Abstracts

NMGS spring meeting

The New Mexico Geological Society annual spring meeting was held on April 9, 1999, at New Mexico Institute of Mining and Technology, Socorro. Following are the abstracts from all sessions given at that meeting.

SESSION 1—ECONOMIC GEOLOGY TODAY: DEPOSITS, EXPLORATION, AND ENVIRONMENTAL SOLUTIONS

BASE AND PRECIOUS METALS AND URANIUM DEPOSITS IN NEW MEXICO—AN OVERVIEW, by *Virginia T. McLemore*, ginger@gis. nmt.edu, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Pedro de Abalos established the first mining claim in the Fra Cristobal Mountains on March 26, 1685, although mining by the Indians and Spanish occurred before then. Since then, millions of mining claims have been located, and numerous names given to the mining districts. Minerals have been and still are an important contribution to the economy of New Mexico. More than $30 billion worth of minerals have been produced from New Mexico since the early 1800s (Table 1).

A mining district is a group of mines or mineral deposits that occur in a geographically defined area and are defined by geologic criteria. There are >230 mining districts in New Mexico. Districts producing >$20 million worth of cumulative production of metals include: Mogollon, Bayard, Burro Mountains (Tyrone), Fierro–Hanover, Santa Rita (Chino), Pinos Altos, Lordsburg, Willow Creek (Pecos), Chloride, and Magdalena (in actual cumulative dollars at time of production). Most of the uranium production has come from Ambrosia Lake ($4 billion), Laguna ($2 billion), Churchrock–Crownpoint ($400 million), and Smith Lake ($300 million) (Grants uranium district).

These deposits are found in 20 types ranging in age from Proterozoic through Holocene (Table 2). Deposits that have produced significant Ag and/or Au as the primary product are placer, volcanic-epithermal, Great Plains margin, and carbonate-hosted Ag–Mn replacement. Deposits that have produced significant base- and precious-metals production include carbonate-hosted Pb–Zn replacement, Laramide vein, Laramide skarn, porphyry-Cu, and Proterozoic massive-sulfide. Other deposits with minor metals production include Cu–Ag (±U) vein, Rio Grande rift, Mississippi Valley-type, sedimentary-Cu, and vein and replacement deposits in Proterozoic rocks. Most of the uranium in New Mexico was mined from sandstone deposits, with minor production from limestone deposits.

TABLE 2—Types of mineral deposits in New Mexico (North and McLemore, 1986; McLemore, in press; Cox and Singer, 1986).

NMBMMR classification	USGS model number
Placer gold	39a
Placer tin	none
Volcanic-epithermal vein	25b,c,d,e,g, 26b
Rhyolite-hosted tin	25h
Copper (± silver, uranium) vein deposits	none
Great Plains margin	17, 22c, 18a,b, 18d, 39a
Rio Grande rift barite–fluorite–galena (formerly sedimentary–hydrothermal)	none
Carbonate-hosted Pb–Zn replacement	19a, 18c
Carbonate-hosted Ag–Mn replacement	19a,b
Carbonate-hosted Pb–V–Mo replacement	19a
Laramide skarn	18b,c,a
Laramide vein	22c
Porphyry copper	17, 21a
Sedimentary copper	30b
Mississippi Valley-type (MVT) deposits	32a
Replacement iron	18d
Sedimentary iron	34f
Proterozoic volcanogenic massive-sulfide deposits (VMS)	24a,b, 28a
Veins and replacements in Proterozoic rocks	22c, 26b
Syenite/gabbro-hosted Cu–Ag–PGE	none

TABLE 1—Estimated total production of major commodities in New Mexico. Figures are subject to change as more data are obtained (these are minimum estimates).

Commodity	Years of production	Estimated quantity of production	Estimated cumulative value ($)	Quantity in 1997	Value in 1997 ($)	Ranking in U.S. in 1997
Copper	1804–1997	>9.21 million short tons	>12 billion	286,825 short tons	598,071,508	3
Uranium	1948–1997	>171,000 tons	>6.7 billion	216,393 lbs	2,185,557	6
Gold	1848–1997	>3.1 million troy ounces	>363 million	28,709 troy ounces	10,474,832	10
Zinc	1903–1991	>1.51 million short tons	>337 million	none	–	–
Silver	1848–1997	>116 million troy ounces	>247 million	468,742 troy ounces	2,480,477	10
Molybdenum	1931–1997	>120 million pounds	>148 million	8,343,729 lbs	107,851,657	6
Lead	1883–1991	>366,000 short tons	>56.7 million	none	–	–

References

Cox, D. P., and Singer D. A., editors, 1986, Mineral deposit models: U.S. Geological Survey, Bulletin 1693, 379 pp.

