number of samples of saline water from the basin-fill aquifer of the Estancia Basin and from the San Andres Limestone aquifer in the southeastern part of the State. However, larger spatial variations in scale-forming tendencies, such as those of saline water from the aquifers in the undifferentiated rocks of Cretaceous age in northwestern New Mexico and the aquifers in the rocks of the Dockum Group of southeastern New Mexico, appear to be more common.

BIRD FOOTRPINTS FROM THE MIOCENE "ABIQUIU" FORMATION OF NORTH-CENTRAL NEW MEXICO WITH A REVIEW OF CENOZOIC TETRAPOD TRACKS OF NEW MEXICO

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A new fossil specimen from New Mexico Museum of Natural History locality 5585 in the southwestern Jemez Mountains represents the second record of fossil bird tracks from New Mexico. The strata that yielded the specimen were previously mapped as Zia Formation, but recent work by Shari Kelley indicates that the strata are more likely equivalent to the Abiquiu Formation. The Oligocene to Miocene sedimentary rocks in this area can be divided into lower volcaniclastic member and an upper fluvial sandstone member. The tracks are from low in the fluvial unit. The tracks are from low in the fluvial unit. The fluvial unit has an $^{40}Ar/^{39}Ar$ age of 20.61$\pm$0.07 Ma on an ash bed about 6.5 km NE of NMMNH locality 5585. This is a lower Miocene (close to the boundary of the Arikareean and Hemingfordian land-mammal "ages") age.

The new specimen consists of a nearly rectangular slab with dimensions of approximately 26 x 12 x 2.5 cm. There at least 16 bird tracks on one surface which all appear to represent one ichnotaxon. The impression of digit II is 2.25-2.5 cm long and is straight or incurved. The digit impressions of II and IV are straight and about 1.5 and 2 cm in length respectively. A distinct hallux impression is located immediately posterior to digit impression II and is 04-0.6 cm long. There is no preservation of webbing. In at least two instances there are double imprints of digit impressions suggesting that the bird stayed in one location for a period and shifted its position. There are no clear trackways or indication of a preferred orientation to the tracks. These factors suggest terrestrial feeding activity.

The Zia Sandstone has produced an Arikareean body fossil fauna in New Mexico, but it lacks birds. Tetrapod tracks are known from the Eocene, Oligocene, Miocene and Pliocene strata of New Mexico. With the exception of Eocene tracks from the Baca Formation of west-central New Mexico, and Pliocene tracks from the Ogalalla Formation of east-central New Mexico, all Cenozoic tetrapod tracks from New Mexico are in the Rio Grande rift or associated basins (e. g., Tularosa basin). With one exception these tracks all pertain to mammals (camels, artiodactyls, proboscideans, cats) and most of them are of large, terrestrial ungulates. The only other bird tracks in New Mexico are from the Middle Miocene (Barstovian) Cerro Conejo Member of the Zia Formation in Sandoval County.

OVERVIEW OF GEOLOGY OF WINE-PRODUCING AREAS IN NEW MEXICO

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The first grapevines in New Mexico were planted in 1629 at Senecu, a Piro Indian pueblo south of Socorro, within the Rio Grande rift. This was almost a century and a half before the first vineyards in California. By 1800 there was widespread wine production in New Mexico in two areas within the Rio Grande rift (1) Bernalillo to Socorro; and (2) Mesilla to El Paso.

By the 1880 census there were 3150 acres of vineyards in New Mexico with production of almost a million gallons annually. This production was principally in the Rio Grande valley. However, frequent flooding and higher water tables in the Rio Grande valley adversely affected vineyards. Wine production fell to 296,000 gallons in 1890, 34,208 in 1900, and 1,684 in 1910. The New Mexico wine industry was reborn in 1978, and today the state produces almost 350,000 gallons of wine a year.

Currently, there are about 23 wineries in New Mexico. The majority (16) are located within the Rio Grande rift from near Taos in the north to La Union in the south. These vineyards are located on Neogene basin fill of the Santa Fe Group or Quaternary alluvium. Three vineyards are located in the Tularosa basin, also on Neogene basin fill. Two of the largest vineyards are located on Neogene sediments of Basin and Range basins near Deming, presumably related to property values. The remaining vineyards are located in river valleys of different sizes from the Pecos Valley near Ribera to the Embudo valley near Dixon.

A NEW FLORA FROM THE CREVASSE CANYON FORMATION IN CENTRAL NEW MEXICO

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This research documents a moderately well preserved, previously undescribed fossil leaf assemblage from the Crevasse Canyon Formation near Carthage, New Mexico. The Crevasse Canyon Formation has been correlated with two other localities, near Riley and near Truth or Consequences, for which the depositional environments have been established. The new flora is being analyzed in the context of the depositional environments described by Wallin (Truth or Consequences) and Johansen (Riley). Near Truth or Consequences the Crevasse Canyon Formation was deposited in a mixed sandy lagoonal setting and in mixed and suspended load streams of moderate sinuosity on an upper coastal or deltaic plain. The thick-bedded sands were interpreted as channel fill deposits, and moderately sorted sandstones as crevasse splay deposits. Near Riley the Crevasse Canyon is largely the consequence of crevasse splay deposits that comprise a wedge of coastal plain and littoral sediments which prograded northeastward into the western interior seaway. The important fossil-bearing strata in the Crevasse Canyon Formation at Carthage compare most favorably with the fluvially deposited rocks at Truth or Consequences and Riley. Both Wallin and Johansen note fossil plant material, but none as well preserved as the leaf material at Carthage, where one known bed of well-preserved leaf material occurs with more widely distributed fossilized tree trunks and vertebrate bone fragments. Taking the leaves in context with the associated rocks, we can better constrain the local depositional environment of the Crevasse Canyon Formation, and learn more about late Cretaceous climate in central New Mexico. So far, three of the taxa collected have been identified, including *Quercus viburnifolia*, *Ficus sp.*, and *cf. Plantanus sp*.

CAMPANIAN (LATE CRETACEOUS) SELACHIAN FAUNA FROM THE CLIFF HOUSE SANDSTONE NEAR CUBA, NEW MEXICO

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Prominent outcrops of the Campanian Cliff House Sandstone in the San Pablo Quadrangle near Cuba, New Mexico, include a basal sandstone that is as much as 5 m thick. Above this massive, thick-bedded sandstone is a thinner, sandy shale unit. This sandy shale contains abundant selachian teeth at NMMNH localities 5595 and 5596. The sandy shale unit ranges from 1 to 2 m thick, and is capped by another massive sandstone that is up to 10 m thick. The abundant selachian fauna is composed of *Scapanorhynchus raphiodon, Squalicorax* sp., *Ischyriza mira, Ptychotrygon triangularis,* and *Pseudopyholophus mcnultyi.* In New Mexico, this is the youngest Late Cretaceous selachian fauna to have this characteristic assemblage. The fauna here is slightly less diverse than the older faunas (faunas of the Dalton and Hosta sandstones, El Vado Member of the Mancos Shale, Semilla Sandstone and the Atarque Sandstone) but has the same dominant members. This selachian chronofauna arises in the Turonian, and remains very consistent through the middle Campanian. This consistent chronofauna is composed of *Scapanorhynchus raphiodon, Pseudohypolophus mcnultyi, Ptychotrygon triangularis*, a *Squalicorax* species and usually a *Ptychodus* and an *Ischyrhiza* species, depending on the facies of the localities. *Squalicorax* and *Ptychodus* are the only genera that clearly evolve and change species during this succession. The other dominant species of the chronofauna are indistinguishable from oldest to youngest.

STRATIGRAPHY AND TECTONIC IMPLICATIONS OF OLIGO-MIOCENE ROCKS IN THE SOUTHWESTERN JEMEZ MOUNTAINS, NEW MEXICO

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Little is known of the early development of the northwestern Albuquerque basin. Oligo-Miocene deposits exposed in the southwestern Jemez Mts. that have been previously assigned to the Abiquiu Fm. provide important information on the initial development of the Rio Grande rift in central New Mexico. The type area of the Abiquiu Fm, in the adjacent Española basin, contains three members: a lower, nonvolcanic member containing abundant Proterozoic granite and quartzite derived from the Tusas Mts, and to a lesser extent, the Sierra Nacimiento; a middle (Pedernal) member of chalcedony and chert; and an upper volcaniclastic sandstone member containing clasts of rhyolitic Amalia Tuff.

Ongoing studies of the SW Jemez Mts. recognize two units underlying the ~19-22 Ma Piedra Parada Member of the Miocene Zia (Sand) Fm. These two units differ from the type Abiquiu section, so pending additional study, assignment to the Abiquiu Fm is not recommended. The lower volcaniclastic unit (LVU) is exposed along the hanging wall of the Jemez fault, west of Cañon and Gilman, where it consists of poorly sorted, volcanic-bearing sediments interpreted as debris flow facies. LVU clasts are rounded, up to 15-cm in diameter, of intermediate, basaltic, and rhyolitic composition, and were derived from an as yet undetermined source. This unit also contains minor Proterozoic and Permian clasts. Most LVU gravel contains plagioclase and pyroxene phenocrysts; fewer clasts contain hornblende, and sparser clasts contain quartz phenocrysts. The upper unit is white to tan, medium-grained sandstone that is alternately well cemented with silica and poorly cemented and is interlayered with volcanic ash. This upper unit is similar to upper member Abiquiu sediments to the north, but lacks 25 Ma Amalia Tuff. A biotite-rich ash bed from the upper unit in Cañon de la Cañada yields a $^{40}Ar/^{39}Ar$ age of 20.61 ± 0.07 Ma, younger than the 23-25 Ma determined for stratigraphically similar strata to the north. The LVU is 60 m thick near Cañon, thins to 40 m at Gilman, and appears to have filled a rugged paleotopography developed adjacent to the Jemez fault. To the south and west, on the footwall of the San Ysidro fault, a lag of Oligocene tuff clasts mark the Zia-Galisteo Fm boundary, suggesting that volcaniclastic deposits might have been more widespread than at present, and that some of the deformation along western rift-boundary faults occurred prior to Zia Fm deposition. The basal unit thins abruptly to the north and east and is generally represented by fluvial and debris flow deposits <1 m thick that contain only granitoid and volcanic clasts and local 1-m thick limestone beds. Possible sources include the San Juan, Mogollon-Datil, or Ortiz-Espinaso volcanic fields. Paleocurrent directions recorded by imbricated cobbles (n=28) in the lower volcaniclastic unit at one site near Cañon suggest flow toward the northwest. Paleocurrent data and the northward decrease in thickness suggest sources to the southeast. Available subsurface data from deep oil-test wells in the Albuquerque basin indicates a thick succession of volcanic-bearing sand and mud between the Zia and Popotosa fms and subjacent Galisteo Fm. The lack of coarse volcaniclastic deposits in the subsurface does not support a Mogollon-Datil source. The lack of Amalia Tuff clasts in the section does not support structural or depositional linkage between the Española and Albuquerque basins during late Oligocene to Miocene time.