McLemore, V. T., in press, Silver and gold in New Mexico: New Mexico Bureau of Mines & Mineral Resources, Resource Map 21, 59 pp., scale 1:1,000,000.

North, R. M., and McLemore, V. T., 1986, Silver and gold occurrences in New Mexico: New Mexico Bureau of Mines & Mineral Resources, Resource Map 15, 32 pp., scale 1:1,000,000.

GEOLOGY AND MINERALOGY OF THE JONES HILL MASSIVE SULFIDE DEPOSIT, PECOS, NEW MEXICO, by *Robert C. Thompson*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *Virginia T. McLemore*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

The Jones Hill massive sulfide deposit is located in the Santa Fe mining district on the border of Santa Fe and San Miguel Counties approximately 15 mi northeast of Santa Fe. The area is part of the Proterozoic Pecos greenstone belt in the southern Sangre de Cristo Mountains. The Jones Hill mine was worked in the 1930s by three adits and one shaft, but no production data exist from that period. The massive sulfide deposit at the Pecos mine 4 mi to the east produced over 2 million tons of ore with average grades of 12.95% zinc, 4.00% lead, 0.078% copper, 3.4 ppm silver, and 0.011 ppm gold before shutting down in 1939 due to bad ground at depth.

The massive sulfide deposits are hosted by Proterozoic volcanic sequences of bimodal mafic-felsic composition. The deposits are generally lensoid and stratabound within a host of metavolcanic and metaclastic rocks. Deposition is from high temperature hydrothermal solutions associated with volcanism. The deposits are typically mined for lead and zinc with precious metals as a byproduct. The Jones Hill deposit is a Proterozoic volcanogenic polymetallic deposit with copper-lead-zinc-silver-gold ore reserves projected to be 12 million tons in two blocks, an upfaulted block projected at 5 million tons and a lower block of 7 million tons of ore. Upper block ore grades average 4.60% zinc, 2.47% copper, and 0.072 ppm gold; the lower block ore grades average 3.81% zinc, and 4.44% copper with an increase in the down-dip direction.

The massive sulfide deposit occurs at the contact between Proterozoic rhyolite domes and overlying metamorphic rocks. The volcanic package was intruded by granite, mineralized, and folded and faulted. There is an angular unconformity between the Proterozoic volcanics and the overlying Paleozoic sediments. The Jones Hill thrust fault then offset the deposit 2,000 ft. The primary ore minerals are sphalerite, galena, and chalcopyrite. Bornite, argentite, molybdenite, proustite, native gold, and tetrahedrite are found in lesser amounts. The sulfide minerals in the gangue material include pyrite, arsenopyrite, and pyrrhotite. The gangue minerals are extensive but basically contain mafic minerals along with quartz, fluorite, kaolinite, sericite, talc, and calcite. Alteration is stronger in the footwall near the ore zone.

QUARTZ VEINS AS PROXIES FOR FLUID PRESSURE EVOLUTION IN THE CONTACT AUREOLE OF THE 1.4 GA SANDIA PLUTON, NEW MEXICO, by *A. Cavosie*, acavosie@unm.edu, *L. Pletsch-Rivera*, *J. Selverstone*, and *Z. Sharp*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131; and *B. Dutrow*, Department of Geology and Geophysics, Louisiana State University, Baton Rouge, LA 70803-4101

A fracture generation model proposed by Dutrow and Norton (1995, JMG 13) predicts that the heating resulting from pluton intrusion into fluid-saturated, low-permeability host rock will repeatedly increase pore fluid pressure and cause multiple fracturing events at individual localities. At conditions of 3 kbar and 800°C, the model predicts the greatest fracture density approximately 100 m from the pluton contact. I used quartz veins as proxies for fracture propagation in a natural contact aureole in order to test the assumptions and predictions made by this model.

The contact aureole of the 1.4 Ga Sandia pluton records peak conditions of around 3 kbar and 750°C. Field observations indicate that quartz veins are most abundant 400–1,000 m from the pluton contact and are rare close to the contact. XRF analyses indicate a 6 wt.% decrease in SiO_2 and an increase in other elements in the host schist immediately adjacent the vein in one sample location, whereas no depletion selvage has been determined in other sample locations. $\delta^{18}O$ values of quartz at ~400 m from the contact are 13.3 per mil in the vein and 13.6 per mil in the host rock.

The spatial distribution of quartz in veins, SiO_2 depletion in vein selvages, and host-rock buffered $\delta^{18}O$ values all support the model prediction that sequential heating of the country rock induced multiple fracturing events via in situ increase in pore fluid pressure. However, the absence of depletion selvages at 3–4 m wide veins suggests far traveled, plutonic fluids. I prefer a model in which initial heating increased the in situ pore fluid pressure initiating fracturing, and produced quartz veins and a new aureole fluid network system; subsequently, pluton-derived fluids would have a conduit to migrate outwards through the aureole. Fluids in the aureole were thus both internally and externally derived, and fracturing events likely resulted initially from buildup of in situ pore fluid pressure followed by an increase in magmatic fluid pressure.

ORE-CONTROLLING FOLDS, TODILTO URANIUM DEPOSITS, GRANTS DISTRICT, NEW MEXICO, by *William R. Berglof*, berglof@ad.umuc.edu, University of Maryland, Asian Division, Unit 5060 Box 0100, APO AP 96328; and *Virginia T. McLemore,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Several different types of folds and fold-like structures, on different scales, affect the Todilto Limestone (Luciano Mesa Member of the Todilto Formation, Lucas et al. 1995), or are present within it, in the Grants uranium district. These include: regional large-scale folds affecting the Todilto and units above and below it; large-scale intraformational folds with mappable axes; mounds or pillow-like structures within the limestone, possibly stromatolites; and several types of small-scale intraformational folds. The latter include sharp folding of varve-like thin bedding; within-layer folds resembling those described elsewhere as "enterolithic”; and micro-folding of thin layers, including the "crinkly" bedding common in the middle and upper portions of the Luciano Mesa Member of the Todilto. The large-scale intraformational folds have clearly influenced the localization of uranium deposits in the Todilto, apparently by providing zones of permeability through which mineralizing solutions moved. Such intraformational folds are conspicuous only in or near known uranium deposits. Not all of the folds are mineralized, but all primary uranium deposits in the Todilto are associated with the folds. Many folds were exposed in mines that are now inaccessible; others are exposed on rim outcrops. Small, isolated uranium deposits distant from Grants (Laguna, Sanostee, and Box Canyon) were also associated with folds of this type.

The origin of the ore-controlling folds has remained controversial since they were first recognized during initial development and mining of Todilto uranium deposits shortly after 1950. An early suggestion that the ore-controlling intraformational folds relate to Laramide tectonic activity seems unlikely, as isotopic dating of uraninite indicates that the deposits formed in Jurassic time shortly after the host rocks were deposited. Evidence of soft-sediment deformation is abundant, consistent with early formation.

One hypothesis is that the weight of encroaching dune sands of the overlying Summerville Formation deformed soft lime muds of the Todilto. Some folds resemble tepees; along with small-scale enterolithic folds, these could relate at least in part to forces of crystallization or hydration of calcite and gypsum. The extensive anhydrite/gypsum beds of the overlying Tonque Arroyo Member are absent where the limestone is mineralized with uranium. Mappable intraformational fold axes may be distributed more or less randomly, or may show a preferred orientation within a small area or single mine; this does not seem to uniquely favor any hypothesis.

Earthquakes occurring during sedimentation are increasingly recognized as a possible cause of soft-sediment structures, sometimes called "seismites," which can develop even on gentle slopes. Tectonic activity during Todilto deposition is possible; active folding appears to have influenced the geometry of mineralized sandstones of the younger Morrison Formation. Some Todilto folds resemble ones occurring in the Pleistocene Lisan Formation along the Dead Sea in Israel and Jordan, believed to be a sedimentological analog of the Todilto in a different tectonic setting. The Lisan folds apparently formed at least in part from seismogenic processes (Marco and Agnon, 1995).

The Todilto uranium deposits are the largest known deposits in limestone and appear to reflect a rare combination of circumstances. Intraformational folds in the Todilto, many of which localize uranium deposits, also appear to represent a somewhat unlikely combination of multiple origins; it is difficult to establish the relative importance of each process.