GEOLOGIC MAP AND VOLCANIC HISTORY OF THE BEAR SPRINGS PEAK 7.5-MINUTE QUADRANGLE, SOUTHERN JEMEZ MOUNTAINS, NEW MEXICO

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The Bear Springs Peak (BSP) quadrangle in the southern Jemez Mountains records a significant portion of Keres-Group volcanism, the earliest phase of volcanic activity in the Jemez Mts. Volcanism in the BSP area occurred primarily along N-S and SW-NE structural features when this area represented the western margin of the Rio Grande rift. The oldest deposits include flows and tuffs of the Canovas Canyon Rhyolite (Tcc and Tcct) and basalts of the Paliza Canyon Fm (Tpb). New and previous age data suggest that this bimodal volcanic suite was emplaced primarily between 10 and 8.5 Ma, with most of the basalts erupted west of Bear Springs Peak and rhyolites erupted primarily from N-S-trending fractures traversing the central portion of the quadrangle.

The Paliza Canyon Fm is widespread, including intercalated basalt flows (Tpb) and volcaniclastic sediments (Tg) in the western portion of the quadrangle, a thick (>300 m) package of dominantly andesitic rocks (Tpa) exposed in the western wall of Peralta Canyon, and a younger set of dacitic lavas (Tpd) exposed along the quadrangle's northern border and in the Ruiz Peak area. On the western half of the quadrangle, volcaniclastic sediments are intercalated with basaltic and andesitic lavas. In some locations, ponding of Paliza Canyon lavas occurred along fault margins, suggesting contemporaneous tectonic and eruptive activity. In general, thick andesite is sandwiched between the older mafic lavas and the younger dacitic lavas, with the entire sequence emplaced mostly between ~10 to 7 Ma.

Rhyolitic volcanic activity in the BSP area returned shortly after 7 Ma, as a wide variety of flows, domes (Tbr) and tuffs (Tbt) related to the Bearhead Rhyolite were emplaced between ~6.8 to 6.0 Ma. Although most of these rhyolites intruded as domes and plugs along earlier N-S structural features, rhyolite dikes along the western edge of Peralta canyon trend NE-SW. Rift-related structural activity continued after emplacement of the Peralta tuff member, as >60 m of displacement of this unit is observed along the Cerrito Yelo fault south of Cerrito Yelo. Following the Bearhead Rhyolite episode of volcanic activity, volcanism in the Jemez Mountains shifted northward while late Miocene to early Pliocene volcaniclastic sediments of the Cochiti Fm were deposited in the southeast portion of the BSP quadrangle. After ~5 Ma of volcanic quiescence in the BSP area, primary volcanic deposits reappeared in the Quaternary, as distal flows of the Bandelier Tuff (both Otowi and Tsirege members) partially filled paleocanyons where the modern Peralta, Paliza and San Juan canyons now exist. Capping the volcanic sequence is the 50-60 ka El Cajete tephra, erupted from the El Cajete crater ~9 km north of the quadrangle. The distribution and thickness of the deposit in the BSP quadrangle (>5 m thick in pumice mines north of Paliza Canyon), clearly indicates a SSE dispersal axis during this phase of the eruption.

STRUCTURE AND MIDDLE-UPPER MIOCENE STRATIGRAPHY OF THE VELARDE GRABEN, NORTH-CENTRAL NEW MEXICO, AND LATE CENOZOIC TECTONIC IMPLICATIONS

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Recent geologic mapping and geophysical investigations have elucidated the structure and upper Santa Fe Group stratigraphy of the Velarde graben, which in turn has refined interpretations regarding late Cenozoic rift tectonism. The Velarde graben is a 6-10 km-wide, NE-trending extensional feature in the northern Española Basin of the Rio Grande rift. We restrict the Velarde graben to a 19 km-long gravity low between the town Hernandez to the south and the north tip of Black Mesa. Slip associated with the Embudo fault system to the north is interpreted to have been partitioned amongst the major faults in the Velarde graben. In the southern graben, a significant lateral transfer of slip likely occurs between these faults and the down-to-the-east Hernandez fault (new name) to the south. The area of this transfer coincides with transverse folds and may be considered a fault segment boundary. Throw values along the Velarde graben border faults since 7.7-8.4 Ma range from 65 m to 435 m. On the southern tip of Black Mesa, comparison of vertical slip rates for the Hernandez fault over two time periods yields slightly higher vertical slip rate values for 3-8 Ma (48-56 m/Myr) compared to 0-3 Ma (35-48 m/Myr). Comparison of vertical offset values in the upper Santa Fe Group with inferred throw of the bedrock and lower Santa Fe Group indicate that the Velarde structure was active prior to the late Miocene. This is consistent with a steepening of seismic reflectors with depth along the eastern margin of the Velarde graben.

LITHOFACIES AND PALEONENVIRONMENTS OF THE TYPE SECTION OF THE PENNSYLVANIAN OSHA CANYON FORMATION, JEMEZ MOUNTAINS, NEW MEXICO

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The Pennsylvanian (Morrowan) Osha Canyon Formation is 27.3 m thick at the type locality near Guadalupe Box in the Jemez Mountains. It is underlain by red and greenish shales of the Mississippian Log Springs Formation, and sharply overlain by coarse-grained, trough-crossbedded, quartzose fluvial sandstones of the Sandia Formation. At the type section, the Osha Canyon Formation is entirely of marine origin and composed of red, purple and greenish marly shale (80.6% of the type section) and interbedded light-gray and reddish limestone beds and mixed siliciclastic-carbonate sandstone (19.4%). Marly shales are poorly exposed, and contain brachiopods and small solitary corals, particularly in unit 10 of the section. Shales of unit 14 also contain small gray limestone nodules. The ledge-forming limestones are 0.1 to1 m thick, wavy bedded and composed of abundant large skeletal fragments derived mostly from brachiopods and crinoids, and subordinately from bryozoans, gastropods and other organisms. Limestones also contain siliciclastic grains, mostly quartz grains, and subordinate granitic rock fragments. The amount of siliciclastic grains increases towards the top of the section. The uppermost 2.5-m-thick interval is a fossiliferous, mixed siliciclastic-carbonate sandstone. The siliciclastic material is probably derived from the nearby Peñasco uplift. Sediments of the Osha Canyon Formation were deposited in a shallow marine shelf environment of normal salinity. The fossiliferous marly shales formed in a shallow-water, low-energy environment below the wave base, whereas the limestones and the mixed siliciclastic-carbonate sandstone on top reflect deposition in a shallow marine, high-energy environment above the wave base.

LATE PENNSYLVANIAN (VIRGILIAN) MARINE INVERTEBRATE ASSEMBLAGES IN THE HOLDER FORMATION, DRY CANYON, SACRAMENTO MOUNTAINS, NEW MEXICO

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The Holder Formation along Dry Canyon consists mainly of a 75 m-thick cyclic sequence of Virgilian marine siliciclastics, marine carbonates, and alluvial siliciclastics above a large basal algal bioherm complex (Yucca mound), deposited on a narrow shelf just west of the shoreline of the Pedernal land mass. Holder marine invertebrates have been little studied; here two quite different marine assemblages from road cuts in the upper part of the Holder, around Milepost 5 of US-82, are summarized. The first assemblage is from a 1-m-thick interval of dark gray calcareous mudstone within a regressive sequence about 45 m above the top of the bioherm. This assemblage is dominated by gastropods (18 species, of which *Retispira espinasa*, 42%, *Taosia crenulata*, 17%, *Colpites monilifera*, 13%, *Hypselentoma perhumerosa*, 9%, and *Goniasma lasallensis*, 7%, are most abundant), and bivalves (9 species; *Polidevcia arata*, 56%, cf. *Sedgwickia topekaensis*, 25%, and *Myalinella* sp., 11%, most abundant), with rare brachiopods (*Linoproductus*) and nautiloid cephalopods (*Metacoceras*, *Pseudorthoceras*). Three of the five most common gastropods are also present in the overlying Laborcita Formation, but *H. perhumerosa* and the bivalve cf. *Sedgwickia topekaensis* have not previously been reported from New Mexico. The absence of most stenohaline marine groups (crinoids, bryozoans, corals, fusulinids) and low taxonomic diversity of this assemblage suggest abnormal marine conditions.

The second assemblage, from 15-20 m above the first, at the top of the road cut, is from interbedded dark gray shale and thin-bedded limestone. It includes gastropods (42 species), bivalves (19 species), brachiopods (22 species), as well as cephalopods, scaphopods, solitary rugose corals, bryozoans, crinoids, echinoids, trilobites, ostracods, fish teeth, and fusulinids. The most common gastropods are *Euphemites* sp. (18%), *Donaldina stevensana* (14%), *Amphiscapha subrugosa* (9%), *Glabrocingulum (Ananias)* spp. (8%), *Retispira tenuilineata* (6%), *Strobeus* spp. (6%), and *Hypergonia* n. sp. (5%). Bivalves are dominated by fragments of *Myalina (Orthomyalina) subquadrata* (41%), followed by *Nuculopsis* spp. (19%), *Edmondia* (10%), and *Permophorus* (8%). The most abundant brachiopods are *Crurithyris planoconvexa* (54%), *Neochonetes granulifer* (16%), *Kutorginella* aff. *lasallensis* (12%), *Composita subtilita* (5%), and *Neospirifer* cf. *dunbari* (4%). The productoid *Kutorginella* has not previously been reported from New Mexico. High taxonomic diversity, abundant stenohaline groups, large numbers of molluscs, and dominantly dark gray shale substrate indicates that the fauna of the second assemblage lived in a nearshore, quiet, normal marine environment characterized by moderate influx of fine-grained siliciclastics. Many of the species in these Holder assemblages are known from Virgilian strata elsewhere in New Mexico, but the taxonomic composition and relative abundances of taxa in the two assemblages are distinctive.

FISSURES ASSOCIATED WITH THE PAJARITO FAULT SYSTEM, RIO GRANDE RIFT, NEW MEXICO

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Three types of fissures have been identified in portions of the Pajarito fault system, which locally defines the active western margin of the Rio Grande rift in the area of Los Alamos, New Mexico. The fault system is approximately 50 km long and up to 5 km wide in places, and is primarily expressed at the surface as a complex series of normal faults, monoclines, faulted monoclines, and zones of distributed faulting. The fault system displaces the 1.2-million-year-old Bandelier Tuff more than 150 m in places, and paleoseismic studies suggest three surface-rupturing seismic events in the Holocene. Fissures have been identified at the upper hinges of monoclinal folds, as openings along faults, and in linear alignments of large holes and cracks where there is little or no other surface expression of faulting. Tensional fissures are commonly found at the upper hinges of monoclinal folds in the Pajarito fault system, and appear to be associated with seismic events. Such fissures are typically filled with large, angular blocks of adjacent lithologies (typically tuff) and finer-grained (commonly laminated) material that washes into the fissures. Paleoseismic trenching investigations across such tensional fissures in the Pajarito fault system indicate that they can be useful for dating paleoseismic events. Fissures associated with the Pajarito fault system accommodate significant opening on normal faults and fault-propagation folds, and are therefore important in assessing surface and shallow subsurface hydrology. The possibility that fissures opened during seismic events also has consequences for evaluating seismic surface rupture hazards.

FIRST RECORD OF THE INVERTEBRATE ICHNOFOSSIL *HAMIPES* FROM THE LOWER PERMIAN OF NEW MEXICO

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New Mexico's Early Permian vertebrate track record has received considerable attention over the last decade and is now recognized as a global standard. However, its Early Permian invertebrate ichnofaunas are less well known and have been relatively understudied. Here, we document an occurrence of *Hamipes*, an invertebrate ichnotaxon that has previously been unreported from New Mexico.

The specimen (NMMNH P-32661) is from New Mexico Museum of Natural History locality 1339, which is in the upper part of the Sangre de Cristo Formation (Wolfcampian) of San Miguel County, New Mexico. A diverse vertebrate ichnofauna is present, dominated by typical Early Permian ichnogenera such as *Dromopus* and *Batrachichnus*. An invertebrate ichnofauna is also present, consisting of ichnogenera such as *Paleohelcura* and *Dendroidichnites*. The paleoenvironment is interpreted as a sheet-flood deposit on an extensive floodplain.

P-32661 is preserved in convex hyporelief, with only a single-track row shown on the slab. This is either a partial specimen or undertracks in which a second track row did not impress. The track row width is 20 mm, and the total length is 20 cm. The track row contains regular, paired, thin, slightly curved scratch mark impressions, which terminate in comma-shaped mounds. The individual impressions are 25 mm long, with a repeat distance of 25 mm. We refer P-32661 to the ichnogenus *Hamipes* Hitchcock, 1858, based on the similarity of this specimen to the type material. Due to the large size of this specimen, the probable arthropod track-maker was a crustacean and not an insect.

There are three separate invertebrate ichnofaunal assemblages in the Lower Permian strata of New Mexico, which are located on a north-to-south transect of the state. The southernmost ichnoassemblage, centered near Las Cruces, is found in coastal tidal flat facies of the Robledo Mountains Formation that show periodic freshwater influence. This diverse ichnoassemblage is distinct in having four arthropod ichnotaxa, including *Tonganoxichnus robledoensis*, which are known only from their type localities within the Robledo Mountains Formation. Another ichnoassemblage, from the central part of the state around the Lucero uplift and Socorro, is low in ichnodiversity. It is found in transitional brackish water-influenced facies low in the Abo Formation. The characteristic ichnotaxon within this ichnoassemblage is *Palaeophycus*, an infaunal burrow attributed to polychaete makers. Another ichnoassemblage occurs in the northern part of the state, near Villanueva in San Miguel County. It is found within floodplain facies of the Sangre de Cristo Formation that were far inland during Wolfcampian time. The ichnodiversity of this arthropod-dominated ichnoassemblage is less than that of the southern ichnoassemblage. However, it may contain different ichnotaxa in addition to *Hamipes*. Continued investigation is needed to further determine the compositional similarities and differences between these ichnoassemblages.

NEW RECORDS OF THE INVERTEBRATE ICHNOFOSSILS *ROBLEDOICHNUS* AND *TONGANOXICHNUS* FROM THE LOWER PERMIAN OF NEW MEXICO

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Tonganoxichnus robledoensis and *Robledoichnus lucasi* are ichnotaxa that have previously been reported only from single occurrences in Lower Permian strata of southern New Mexico. Here we record the first occurrence of these ichnotaxa outside of their type localities within the Robledo Mountains Formation, thus augmenting their distribution.

Single specimens of each ichnotaxon occur in association on a slab that was collected from New Mexico Museum of Natural History (NMMNH) locality 5383 in the lower part of the Abo Formation in the Red Gap area of the Fra Cristobal Mountains in Sierra County, New Mexico. The specimens are from a 0.7-meter thick unit of thinly bedded, ripple-laminated sandstone. A low diversity tetrapod ichnofauna that is dominated by *Batrachichnus* occurs at this site. Several specimens of the invertebrate burrow *Taenidium* have also been found. The paleoenvironment was a fluvial sandflat on a coastal floodplain.

NMMNH P-40869 is a positive body imprint that we tentatively assign to *Tonganoxichnus* cf. *T. robledoensis* Braddy & Briggs, 2002. This bilaterally symmetrical trace shows medial anterior, posterior, and terminal imprints that are characteristic of this ichnospecies. Lateral imprints of similar length differ from the Robledo Mountains Formation type material in their orientation to the mid-line. Braddy and Briggs recognized two types within *T. robledoensis,* thought to represent minor variations in jumping behavior. Both forms have three pairs of lateral imprints that are anteriorly directed. The Fra Cristobal specimen has three pairs of lateral imprints in which; the anterior imprints are anteriorly directed, the medial imprints are laterally directed, and the posterior imprints are posteriorly directed. This orientation is similarly found in *T. buildexensis*, a resting trace that is known from the Upper Carboniferous of Oklahoma, Kansas and Indiana. The Fra Cristobal specimen suggests that orientation of the lateral imprints is either an additional type of behavioral variation within this ichnospecies or a new ichnospecies. More specimens are needed to sample this feature adequately.

P-42176 is a positive trackway that we tentatively assign to *Robledoichnus lucasi* Kozur & Lemone, 1995. Two track rows of walking imprints are shown that contain a two-imprint arrangement comparable to the type specimen from the Shalem Colony section of the Robledo Mountains Formation. A separate landing trace is not preserved. The trackway is 7 cm long and 1 cm in external width. It is separated from P-40869 by a distance of 7 cm. The external width of the trackway coincides with the distal width of the leg appendage imprints seen on the associated *T. robledoensis*. Kozur and Lemone thought that the producer of *R. lucasi* was a flying insect. We propose that *R. lucasi* instead was produced by an apterygote monuran, the same animal that presumably produced *Tonganoxichnus*.

PLIO-PLEISTOCENE FAULTS AND UNCONFORMITIES IN AND BETWEEN THE ARROYO OJITO AND SIERRA LADRONES FORMATIONS AND POST-SANTA FE GROUP PIEDMONT, MESA DEL SOL AND LLANO DE MANZANO, CENTRAL ALBUQUERQUE BASIN, NEW MEXICO

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The southern Mesa del Sol and adjacent Llano de Manzano are shattered into more than a dozen tilted fault blocks between the Rio Grande valley and Hubbell Bench on the eastern side of the Isleta Reservation. Maximum surface offsets of the faults are about 15 m, but underlying unit separations are much larger, with 10-30-m differences in thicknesses. Angular unconformities and disconformities within and between fault blocks are recognized by geometric relationships, clast compositions, and sequences of dated or geochemically fingerprinted volcanic fragments. These unconformities occur between (1) upper Arroyo Ojito Formation (Pliocene), (2) a transitional fine-sand unit (Plio-Pleistocene), (3) the overlying Sierra Ladrones Formation (lower Pleistocene exposures), (4) within the Sierra Ladrones Formation, and (5) between the Sierra Ladrones Formation and the overlying piedmont deposits of the Llano de Manzano (lower to middle Pleistocene).

Volcanic tephra, reworked ash, crossbedded pumice, clasts of rhyolitic tuff, and obsidian are correlated between blocks using $^{40}Ar/^{39}Ar$ ages and geochemical compositions. Ages range from >3 Ma to 1.21±0.03 Ma. Five geochemical groups of pumices and several unique specimens are distinguished in the Pleistocene ancestral Rio Grande deposits (upper Sierra Ladrones axial facies) and are correlated to samples from other areas along a 190-km reach of the Rio Grande, from Santo Domingo to Socorro.

The lowest occurrence of obsidian pebbles (Rabbit Mountain, 1.428±0.003 Ma) on either side of the west-dipping Palace-Pipeline fault zone on the north side of Hell Canyon indicates at least 38 m of offset since early Pleistocene time. East of the fault axial deposits thin to only 32 m, and the underlying transitional unit and upper Arroyo Ojito Formation are exposed. Hanging-wall blocks west of the fault exhibit two angular unconformities, with increasingly more section removed to the west. South of Hell Canyon, westernmost piedmont deposits of the Llano de Manzano truncate all but the lowest 14 m of the axial Sierra Ladrones Formation.

STRATIGRAPHY AND STRUCTURE: THE BORREGO SECTION OF THE PENNSYLVANIAN-PERMIAN HORQUILLA FORMATION, BIG HATCHET MOUNTAINS, NEW MEXICO

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In 1966, Zeller (NMBMMR Memoir 16) described the Borrego section of the Pennsylvanian-Permian Horquilla Fm in the Big Hatchet Mountains (SE¼ sec. 27, T31S, R15W, Hidalgo County). He interpreted the Virgilian-Wolfcampian interval here as a single, homoclinal section about 500 m thick divided into 5 units: (1) lower, limestone-dominated unit, ~120 m thick, late Virgilian-early Wolfcampian; (2) light gray "basinal" shale ~105 m thick; (3) middle limestone, ~60 m thick, early-middle Wolfcampian; (4) light gray "basinal" shale ~102 m thick; and (5) upper limestone, ~90 m thick, middle Wolfcampian. In contrast, Drewes (1991, USGS Map I-2144) mapped shingled thrust faults in which units 1-2 are Horquilla Fm (1) depositionally overlain by Earp Fm (2), separated by a thrust fault from units 3-4, which are Horquilla-Earp again, separated from another thrust fault from unit 5, which is Horquilla. Our study of the Borrego section indicates that Zeller's identification of a single, homoclinal section is correct, though we differ from Zeller in identifying units 2 and 4 as very shallow marine facies of the Horquilla Fm (mostly crossbedded calcarenites, thinly laminated siltstones and grainstones), not a basinal facies. Several observations refute the thrust fault interpretation of the Borrego section: (1) regionally, the Horquilla-Earp contact is late Wolfcampian, so if unit 2 is Earp deposited on Horquilla, then this contact is locally early Wolfcampian, and if unit 4 is Earp deposited on Horquilla, then the contact is middle Wolfcampian, both highly unlikely; (2) fusulinids from units 1, 3 and 5 are in correct temporal order; (3) all beds throughout the section dip ~30-35º to S50ºE; and (4) there is no structural evidence of thrust faults at the bases of units 3 and 5. Therefore, we reject the presence of shingled thrust faults in the Borrego section of the Horquilla Fm.