References

Lucas et al., 1995, New Mexico Geological Society Guidebook 46, pp. 247–255.

Marco and Agnon, 1995, Geology, v. 23, pp. 695–698.

NEW MEXICO'S COAL INDUSTRY, by *Gretchen K. Hoffman*, gretchen@gis.nmt.edu, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM, 87801

Coal production has played a significant role in the economic development of New Mexico beginning in the 1850s and continuing to the present. One of the first documented mines began operating in 1861 at Carthage by the U.S. Army, supplying coal to Fort Craig. With the westward expansion and arrival of the railroads in the 1880s many small coal areas, such as Monero and Madrid, were developed. The mines in these areas supplied coal for the steam engine locomotives and coal and coke to the smelters in the Southwest. Yearly production first exceeded 1 million short tons (st) in 1889. This first upward cycle of coal production peaked in 1918, with over 4 million st of coal. Production dropped after World War I and continued to decline with the economic depression of the 1920s and early 1930s. Conversion to diesel engines by the railroad and cheap natural gas also had an impact on the coal industry, and by 1958 New Mexico coal production had dropped to 86,000 st.

The next upward cycle began in the early 1960s because of the growing population in the Southwest and California and the need for economical energy. Several of the large surface mines operating today (McKinley, Navajo, San Juan) in the San Juan Basin began operation in the 1960s or 1970s. During this time, Kaiser Steel opened the York Canyon underground mine (now Pittsburg and Midway property) in the Raton Basin, which operated until late 1995. The

Lee Ranch (Hanson Natural Resources) and La Plata mines (BHP/San Juan Coal) in the San Juan Basin began production in the 1980s. Today, all of New Mexico's coal mines are surface operations. All of these are dragline operations except for La Plata, which is a truck and shovel operation. San Juan mine started a pilot underground mine in 1997.

Most of the coal from New Mexico is used for electrical generation. Two-thirds of the state's coal production is consumed by the three generating stations (San Juan, Four Corners, Escalante) located in northwestern New Mexico. Half of the electricity produced here is sent over transmission lines to California and Arizona. The remaining coal produced in New Mexico is shipped by rail to generating stations in Arizona from Pittsburg and Midway's (P&M) McKinley mine and Hanson Natural Resource's Lee Ranch mine. P&M's Ancho surface mine near Raton ships coal by rail to Wisconsin.

New Mexico's 1997 coal production was 26.77 million st, up 8% from the previous year's production. New Mexico ranks 13th in coal production for the nation. Wyoming is first with ten times the production of New Mexico. Coal is one of the four mineral fuels produced in New Mexico, ranking third in value behind natural gas (including coalbed methane) and crude oil. Total revenues from coal were $34.3 million in 1997. The majority of these revenues from coal go into funds that support public schools and education. The coal industry is also a major employer in San Juan and McKinley Counties.

Coal resources underlie 20% (15 million acres) of the state's total area. Surface minable coal reserves for the San Juan Basin have recently been estimated by NMBMMR at 6.35 billion st. The Department of Energy estimates an additional 0.75 billion st of surface minable coal in the Raton Basin. These reserves are low-sulfur coals of subbituminous to bituminous rank that have potential for development.

New Mexico coal costs are high; average price per ton is $22.64 for 1997, compared to $6/ton for Wyoming coal. Cost factors are ratio of seam thickness to amount of overburden, health and safety regulations, and reclamation costs. New Mexico coal can not easily compete with Wyoming coal because of the tremendous difference in seam thickness and the lack of an integrated rail network, particularly in the San Juan Basin. Cost of mining and transportation are significant economic factors, particularly because of the deregulation of the power industry. These changes are requiring the New Mexico coal mining industry to be as competitive as possible.

INDUSTRIAL MINERAL PRODUCTION AND POTENTIAL IN NEW MEXICO, by *James M. Barker* and *George S. Austin*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Industrial minerals, rocks, and materials are nonmetallic commodities (IM hereafter). Some produced in New Mexico lead the nation in several categories, and all are important to the economy of the state. Potential for new economic IM deposits is high for certain commodities, but regulation kept exploration and development very low in the 1990s.