Unit 1 and the lower part of unit 2 cross the Virgilian-Wolfcampian boundary and contain conodont faunas of the following ages: (1) bed 6, middle Virgilian, Lecompton cyclothem (=middle of Shawnee Group); (2) bed 38, late Virgilian, Brownville level (=top of Wabaunsee Group, just below base of Newwellian) (3) bed 44 (top of carbonate section), lower Wolfcampian (Newwellian?) (=Admire Group); (4) beds 50, 54, carbonates in base of unit 2, Wolfcampian (Newwellian) (=Admire Group to base of Council Grove Group). All conodont faunas are dominated by *Streptognathodus*, associated with fewer *Adetognathus*--a typical normal marine, shallow water, shelf association. There is no conodont evidence of a "basinal" setting. The basal 7 m of unit 1 is a clastic sequence composed of sandy conglomerate, sandstone and siltstone of fluvial origin. Above a 4.8-m thick covered interval, a 105-m-thick succession of bedded and massive, fossiliferous limestone is exposed. The limestones are mostly bioclastic wackestone, subordinate thin beds of fusulinid wackestone/packstone and massive algal limestone. Solitary corals, brachiopods, gastropods and crinoids occur throughout the section. The thin covered intervals probably are marly shale and shale. Lithofacies and fossil content indicate that the limestones formed in a shallow marine, shelf environment.

STRATIGRAPHY OF THE JURASSIC SAN RAFAEL GROUP ALONG THE PICURIS-PECOS FAULT SYSTEM, SANTA FE COUNTY, NEW MEXICO

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Jurassic strata exposed along the southward extension of the Picuris-Pecos fault system south of Lamy, Santa Fe County (T12-13N, R10E), are assigned to the San Rafael Group (Entrada, Todilto and Summerville formations) and overlying Morrison Formation (Salt Wash, Brushy Basin and Jackpile members). A complete section of the San Rafael Group just north of Arroyo de La Jara consists of four lithostratigraphic units: (1) Dewey Bridge Member of Entrada Sandstone at the base of the section rests sharply on mudstones at the top of the Upper Triassic Chinle Group, is ~5 m thick and consists of white and pink, fine- to medium-grained, ripple-laminated and trough-crossbedded sandstone; (2) Slick Rock Member of Entrada Sandstone is ~18 m thick and is yellow and gray, fine- to medium-grained sandstone with large trough crossbeds or tabular beds with climbing ripples; (3) Luciano Mesa Member of Todilto Formation, ~4 m thick, begins with 0.3 m of waterworked fine sandstone followed by 2.8 m of dark gray, finely laminated, kerogenic limestone capped by 0.7 m of brecciated and vuggy limestone; and (4) the Summerville Formation, ~19 m thick, is pale brown, cyclically bedded, very fine-grained sandstone and siltstone with some gypsum (6 m thick) overlain by interbedded gray limestone (with red chalcedony nodules) and reddish brown mudstone (~3 m thick) capped by ~10 m of reddish brown mudstone with thin, lenticular beds of trough-crossbedded sandstone. The base of the Morrison Formation on the Summerville Formation is a sharp, erosionally scoured surface overlain by medium-grained and pebbly sandstone at the base of the Salt Wash Member. This section of the San Rafael Group is significant to regional San Rafael Group stratigraphy in several ways: (1) it is the easternmost known section of the Dewey Bridge Member and thus the easternmost sedimentary record of the Carmel transgression; (2) it is east of the Todilto gypsum (Tonque Arroyo Member) pinchout and thus another zero isopach point for that unit; (3) it further demonstrates the continuity of the Summerville Formation across northern New Mexico; and (4) its sharp contact with the overlying Salt Wash Member of the Morrison Formation is the most compelling local physical stratigraphic evidence of the J-5 unconformity.

UPPER CRETACEOUS MARINE STRATA AND FOSSILS, LITTLE HATCHET MOUNTAINS, SOUTHWESTERN NEW MEXICO

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Upper Cretaceous marine strata with age-diagnostic fossils of bivalves and ammonites are preserved in the hinge of the Howells Well syncline (sec. 15, T28S, R16W) in the Little Hatchet Mountains of southwestern New Mexico. These strata, long assigned to the upper part of the Lower Cretaceous Mojado Formation, are at least 50 m thick and are mostly dark gray shale with a few thin interbeds of limestone and sandstone and some limestone septarian concretions. We assign these marine strata to the Mancos Shale; they are sharply overlain by nonmarine sandstone at the base of the Upper Cretaceous (Campanian) Ringbone Formation. Fossil localities in the Mancos Shale that are 11 to 30 m below the Ringbone base yield the following taxa: *Ostrea beloiti* Logan, *Inoceramus arvanus* Stephenson, *Acanthoceras*, *Tarrantoceras*, *Moremanoceras* and *Turrilites acutus* Passy. These fossils identify the ammonite zone of *Acanthoceras amphibolum* Morrow, and thus a middle Cenomanian age. These marine strata gradationally overlie a thick succession of quartzarenite strata of the Mojado Formation that contain hummocky cross-lamination and a few bivalves. They were deposited in a shelfal setting below storm wave base and thus record post-Mojado transgression and continuing rapid subsidence along the axis of the former Bisbee rift basin. Paleogeogeographically, the presence of the Mancos Shale in the Little Hatchet Mountains forces a small but significant shift in paleogeographic maps of the middle Cenomanian seaway in the Western Interior. Thus, the seaway (and its southwestern/southern shoreline) can be extended at least 80 km to the SW from the Cooke's Range, and a similar distance to the southeast from Virden, which are the closest previously known outcrops of middle Cenomanian strata to the northeast and northwest of the Little Hatchet Mountains.

GRAVITY MODELING AND LITHOSPHERIC STRUCTURE BENEATH THE JEMEZ LINEAMENT, ARIZONA AND NEW MEXICO

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The Jemez lineament is a NE-SW alignment of late Tertiary volcanic rocks, stretching from southwest Arizona into northeast New Mexico. Ideas for the origin of the lineament include a Proterozoic accretionary structure, but this interpretation is ambiguous because of poorly understood lithospheric structure in the region. Slow seismic P-wave velocities at 50-160 km depth under the Jemez lineament and adjacent to the Colorado Plateau suggest anomalous upper mantle under these features. Constraints from crustal geology and existing seismic data will be applied to constrain long wavelength (>700 km) 2.5-D forward gravity models across the Jemez Lineament and Colorado Plateau region in order to provide insight into the structure of the lithosphere. Xenolith data will also play an important role in the models by constraining the physical properties and composition of lower crustal and upper mantle rocks. Preliminary gravity modeling suggests that topography in parts of our study area is supported by low-density upper mantle, not by Airy model crustal thickness variations.

DEFLECTION OF RIO SALADO TERRACE SURFACES DUE TO UPLIFT OF THE SOCORRO MAGMA BODY, SOCORRO, NEW MEXICO

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The Socorro magma body is located in central New Mexico along the intersection of the Socorro fracture zone and the Rio Grande rift. The inflation rate of the magma body has been approximated at 2 to 4 mm/yr, based on leveling data by Larsen and others (1986) and InSAR data by Fialko and others (2001). This is a rapid rate that will impact the landscape evolution of the nearby Rio Salado drainage. The focus of this study is to evaluate the rate and amount of stream terrace deflection due to uplift of the magma body.

Perturbations of the fluvial system act to offset stream terrace surfaces. The area of maximum uplift is localized. Both the Rio Grande and Rio Salado traverse this zone. Comparison of the modern stream profile with the paleostream profiles (indicated by the fluvial terraces) will show increasing deflection across the zone of maximum uplift.

Preliminary examination of the Rio Salado drainage indicates that there are four terraces. Soils will be used to correlate and to estimate the ages of the terraces, based on the degree of $CaCO_3$ accumulation. This study will constrain the relative ages of the surfaces, determine the degree of uplift and form the basis for numeric age dating of the terrace surfaces.

MAP OF SURFICIAL GEOLOGIC MATERIALS OF NEW MEXICO NEARS COMPLETION

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John W. Hawley, along with colleagues, has been working on a surficial geologic map of New Mexico since the mid 1970s. Surficial data for the state were compiled predominantly in the 1980s on USGS 1:250,000 topographic quadrangles. Map units were differentiated into three orders of classification: 1) major genetic materials and their relative ages, 2) lithologic character of clasts and bedrock terranes, and 3) particle size and dominant textural classes. Point symbols for volcanic features were also depicted. These efforts culminated in a wealth of data, which in turn led to extreme challenges for cartographic organization and digital production. Two separate efforts in the mid 1990s and 2000-01 failed to produce either a surficial map or a digital product.

The New Mexico Bureau of Geology and Mineral Resources received funding in 2002 to reorganize the data and produce digital coverages for quadrants of the state. Vast technological advances since the original map data were compiled has led to both data refinement and enrichment; the original dataset was greatly enhanced by overlaying it upon both a 30-m digital elevation model (DEM) and a TM satellite image of the state. To date, digital surficial data for the NW, NE, and SE quadrants of the state have been compiled. Final completion of data capture and production of both a map of genetic/age classes, as well as a GIS-based digital product displaying all surficial data is expected by the end of 2004.

MAPPING FAULTS IN THE LIGHTNING DOCK KNOWN GEOTHERMAL AREA, ANIMAS VALLEY, NEW MEXICO USING SOIL CO_2 FLUX MEASUREMENTS

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When geothermal fluids rise, they commonly boil giving off their dissolved gases, especially carbon dioxide, the predominant vapor phase (other than water vapor) in geothermal systems. The CO_2 is likely to rise along the same faults that act as pathways for the rise of the geothermal fluids. By measuring soil CO_2 flux, it is possible to detect the CO_2 plume associated with a fault and is therefore useful in locating faults that may be buried. By mapping out the location of faults, drill targets are easier to identify and can save money when exploring for geothermal fluid reservoirs. The Lightning Dock Known Geothermal Resource Area (LDKGRA) is located southwest of Lordsburg, New Mexico and has no known surface expression. Shallow near boiling geothermal waters are used to heat greenhouses and raise fish fingerlings. Silica and alkali geothermometers indicate a shallow reservoir temperature of about 165^{o} C. Drilling to find this resource is difficult because faults in the LDKGRA are covered by hundreds of meters of alluvium, and are difficult to locate by geophysical methods. Over four hundred fifty soil CO_2 flux measurements at 50 to 100 meter East-West spacing were made near the main surface heat anomaly of the LDKGRA to develop and test the soil CO_2 technique as a method of geothermal exploration. Measurements were made by the accumulation chamber method using a LI-COR CO_2 analyzer and an aluminum box with volume of 0.01 m^3 placed on the ground away from vegetation. The fluxes of CO_2 into the box were measured over at least 200 seconds and showed a range from a low value of 0 g m^{-2} day^{-1} to a high value of 12 g m^{-2} day^{-1}. The sites of the highest CO_2 flux are believed to mark buried faults. One such probable fault lies on line with a fault hypothesized from geological data by previous workers. Previous well water analyses show that the shallow ground waters trending southwest of the discovery well have anomalous CO_2. Soil CO_2 flux measurements varied at control points within acceptable ranges.

QUANTIFYING THE INFLUENCE OF CALCIUM CARBONATE ACCUMULATION ON THE HYDRAULIC PROPERTIES OF SEMI ARID SOILS: SEVILLETA NATIONAL WILDLIFE REFUGE, NEW MEXICO

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Soil properties such as texture, bulk density and porosity have a major influence on the partitioning of rainfall into infiltration and runoff. Thus they determine the water available for aquifer recharge, stream flow and ecosystem processes. Quantifying soil hydraulic properties is difficult and time consuming and most researchers use empirically derived relationships between soil physical attributes and soil hydraulic properties when modeling water movement in vadose zones. These relationships termed pedotransfer functions are the basis of well-known vadose zone models such as those developed by Van Genuchten (1980), Brooks and Corey (1964).

In the semi arid southwestern United States, where quantifying rainfall partitioning is of great importance, the soils are characterized by the accumulation of soluble salts, principally calcium carbonate into calcic horizons. Studies have shown that the accumulation of calcium carbonate in soils can influence soil hydraulic properties, including moisture retention and saturated and unsaturated hydraulic conductivity (Baumhardt and Lascano, 1993; Gile 1961; Aronovici et al., 1972, Dong, et al., 2003). However, this data shows no consistent pattern of soil hydraulic properties with varying amounts of calcium carbonate.

Studies have shown that the calcium carbonate content of arid soils increases with increasing age of the soil producing systematic morphological changes in calcic horizons (Gile et al., 1962, Bachman and Machette 1973). They recognized six stages of calcic horizon development recording the gradual accumulation of calcium carbonate cementing the matrix of soils until eventually producing an impermeable layer within the soil profile. I believe that the reported variation in hydraulic properties of calcic horizons reflects the unrecognized variation in calcic horizon development used in the studies of hydraulic properties.

I propose to measure the hydraulic properties of a chronosequence of sandy aridisols, which show a systematic increase in calcium carbonate content, and morphology with increasing age. We will produce a systematic data set relating K_{sat}, K_{unsat}, and moisture retention curves to calcium carbonate content and stage of calcic horizon development. Ksat will be determined in the lab from soil blocks, Kunsat in part by disc infiltrometer and by water potential meter, and moisture retention curves by moisture loss from lab samples. Soil properties such as particle size, calcium carbonate content, and bulk density will be measured for each sample characterized hydrologically.

AN ALTERNATIVE MODEL FOR LARAMIDE MAGMATISM IN THE SW US: IMPORTANCE OF LATE JURASSIC CONTINENTAL RIFTING

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The cause of Laramide magmatism in Arizona, New Mexico, Trans-Pecos Texas, and northern Mexico is an enigma because the magmatic zone extended further inboard and to younger ages than Mesozoic arc magmatism elsewhere in the Cordillera. Early models for Laramide magmatism relate an eastward sweep of magmatism to progressive shallowing of the Farallon plate. Advances in geochronology and petrologic models of subduction zones now preclude shallow subduction as the cause for Laramide magmas. For instance, at 80 Ma, intrusion in the Sierra Nevada batholith waned while Laramide magmatism began in Arizona and New Mexico, suggesting that the locus of magmatism shifted from one area to the other rather than sweeping systematically eastward. Investigation of shallow-angle subduction worldwide demonstrates that magmatism ceases as the angle of subduction decreases; modern shallow-angle subduction zones are nearly devoid of active volcanoes.

We propose that Laramide magmatism in Arizona, New Mexico, Trans-Pecos Texas, and northern Mexico was not caused by typical subduction processes, although the igneous rocks have arc-like geochemical signatures. Instead, we suggest that Laramide magmatism was controlled by the mantle structure inherited from the preceding tectonic event. During Late Jurassic time, southwestern North America experienced extension, resulting in the Border continental rift. The Border rift is defined by thick accumulations of fault-bounded alluvial and oceanic strata intercalated with rhyolitic ash-flow tuffs and asthenosphere-derived basalts. Border rift basalts have been documented in Kimmeridgian/Tithonian marine and terrigenous strata in the Chiricahua Mountains of southeast Arizona, in Upper Jurassic strata in the Little Hatchet Mountains of southwest New Mexico, and as allochothonous blocks in diapiric Upper Jurassic salts in the La Popa basin of northeast Mexico. The position of the Border rift coincides with the zone of Laramide magmatism. Thus, we interpret Laramide magmatism as the result of dehydration of the Farallon slab, and subsequent mantle melting, as the slab entered hot asthenospheric mantle emplaced at shallow depths during Border rift extension. Partial melts of hydrated mantle experienced crustal contamination during ascent, resulting in Laramide igneous rocks with arc-like geochemical signatures.

GEOLOGY OF THE SODA DAM TRAVERTINE DEPOSITS, SANDOVAL COUNTY, NEW MEXICO

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Soda Dam is an active travertine mound located in the Jemez Mountains, Sandoval County, New Mexico. Associated with it are several thermal springs and a number of other travertine deposits of various ages and sizes. Although the thermal springs at Soda Dam have received considerable attention in the past, the travertine deposits have only now been mapped in detail.

In the Soda Dam area, Precambrian gneiss is overlain by Paleozoic sedimentary rocks and Quaternary travertine. From oldest to youngest, the sedimentary strata include the Mississippian Arroyo Peñasco and Log Springs Formations, and the Pennsylvanian Osha Canyon, Sandia, and Madera Formations. A northeast-striking, high-angle normal fault intersects the western end of Soda Dam. Herein designated as the Soda Dam fault, it is exposed for only about 40 m where it separates clastic sediments of the Sandia Formation from Precambrian gneiss. The Soda Dam fault is the primary conduit for the thermal waters that have formed and continue to form the travertine deposits. The thermal waters migrating along the fault are further dispersed by two dominant fracture sets having trends of N20-41^{o} E and N43-56^{o} W. Soda Dam, which has formed along a northwest-trending fracture, is one of the larger and currently the most active of the travertine deposits, a consequence of being connected directly to the Soda Dam fault.

LATE PLIOCENE (LATE BLANCAN) AND EARLY PLEISTOCENE (EARLY IRVINGTONIAN) VERTEBRATE FAUNAS FROM THE CAMP RICE FORMATION, MESILLA BASIN, SOUTHERNMOST NEW MEXICO

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Three stratigraphically superposed Plio-Pleistocene vertebrate faunas are known from the Camp Rice Fm in the Mesilla Basin, Doña Ana County: Mesilla Basin Faunas A, B, and C, from oldest to youngest (hereafter Mesilla A, B, and C). Mesilla A and B are from the late Blancan land-mammal “age” (late Pliocene) and Mesilla C is from the early Irvingtonian land-mammal “age” (early Pleistocene). The Mesilla A fauna is composed of only six species, including the glyptodont *Glyptotherium* and the three-toed horse *Nannippus peninsulatus*. The presence of *Glyptotherium* establishes a late Blancan or younger age for this fauna because the first appearance of South American immigrants in North America, including *Glyptotherium*, defines the beginning of the late Blancan at about 2.7 Ma. The presence of *Nannippus peninsulatus* is indicative of Blancan faunas older than 2.2 Ma. *Nannippus* and several other typical North American Blancan mammal genera (*Borophagus*, *Hypolagus*, *Rhynchotherium*) went extinct at ~2.2 Ma (*Nannippus* extinction datum). Mesilla A occurs in normally magnetized strata in the upper Gauss Chron above the Kaena Subchron (3.04 Ma) and below the Gauss/Matuyama boundary (2.58 Ma). Mesilla A is one of only six late Blancan faunas in the Southwest that document the presence of South American immigrant mammals in the upper Gauss Chron (~2.6-2.8 Ma). Mesilla B is the most diverse late Blancan fauna in New Mexico, with at least 35 species of vertebrates: 3 bony fish, including gar; 2 amphibians (frog and salamander); 7 reptiles (4 turtles, 2 snakes, lizard); 2 birds; and 21 mammals. The most age-diagnostic mammals in the Mesilla B fauna are *Glyptotherium arizonae*; the mylodont ground sloth *Paramylodon harlani*; the mole *Scalopus*; the rabbit *Aluralagus virginiae*; the small sabercat *Smilodon gracilis*; the large tapir *Tapirus haysii*; and the giant camelids *Gigantocamelus spatula* and *Blancocamelus meadei*. *Gigantocamelus* and *Blancocamelus* confirm a Blancan age for Mesilla B as these two genera are not known from the Irvingtonian. *Glyptotherium arizonae*, *Paramylodon harlani*, and *Smilodon gracilis* are unknown in southwestern faunas before the latest Blancan, an age supported by the absence of Blancan genera that disappear by 2.2 Ma (e.g., *Nannippus*) as well as Irvingtonian mammals that appear after 1.8 Ma (e.g., *Mammuthus*). *Aluralagus virginiae* is restricted to latest Blancan faunas. Biostratigraphy and magnetostratigraphy constrain the age of Mesilla B to the latest Blancan (1.8-2.2 Ma). The Mesilla C fauna contains *Mammuthus*, the defining genus for the Irvingtonian. In addition to the primitive mammoth *Mammuthus meridionalis*, other mammals from Mesilla C indicative of the Irvingtonian are the megalonychid ground sloth *Megalonyx wheatleyi*, the wolf *Canis armbrusteri*, the beaver *Castor canadensis*, and the lamine camelid *Palaeolama mirifica*. Magnetostratigraphy places Mesilla C in the upper Matuyama Chron between 1.07 and 1.81 Ma and two pumice beds dated at 1.32 Ma and 1.59 Ma occur in the stratigraphic interval containing early Irvingtonian mammals. Biostratigraphy, radioisotopic dates, and magnetostratigraphy constrain the age of Mesilla C between 1.1 and 1.6 Ma. Mesilla C thus correlates with the Tijeras Arroyo local fauna from the Albuquerque Basin, which also contains *Mammuthus meridionalis* and is bracketed by dates of 1.26 and 1.61 Ma.

PETROGRAPHIC ANALYSIS OF CUTTINGS FROM THE YATES #2 LA MESA WELL AND IMPLICATIONS FOR THE TECTONIC HISTORY OF THE SOUTHERN ESPANOLA BASIN

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The 2350 m (7710') Yates #2 La Mesa well, west of Santa Fe, is surrounded by a considerable amount of controversy because of different interpretations of formations present in the well. Petrographic analysis of 46 thin sections of cuttings is underway to resolve these controversies, and their implications for the tectonic history of the southern Española basin.

Below the Tesuque Formation are 625 m (3966'-6018' in the well) of volcanic and volcaniclastic rocks. The upper 318 m (3966'-5012') are mafic rocks rich in olivine and clinopyroxene. These rocks lithologically correlate to basanite and basalt lava flows of the Cieneguilla "limburgite" that crop out near La Cienega. The great quantity of vesicular tachylite and sideromelane glass (some replaced by zeolite) implies proximity to a vent. The lower 307 m (5012'-6018') of volcanic material resembles the latitic lava flows and sedimentary deposits of the Espinaso Formation.