New Mexico leads the nation in production of potash, perlite, and zeolite. It is 2nd in pumice and mica and 3rd in humate. In 1996, New Mexico ranked 12th nationally for nonfuel mineral production at about $434 million or 45% of the estimated total value of $963 million reported by the U.S. Geological Survey. This contrasts with national totals where metals are about $^1/_3$ and nonmetals about $^2/_3$ of total value. New Mexico differs because population is low (small local market) while the state is large in area (many possible deposits) and remote (transport costs to distant markets dominate IM economics). Additional IMs produced in New Mexico are aggregate (sand and gravel; crushed stone), cement, gypsum, dimension stone (travertine and limestone), salt, scoria and cinders, and clay (Table 1).

Potential is high for potash and salt, perlite, zeolite, pumice, and humate. The potash- and salt-producing area in southeastern New Mexico is a small part of the surrounding lower-grade potash resource. Deeper potash may be developed through technology. Perlite and zeolite potential is high in the volcanic terrane of southwestern New Mexico where several deposits have been drilled or had minor production. Humate is abundant in the San Juan Basin in northwestern New Mexico at weathered coal outcrops and in some carbonaceous shale. High-calcium limestone, limestone, and gypsum are abundant in the southern $^2/_3$ of the state, but these sources are often distant from consumption centers. Sand and gravel are abundant along the Rio Grande but are locally restricted near urban areas, which raises delivered cost; other areas use crushed stone or caliche, both of which have moderate to high potential.

Potential is moderate for alunite (possible potash/aluminum co-products), stone, silica, garnet, sulfur, barite, fluorite, feldspar, nepheline syenite, pegmatite minerals, sulfur, and diatomite. Clay deposits are generally sparse in New Mexico, but common clay is used locally for pottery, brick, or adobe. Potential is low for borates and most other IMs.

Table 1—Estimated industrial mineral volume and value for 1996 by New Mexico producers.

Industrial mineral commodity (data may be rounded)	Volume '000 mt	Value '000 US$	Price US$/mt	POTENTIAL and comments
Cement (est.)	455	29,575	65.00	HIGH for limestone, cement supply adequate
Clay, common	32	165	5.16	LOW for large deposits, locally common
Dimension stone	<2	210	128.79	HIGH, local demand is low
Gypsum (est.)	600	4,260	7.10	HIGH, mainly in south-central NM
Humate	16	960	60.00	HIGH, large resource, mainly northwest NM
Mica	20	4,400	220.00	MODERATE, mainly north-central NM
Perlite (est.)	600	17,520	29.20	HIGH, large resource, mainly southwest NM
Potash	2,430	225,000	92.59	HIGH, large resource, deep, southeast NM
Salt (est.)	315	15,750	50.00	HIGH, mainly southeast NM
Pumice and pumicite	102	527	5.17	HIGH, large resource, north-central NM
Sand and gravel	9,880	48,500	4.91	HIGH, large resource, urban resource lower
Concrete & concrete products	1,580	9,450	5.97	Highway and building construction
Asphaltic concrete	500	3,200	6.40	Highway construction
Road base & coverings	885	4,150	4.69	Highway construction
Fill	320	627	1.96	Highway and building construction
Other	6,595	31,073	4.71	Highway, buildings, and landscaping
Stone, crushed	3,480	18,850	5.42	HIGH, mainly in eastern NM
Limestone	1,350	6,090	4.50	Abundant in southern $^2/_3$ of NM
"Granite"	1,490	9,240	6.20	Abundant in northern NM
Cinder, scoria	283	2,170	7.66	Hundreds of volcanic cones western NM
Other stone	357	1,382	3.87	Basalt (traprock), quartzite, caliche and others
Zeolite (est.)	15	1,125	75.00	HIGH, mainly southwest NM
TOTAL	31,307	434,224	13.87	Average price (unweighted)

Sources: US Geological Survey, NM Bureau of Mines & Mineral Resources, NM Energy & Natural Resources Department, unpublished files, company data and estimates (est.). st = mt x 1.1023114; $st = $mt/1.1023114

THE APPLICATIONS OF JAROSITE GEOCHRONOLOGY AND STABLE ISOTOPE GEOCHEMISTRY TO ORE DEPOSIT GENESIS AND WEATHERING—SOME EXAMPLES FROM THE RIO GRANDE RIFT, by *Virgil W. Lueth*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801; *Robert O. Rye,* U.S. Geological Survey, Denver Federal Center, Denver, CO 80225; and *Lisa Peters,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Jarosite, $KFe_3(SO_4)_2(OH)_6$, and other K-bearing minerals in the alunite group, can be dated by K/Ar and $^{40}Ar/^{39}Ar$ techniques and contain OH and SO_4 groups that can provide four stable isotope analyses: δD, $\delta^{18}O_{SO4}$, $\delta^{18}O_{OH}$, and $\delta^{34}S$. Age dating and analysis of these isotopic parameters can provide information on the genesis and natural destruction of the deposits by weathering. This information in turn can provide insight into the climatic, geomorphic, and tectonic evolution of an area, as well as the hydrologic controls on present day water quality. A number of jarosite occurrences in the Rio Grande rift have been studied, and preliminary results are reported here.