Above the Precambrian basement at 2297 m (7534') and below the volcanic interval the cuttings are a mixture of limestone and clastic-sedimentary fragments. Many of the limestone fragments contain fossils characteristic of Paleozoic marine facies. Some fossils present are crinoids, brachiopods, bryzoans, benthic foraminifera, and bivalves. The 462 m (6018'-7534') of sedimentary rocks between the Espinaso Formation and basement rocks are, therefore, interpreted as Upper Paleozoic, in contrast to previous published interpretations of Eocene lacustrine limestone in this position.

These results are consistent with Cather's (1992) hypothesis that the Laramide Pajarito uplift occupied the area of the current Española basin. There is little if any Eocene sediment in the La Mesa well and the concept of an Eocene "La Mesa limestone" is inconsistent with the diagnostic fossils in the cuttings. Volcanic rocks buried the denuded Laramide uplift before or during early rift-basin subsidence.

We acknowledge Steve Cather, New Mexico Bureau of Geology and Mineral Resources for providing the thin sections and encouraging this study.

OXYGEN ISOTOPES OF MIDDLE PENNSYLVANIAN APATITIC CONODONTS AS A POTENTIAL RECORD OF PENNSYLVANIAN GLACIAL ICE VOLUME VARIATIONS

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Oxygen isotopes ($\delta^{18}O$) from marine foraminiferal calcite have traditionally been used as climate proxies to determine Cenozoic seawater temperatures and/or glacial ice volumes. Deposits older than the Cenozoic have often been diagenetically altered making paleoclimate interpretations from $\delta^{18}O$ less reliable. Since the P-O bond of apatitic phosphate is stronger than the C-O bond in calcite, $\delta^{18}O$ studies from marine apatite should provide a more accurate means to study paleoclimatic change in pre-Cenozoic deposits. This study focuses on using apatitic conodonts (extinct Paleozoic marine microfossils) to determine changes in Middle Pennsylvanian glacier ice volumes.

The Middle Pennsylvanian Gray Mesa Formation (Desmoinesian) from Mesa Sarca in central New Mexico is characterized by ~77 meter-scale, upward-shallowing carbonate cycles (3-6 m thick) which record orbitally forced (Milankovitch) glacio-eustatic sea-level changes. Cycle durations cluster around 70-140 ka, having been deposited during Gondwanan continental glaciation. Upward-shallowing trends are generally indicated by deeper subtidal skeletal wackestones and mudstones overlain by shallow subtidal skeletal wackestone/packstones. These are commonly capped by subaerial exposure features including pedogenic structures. Conodonts were collected from the base, middle, and top of two separate cycles; these cycle positions represent transgressive (interglacial) through regressive (glacial) depositional phases. Sample sets of 1-10 conodonts will be analyzed for $\delta^{18}O$ using laser ablation techniques (Sharp and Cerling, 1996). For initial ice volume change comparisons, the magnitude of isotopic shift from the bottom to the top of the Pennsylvanian cycles will be compared to the 1.0‰ to 1.5‰ shift recorded in Pleistocene marine glacial-interglacial cycles.

INVESTIGATION ON THE PRESENCE AND ORIGIN OF HIGH CHLORIDE WATERS IN THE SHALLOW HYDROLOGIC SYSTEM IN THE SOCORRO BASIN, NEW MEXICO

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The Rio Grande, an important water source in New Mexico, flows through the Socorro Basin, located in central New Mexico. An interesting feature in the Socorro Basin is the Socorro accommodation zone (SAZ), a 2-km-wide, topographically high zone that separates tilted half grabens of opposite dip directions. There is evidence that the SAZ has had a large influence on volcanism in the area and is a zone of groundwater movement.

This study focuses on the presence, and possible origin of high chloride waters observed in certain areas in the shallow groundwater system in the Socorro Basin. These waters seep into irrigation drains and canals and eventually make their way into the Rio Grande, impacting the water quality of the river.

Water chemistry suggests that these high chloride waters are sedimentary brines with a deep origin. Other water types in the shallow groundwater system include river water, the dominant water type, and water that is chemically similar to Socorro Springs, a warm spring on the western edge of the basin. Water that discharges at Socorro Springs is believed to come from La Jencia Basin an adjacent closed basin to the west.

Existing gravity data for the basin combined with the spatial distribution of high chloride water and Socorro Spring type water imply that upwelling of deep basin brines and regional groundwater flow paths may be structurally controlled and directly related to cross-basinal structures associated with the SAZ. The known relationship between the SAZ and past volcanic events suggests that geothermal waters may also play a part in upwelling of the high chloride waters.

QUANTITATIVE MINERALOGIC EVALUATION OF THE "TRANSITION ZONE" ENVIRONMENT: PRELIMINARY OBSERVATIONS FROM THE CERRO COLORADO PORPHYRY COPPER SYSTEM, REGIÓN I, NORTHERN CHILE

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The 51.8 Ma Cerro Colorado porphyry copper deposit is located approximately 130 km east-northeast of Iquique, Región I, Northern Chile. As part of our preliminary study of the "transition zone", that rock volume comprising the geochemical change from supergene metals accumulation to essentially unoxidized hypogene copper sulfides, fifty ten-meter composite pulp samples were collected from six drill holes representing various ore environments within the Cerro Colorado hydrothermal system. Heavy mineral separates were obtained from all of the ten-meter composite pulp samples, with polished grain mounts of these separates examined using standard reflective light petrographic techniques. For each sample a technique called line integration (Brimhall, G.H, Jr., 1977, *Early fracture-controlled disseminated mineralization at Butte Montana: Econ. Geol. v. 72, p. 37-59*) was used to determine the relative volume percents of each sulfide mineral present.

Preliminary observations of these samples have identified three distinct mineralogic zones: 1) Supergene enrichment zone; 2) Transition zone; and 3) Hypogene protore zone. The supergene enrichment zone is characterized by well-developed chalcocite replacement of pyrite grains and is composed of a pyrite + chalcopyrite + chalcocite mineral assemblage. The "transition zone" is characterized by the incomplete replacement of hypogene bornite, chalcopyrite, and pyrite by chalcocite and covellite and such is composed of a mixed hypogene/supergene mineral assemblage of pyrite + chalcopyrite + bornite + chalcocite + covellite. Mineral ratios of this zone illustrate a general trend, from base of enrichment to hypogene mineralization, of decreasing chalcocite-bornite ratios, increasing pyrite-chalcocite ratios, and an abrupt decrease in the chalcocite-covellite ratio immediately above hypogene mineralization. The partial replacement of hypogene bornite, chalcopyrite, and pyrite by supergene chalcocite and covellite, along with the presence of supergene bornite and chalcopyrite, suggest that the supergene copper-bearing solutions responsible for enrichment could not maintain the low pH and/or copper concentrations need to completely replace these hypogene sulfides. The hypogene zone at Cerro Colorado is characterized by the mineral assemblage pyrite + chalcopyrite + bornite and is interpreted to represent copper sulfides associated with the emplacement of the Cerro Colorado magmatic hydrothermal system.

THE PALEOCLIMATIC IMPLICATIONS OF HOLOCENE SHORELINE STRATIGRAPHY OF THE EL FRESNAL BASIN, NORTHERN CHIHUAHUA, MEXICO

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The El Fresnal basin is one of four sub-basins constituting the formerly extensive Pluvial Lake Palomas system of northern Chihuahua and southern New Mexico. This basin is highly responsive to minor climate changes because of its large drainage area and high elevation headwaters. Castiglia (2002) documented constructional beach ridge complexes (BRCs) in the El Fresnal basin, that record millennially spaced highstands during the Holocene. This chronology shows early (8269±64, 8456±97 ^{14}C yr B.P.), middle (6110±80 to 6721±68 ^{14}C yr B.P.), and two late Holocene highstands (3815±52 to 4251±59 and 221±33 ^{14}C yr B.P.). Using this framework, I describe the detailed stratigraphy and geomorphology of these BRC sediments to refine the BRC chronology. The BRC sediments comprise well-resolved lacustrine sediments that interfinger with distal alluvial fan sediments. The stratigraphic record of the early Holocene BRC shows two highstands punctuated by a soil-forming interval. A lacustrine silty clay unit coarsens to a lacustrine sandy loam unit, and is followed by a unit of small gravel filled channels and minor soil development. These units are indicative of a regressive sequence, and are overlain by a transgressive lacustrine unit and possible deltaic units. Then, as indicated by geomorphic evidence, a major period of erosion and shoreline incision is followed by a middle Holocene highstand. The middle Holocene highstand, during the supposed Altithermal, demonstrates the sensitivity of the basin to subtle climatic perturbations. These records have unique implications for the Chihuahuan Desert paleoclimate, especially when compared to regional lacustrine paleoclimate reconstructions.

GRAVITY MODELS OF THE ALBUQUERQUE BASIN, JORNADA DEL MUERTO BASIN, AND TULAROSA BASIN IN THE RIO GRANDE RIFT

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The Rio Grande Rift is a major Cenozoic continental rift zone that extends south from southern Colorado through Northern Mexico. North of central New Mexico the rift is a narrow feature at the edge of the southern Rocky Mountains. South of central New Mexico the rift widens significantly, forming multiple basins and ranges. The Albuquerque Basin is located in the narrow section of the rift. The Jornada del Muerto Basin and the Tularosa Basin, separated by the San Andres and Oscura Mountains, are located in wider region of the rift. Models of the Albuquerque and Jornada del Muerto Basins have been constructed using seismic and gravity constraints. New gravity data will be used to refine existing models to further constrain fault geometry in the basins. Significantly less modeling has been done on the Tularosa Basin. We present preliminary results for two and a half dimensional Talwani gravity models constructed across the southeast flank of the Oscura Mountains into the northern Tularosa Basin using Pan American Center for Earth and Environmental Studies (PACES) gravity data and density data from wells. These models are used to constrain the presence of a major normal fault and provide additional constraints on the subsurface geometry of the region. We hope these models will provide insight into the formation and relationship of narrow rift zones and “basin and range” style extensional provinces.

STRATIGRAPHY AND ORIGIN OF THE COONEY TUFF-REVISITED: MOGOLLON-DATIL VOLCANIC FIELD, SOUTHWESTERN, NEW MEXICO

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New observations in the Holt Mountain 7½-minute quadrangle near Glenwood, New Mexico are clarifying the volcanic stratigraphy and origin of the Eocene (~34 MY) Cooney Tuff (Ratté and McIntosh, 2001, *The Cooney Tuff and Mogollon Caldera- A Thesis Looking For A Student: New Mexico Geology, v. 23, no. 2, p. 55*). A third mappable member, long suspected, but previously undefined, is now confirmed to underlie the middle Whitewater Creek and the upper Cooney Canyon members. This lower member, provisionally designated the South Fork Member, for outcrops south of the junction of the South Fork and main Whitewater Creek, consists of as much as 300 meters of silicic ash-flow tuff (ignimbrite) and a total of 50 to 100 meters of interlayered basaltic lava flows; and is interpreted as an early, episodic member erupted prior to the major caldera-forming eruptions of the Whitewater Creek and Cooney Canyon Members.

Whereas, the Whitewater Creek Member is a simple cooling unit, 100 to 200 meters thick, whose catastrophic eruption is interpreted to have caused the initial subsidence of the proposed Mogollon caldera, the overlying Cooney Canyon Member consists of a dozen or more compound cooling units, several tens of meters thick, erupted during continued subsidence. Several thin, <1 to ~10 meters thick, dark-colored, fine to coarse-grained volcaniclastic sandstone layers, which are interbedded with the ignimbrites of the Cooney Canyon Member, have long presented problems as to their origin and provenance either as true waterlain sedimentary deposits, or volcanic pyroclastic deposits. New petrographic evidence in the form of unbroken bubble-wall shards, pumice, and possible accretionary lapilli, provide seemingly indisputable evidence of a pyroclastic fall origin for at least some, if not all, of these deposits. Importance of this interpretation cannot be overemphasized with respect to the existence of a Mogollon caldera, for if correct, it confirms the continuity of pyroclastic eruptions, without appreciable time gaps from the last ignimbrite eruptions of the South Fork Member to the final eruptions of the Cooney Canyon Member, representing a total thickness of Cooney Tuff on the order of 1000 meters.

A major southeast trending fault near the south end of the Catwalk National Recreation Trail, on the east side of Whitewater Creek, places Whitewater Creek and Cooney Canyon ignimbrite members of Cooney Tuff down against ignimbrites and interlayered basaltic lava flows of the South Fork Member. This fault, which is cut off at Whitewater Creek by the frontal fault of the Mogollon Rang in this area, is interpreted as a possible, if not likely, segment of the structural wall of the Mogollon caldera, the proposed source of the ~34 MY old Cooney Tuff.

TEMPERATURE MEASUREMENTS IN THE VADOSE ZONE AND RECENT CLIMATE CHANGE IN THE ALBUQUERQUE BASIN

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Climate changes can affect mean annual air temperature, which in turn can be reflected in ground surface temperature change. Below several meters depth, heat transfer in the vadose zones of the southwestern United States is likely dominated by conduction. Therefore, in the Albuquerque Basin, vadose zones of about 100 m and deeper should afford a unique opportunity to examine surface temperature changes over the past several centuries. Increased surface temperatures should be defined by concave upward temperature-depth profiles. In 1996 and 1997 temperatures were measured in the vadose zone at seven sites near the southwest corner of Kirtland Air Force Base. These data were taken with a conventional sensor having a relatively long time constant in air. Although some of the data suggest possible surface warming over the past few decades, the data are quite variable in character even though the measurement sites are within a few kilometers. Recent measurements in 2003 at three additional sites in the Albuquerque Basin, one site within a few kilometers of the Kirtland Air Force Base sites, have been made with a new sensor having a relatively fast time response in air. Interestingly, the recent data at these three sites show little if any surface temperature change. More subsurface temperatures are needed to consider possible surface temperature change and climate change in the Albuquerque Basin. Variations in precipitation, evaporation, and vegetation shading should be considered in terms of their potential effects on surface temperature. At present the influence of these factors on surface temperature cannot be ruled out. Therefore, the thermal effect of recent climate change may be partially masked in the deserts of the southwestern United States.

POST-RESURGENCE LAKES OF THE VALLES CALDERA, NEW MEXICO

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Valles Caldera has contained multiple lakes since resurgence at >1.1 Ma. The three youngest lakes recognized from geologic mapping formed subsequent to the three youngest episodes of volcanism. The youngest was formed at *ca*. 50-60 ka by burial of the East Fork Jemez River canyon by thick deposits of El Cajete pumice. This lake was 10 km long and 5 km wide, covering much of the Valle Grande; beach ridges, spits, and wave-cut shorelines mark its extent. The El Cajete-dammed lake probably drained rapidly once an outlet was established, sending an outburst flood down San Diego Canyon. An older, larger lake also occupied much of the Valle Grande, formed by damming of the East Fork by *ca*. 520 ka South Mountain rhyolite flows. This lake was longer lived, and well logs indicate at least 85 m of clayey diatom-rich sediment may be associated with this lake. An additional lake occupied most of the northern moat of the caldera, extending about 19 km eastward from a *ca*. 580 ka San Antonio Mountain rhyolite dam into Valles San Antonio, San Luis, Santa Rosa, and Toledo. The part of the lake in Valle Toledo completely filled with diatom-rich sediment and is conformably overlain by fluvial deposits. Downstream, however, fluvial terraces unconformably overlie lacustrine sediments and indicate draining before the lake filled with sediment, caused by incision of the outlet. Surface and subsurface data indicate the presence of additional post-resurgence lakes in the caldera, although their ages and characteristics are less well constrained.

THE SCLEROTIC RING OF THE LATE TRIASSIC THEROPOD DINOSAUR *COELOPHYSIS*

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We report the first complete sclerotic ring of the Triassic dinosaur *Coelophysis bauri* from the New Mexico Museum of Natural History's Whitaker Quarry block, C-8-82. The block is from the Apachean Rock Point Formation of the Chinle Group in north-central New Mexico. Specimen P-42200 is a gracile morph of *Coelophysis* with a skull length of 123 mm, which places it in the large juvenile or small gracile adult range. The anterior orbit and sclerotic ring show no deformation, but the posterior portions show slight elongation in the caudal direction. The orbit has a mean diameter of 31 mm and contains ~20 articulated ossicles preserved in a ring measuring ~21 mm outside diameter, and ~12 mm inside diameter. As preserved, the ring occludes 63% of the orbit. Individual ossicles are sub-trapezoidal to sub-triangular, except for the nasal and temporal ossicles, which are more elongate oval in shape. The ossicles show a sigmoid radial cross section. The ossicles typically measure ~7 mm wide (circumferentially) and ~5 mm high (radially), with the wider bases of the elements bounding the corneal aperture. The elongate nasal and temporal ossicles are ~10 to 12 mm long and ~5 mm high.

Colbert (1989, Museum of Northern Arizona Bull. 59) observed four or five partially articulated sclerotic ossicles in a Harvard University specimen of *Coelophysis* (MCZ 4327) and extrapolated that there would be a total of 20. He estimated that they were arranged with the dorsal and ventral elements being outermost in a series of four sequentially overlapping plates that proceeded anteriorly and posteriorly and ultimately overlapped the nasal and temporal ossicles from both the top and bottom. This arrangement has mirror-symmetry antero-posteriorly and dorso-ventrally. Our discovery demonstrates that Colbert's extrapolations were essentially correct.

The ring anatomy revealed by this specimen offers rare insight into visual acuity and accommodation in the eye of *Coelophysis*. Based on analysis of the ring and orbit morphology and comparison to extant reptile and bird outgroups, we conclude that *Coelophysis* was a diurnal, visually oriented predator.

MICROSTRATIGRAPHY AND FAUNA OF A SINGLE BLOCK FROM THE LATE TRIASSIC WHITAKER (*COELOPHYSIS*) QUARRY (ROCK POINT FORMATION: CHINLE GROUP), NORTH-CENTRAL NEW MEXICO

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New Mexico Museum of Natural History's Apachean age Whitaker Quarry block (C-8-82) has been under preparation since September, 2003. The volume of the 2-m-long, 1.4-m-wide, and 1.1-m-thick block is ~2 m^3. Microstratigraphic study of the block shows two fining upward sequences above a basal sandy siltstone. The upper 5 cm of this bed contains the ostracode, *Darwinula*, and the conchostracan, *Lioestheria*, that likely indicate a topographic low containing a (probably ephemeral) pond. This is the first report of calcareous microfossils from the Whitaker Quarry. The basal coarse silt and very fine sand of sequence one fines up to very fine silt with clay lenses. Sequence two has a basal matrix-supported conglomerate that fines up to very fine silt. All beds above the invertebrates contain elongate rip-up mud clasts that are closely aligned and trend WNW-ESE. These flow indicators agree well with the established scheme of a northwest-draining Chinle basin. The block stratigraphy indicates two flood events of increasing energy.

To date, the fauna from the block comprises the aforementioned invertebrates; the redfieldiid fish *Synorichthyes,* the coelacanth fish *Chinlea*, the archosauromorph *Vancleavea*, a phytosaur, probably pertaining to *Redondasaurus gregorii*, and the theropod dinosaur *Coelophysis bauri*. Additionally, an indeterminate redfieldiid-like fish, several isolated enigmatic scutes, and teeth of a possible sphenosuchian or ornithischian dinosaur are present. In general, the fossil material coarsens up throughout the block. Sequence one contains (ascending order) the invertebrates, fish scales and bones, whole fish, non-dinosaurian tetrapods and very small juvenile dinosaurs. Sequence two contains the larger juvenile and adult dinosaurs. The invertebrates constitute the only previously undocumented fauna from the Whitaker quarry.

^{40}AR/^{39}AR K-FELDSPAR THERMOCHRONOLOGY OF PROTEROZOIC TO DEVONIAN METASOMATIC K-FELDSPAR IN BASEMENT ROCKS, SANGRE DE CRISTO RANGE, NEW MEXICO, USA

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Precambrian amphibolite, tonalite, and granodiorite basement lithologies in the southern Sangre de Cristo Range, New Mexico are extensively K-metasomatized, crosscut by K-feldspar + epidote veinlets, and exhibit microtextures indicative of pervasive in situ replacement of primary igneous Na-plagioclase by K-feldspar + epidote. ^{40}Ar/^{39}Ar thermochronology of metasomatic K-feldspar in the Pecos River valley yields complex age spectra with a diversity of apparent ages ranging from ~420 Ma to older than 1100 Ma that could suggest several discrete metasomatic episodes. Interestingly, coexisting plutonic microcline and metasomatic K-feldspar do not yield similar age spectra or apparent ages. In fact, K-feldspar from one highly metasomatized 100 m^2 outcrop preserve the regional post-Grenville (*ca*. 1100 Ma) cooling signature similar to unaltered samples across the Sangre de Cristo Range while metasomatic K-feldspar exhibit undualatory behavior and total gas ages of *ca*. 800 Ma, 700 Ma, 600 Ma, and 420 Ma. The ability of the K-feldspar to retain distinct apparent ages and argon distributions despite their proximity does not favor a high temperature (>200°C) regional event during the Paleozoic. In another metasomatized location, older metasomatic ages may reflect locally higher temperature fluids, as K-feldspar from a *ca*. 1.4 Ga pegmatite is completely reset to an apparent age of *ca*. 800 Ma. The alternative, which is preferable given the complications of sustaining a hydrothermal system with discrete high and low temperature regimes on the meter scale, is that the intense chemical environment during metasomatism is responsible for partial to complete resetting of older metasomatic and igneous K-feldspar. This research addresses the ability to interpret Neoproterozoic K-feldspar growth ages from hydrothermally and chemically induced argon loss in older K-feldspar. Distinction between these mechanisms is critical in order to reconcile accurate geologic thermal histories while recognizing the effects of post-crystallization chemical and/or hydrothermal alteration.

PLIOCENE TO PLEISTOCENE LANDSCAPE EVOLUTION OF THE SOUTHWESTERN JEMEZ MOUNTAINS, NEW MEXICO

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Fluvial, debris flow, and colluvial wedge deposits that lie below and within the 1.8 to 1.2 Ma San Diego Canyon and Bandelier tuffs are well exposed in Cañon de San Diego, Virgin Canyon, and Paliza Canyon in the southwestern Jemez Mts. We recognize at least four packages of Pliocene(?) to Pleistocene fluvial sediment. The oldest gravel (Cochiti) is below the San Diego Canyon (SDC) Tuff and rests on rocks ranging from Permian Abo Formation to Miocene Paliza Canyon Andesite. The axial fluvial gravels contain a variety of clasts, including Paliza Canyon volcanic rocks, Proterozoic granitioids and metamorphics, Permian sandstone, and Pedernal Chert. The Proterozoic component decreases toward the east. The presence of Pedernal Chert implies a source region either in the northern Jemez Mts. or in the San Pedro Parks. Paleocurrents indicate a meandering stream with a strong component of southerly paleoflow.

The 1.8 Ma San Diego Canyon Tuff locally filled in a drainage to the west of the modern Jemez River. This drainage persisted during multiple episodes of small-volume SDC eruption, as indicated by erosion of ignimbrites "A" and "B." Abundant pumice clasts in a red sandstone at least 5 m below ignimbrite "A" may signal an early phase of the eruption. Gravels within the SDC Tuff generally have the same composition as the older gravels. In many places, the SDC Tuff gravels are as much as ~300 m above modern grade, but immediately west of Jemez Springs, the gravels are only about ~122 m above modern grade. The paleocurrent directions are highly variable, ranging from northeast to southwest.

Gravels between the SDC Tuff and the 1.6 Ma Otowi member of the Bandelier Tuff are rare and are dominated by clasts of Paliza Canyon volcanics and mafic lithics locally reworked out of the SDC Tuff. The eruption of the Otowi member of the Bandelier Tuff changed the landscape of the southwestern Jemez Mountains dramatically, totally disrupting the pre-existing drainage pattern. Only one pre-Otowi stream, located near the edge of the outflow sheet in Virgin Canyon, quickly became re-established following the eruption. At this remarkable outcrop, the Guaje pumice, the basal unit of the Otowi member, is crossbedded and eroded, indicating that the pumice fell into an active stream. This stream then cut a paleo-Virgin Canyon that is located west of the modern drainage. The Tshirege member of the Bandelier Tuff subsequently filled this paleocanyon, which was nearly as deep as the modern Virgin Canyon.

A considerable paleotopography developed during the 400,000 years between the Bandelier eruptions. Stream gravels dominated by Paliza Canyon volcanic clasts, reworked lithic clasts out of the Otowi, and a few Permian sandstones are preserved between the Bandelier tuffs southeast and northwest of Jemez Springs, on Mesa de Guadalupe, and on Cat Mesa. On Cat Mesa and on Virgin Mesa, Tshirege member filled in SW-trending paleocanyons cut into the Otowi member.

TURONIAN AMMONITES FROM THE UPPER CRETACEOUS D-CROSS MEMBER OF THE MANCOS SHALE, PUERTECITO, SOCORRO COUNTY, NEW MEXICO

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The Turonian ammonite zones of *Scaphites ferronensis*, *Scaphites whitfieldi* and *Prionocyclus novimexicanus* are present in the D-Cross Member of the Mancos Shale near Puertecito, New Mexico. In the study area, the D-Cross Member is approximately 44 meters thick and is underlain by the Fite Ranch Member of the Tres Hermanos Formation and overlain by the Gallup Sandstone. The ammonite fauna includes *Scaphites ferronensis* Cobban, *Scaphites whitfieldi* Cobban, *Prionocyclus novimexicanus* (Marcou) and *Baculites* sp. *Coilopoceras inflatum* Cobban and Hook and *Prionocyclus wyomingensis* Meek have not been recovered from the Puertecito area. *S. ferronensis* is common in a zone of limestone concretions ~ 3 m above the base of the D-Cross. Most of the ammonites occur in concretions in gray shale in a 21-m-thick interval that begins about 10 m above the D-Cross base. *S. whitfieldi* is locally abundant in this interval in small, orange limestone concretions. A third ammonite-producing interval yields *P. novimexicanus* from concretions in a 4-m-thick interval of shale that ends about 3 m below the D-Cross top. At Puertecito, *P. novimexicanus* is common throughout most of the D-Cross section. *Baculites* occurs in the *S. ferronensis* Zone and low in the *S. whitfieldi* Zone. This is the first report of *Baculites* from the D-Cross Member at Puertecito.

The occurrence of the standard zone of *S. ferronensis* near Puertecito indicates correlation of the lowest part of the D-Cross there with the lower part of the D-Cross at Cebollita Mesa and D-Cross Mountain. The occurrence of the standard zone of *S. whitfieldi* in the lower-middle part of the D-Cross at Puertecito indicates correlation with the middle part of the D-Cross at Cebollita Mesa and the very upper part of the Juana Lopez Member at the type and reference sections. The collignoniceratid zone of *P. novimexicanus* also occurs in New Mexico in the D-Cross Member throughout most of the section at Cebollita Mesa, the lower part of the section at D-Cross Mountain, Carthage, and Riley, and at the top of the Juana Lopez Member at the type and reference sections. The *S. ferronensis* Zone is of late middle Turonian age, the *S. whitfieldi* Zone is of early late Turonian age, and the *P. novimexicanus* Zone is of late Turonian age.

FIRST OCCURRENCE OF THE TEIID LIZARD *PENETEIUS* FROM THE LATEST CRETACEOUS NAASHOIBITO MEMBER, KIRTLAND FORMATION, SAN JUAN BASIN, NEW MEXICO

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Three Teeth from the Naashoibito Member, Kirtland Formation can be referred to the unusual teiid lizard *Peneteius*. Specimens NMMNH P-36544, P-41223, and P-41224 were recovered by screen washing from NMMNH locality 4005. The locality 4005 has also yielded isolated teeth mammals including the Lancian index taxon *Essonodon browni*, dinosaurs, crocodilians, and other squamates.

P-41223 represents an isolated lower tooth, P-36544 and P-41224 are upper teeth. Isolated osteoderms (P-36543) from locality 4005 may also belong to the same taxon. The Naashoibito Member *Peneteius* teeth closely resemble the teeth of *P. aquilonius*, from the late Maastrichtian Hell Creek Formation of Montana. *Peneteius* is also known from the late Maastrichtian of Montana and the Campanian of Utah and Texas.

Peneteius has teeth with a more complicated structure than is known for any other lizard. They are convergent on the molariform cheek teeth of mammals. It was a relatively small lizard with an estimated snout to vent length of about 80 mm and may have had an insectivorous diet. Its mammal-like teeth may have allowed it to orally process food more efficiently than other lizards.

PERMIAN STRATIGRAPHY AND CYCLES OF DEPOSITION IN THE LUCERO UPLIFT, CENTRAL NEW MEXICO

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Permian strata exposed in the Lucero uplift of Valencia County, central New Mexico, are a succession of nonmarine and marine sedimentary rocks ~660 m thick that are assigned to the (in ascending order) Abo, Yeso, Glorieta and San Andres formations. The Abo Formation disconformably overlies the upper Virgilian Red Tanks Member of the Bursum Formation and is ~150 m thick, consisting of red-bed mudstone, arkosic sandstone and siltstone. The Yeso Formation conformably overlies the Abo Formation and is ~348 m thick. It can be divided into the lower, Meseta Blanca (~70 m thick) and overlying Los Vallos (~278 m thick) members. The Meseta Blanca Member is quartz-rich sandstone in beds that are trough crossbedded or display climbing ripple laminations. The Los Vallos Member is mostly very fine-grained sandstone, siltstone and gypsum with some thin but persistent beds of dolomite/limestone. The Glorieta Sandstone disconformably overlies the Yeso Formation, is ~53 m thick and consists of quartzose sandstone and a single, 7-m-thick bed of gypsum. It is conformably overlain by the San Andres Formation, which is ~109 m thick and mostly gypsum with lesser amounts of limestone, sandstone and shale. In the Lucero uplift, the Middle Triassic Moenkopi Formation rests disconformably on the San Andres Formation.

Permian rocks in the Lucero uplift represent the transition from fluvial depositional conditions through eolian and tidal flat to shoreface and finally to shallow marine conditions. While there is depositional cyclicity evident in the Yeso, Glorieta and San Andres formations, the cycles in the Lucero uplift section cannot be directly correlated to sea-level cycles documented in West Texas, suggesting that regional tectonic or subsidence-related processes affected deposition of the Leonardian sediments in central New Mexico.

NEW VERTEBRATE FAUNA FROM THE LATE TRIASSIC MESA MONTOSA MEMBER (PETRIFIED FOREST FORMATION: CHINLE GROUP), CHAMA BASIN, NORTH-CENTRAL NEW MEXICO

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The vertebrate fauna of the lower Petrified Forest Formation of the Chinle Group is generally not well known. However, recent work in the Mesa Montosa Member of the Petrified Forest Formation in the Chama basin of north-central New Mexico has greatly expanded the known fauna from this unit. Taxa include the metoposaurid amphibian cf. *Buettneria*, indeterminate phytosaurs (Parasuchidae), the aetosaurs cf. *Typothorax coccinarum* and *Paratypothorax*, the enigmatic archosaur *Vancleavea*, and theropod dinosaurs. An unusual vertebra and a distinctive shell(?) fragment may pertain to a pterosaur and a turtle, respectively, both of which are rare in the Late Triassic. Other fossil material recovered from the Mesa Montosa Member includes numerous coprolites and unionid bivalve shells. The assemblage of vertebrates recovered thus far indicates that the Mesa Montosa Member is Revueltian in age. All of the fossils were collected from a coarse brown sandstone that contains some pebbles and calcrete nodules and is less than a meter below the contact between the Mesa Montosa Member and the overlying Painted Desert Member. These fossils are disarticulated and fragmentary, very few of the fossils are unweathered and many are abraded to the point where identification is impossible. Thus, these fossils represent a time-averaged, attritional assemblage that is most likely derived from the floodplain near the channel system that deposited the sandstone. More complete skeletal elements have been recovered from a green shaley siltstone underlying the sandstone, but fossils are much less abundant in this layer than in the overlying sandstone.