Geochronologic and stable-isotope studies of supergene jarosite are underway at the copper porphyry deposits in the Organ and Jarilla Mountains on the southeast margin of the rift. These studies are patterned after the work at Creede, Colorado, by Rye et al. (1993). Jarosite and alunite can be used to define the hydrogeochemical environment of supergene jarosite and alunite mineralization, record the age of paleowater tables, reconstruct climate, geomorphic, and tectonic history of the area. Sulfur isotopes trace sulfur to precursor sulfide sources. Hydrogen and oxygen isotopes can be used to infer climate changes during the course of supergene oxidation. The ages and distribution of jarosite and alunite in time and space define periods of uplift related to tectonic events.

An extensive geochronological and stable-isotope study of jarosite at the Copiapo mine, Doña Ana County, New Mexico, has defined a new mode of occurrence—hydrothermal jarosite related to sour gas from sedimentary basins. Mineralization is hosted by a fault cutting Pennsylvanian-age limestone and consists of a replacement body with sequential deposition of halloysite, fluorite, prosopite, gypsum, hematite, jarosite and natrojarosite. $^{40}Ar/^{39}Ar$ age dates on hydrothermal jarosite and natrojarosite display a narrow range of apparent ages from 5.0 ± 0.12 to 4.5 ± 0.16 Ma with the natrojarosite consistently younger. Low sulfur isotope values for the jarosites ($\delta^{34}S$ = –16 to –24) indicate a basin-derived source of H_2S with subsequent oxidation during mineralization. Hydrogen (δD_{smow} = –64 to –96) and oxygen isotope ($\delta^{18}O_{smow}$ = –4 to –10) values of parent waters indicate an exchanged meteoric water origin typical of basin derived brines similar to the deep saline ground waters found in the basins today. Calculated temperature of formation, from the fractionation of ^{18}O between the SO_4 and OH sites in many of the jarosites, is approximately 130° C.

Analysis of jarosite from the Hansonburg deposits, Socorro County, New Mexico, reveals a range of apparent ages from 7.9 ± 0.85 Ma to 1.63 ± 0.06 Ma. Each specific age of jarosite mineralization contains a unique mineral paragenesis and distinct stable-isotope signatures. Both hydrothermal and supergene jarosites are present. Hansonburg, Copiapo, and many other jarosite-bearing deposits along the rift contain abundant hydrothermal fluorite, suggesting that they have fundamentally similar origins controlled by tectonic events, climate, and the evolution of brines and sour gas in sedimentary basins.

Reference

Rye, R. O., Bethke, P. M., Lanphere, M. A., and Steven, T. A., 1993, Age and stable isotope systematics of supergene alunite and jarosite from the Creede mining district, Colorado: implications for supergene processes and Neogene geomorphic evolution and climate of the southern Rocky Mountains: Geological Society of America Abstracts and Programs, v. 25, p. A-274.

COPPER OXIDE DEVELOPMENT IN ARID ENVIRONMENTS, by *Chadwick J. Spencer*, cspencer@nmt.edu, and *William X. Chávez, Jr.*, wxchavez@nmt.edu, Department of Mineral Engineering, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Copper oxides are presently a topic of great interest in the mining and metallurgical industry because of the ease with which they can be leached and the resulting low cost of copper extraction. Copper oxide minerals occur in the oxidized zone of porphyry copper deposits as a result of the oxidation of hypogene copper sulfides, and of former enrichment zones as a result of in situ oxidation of "enrichment blankets." The formation of copper oxide minerals can occur in any climate, but extremely arid conditions engender the formation of exceptionally deep oxidized zones as a result of sparse flushing with surface water and very deep phreatic zones. Oxide zones of laterally continuous copper oxide development in extremely arid environments have been noted as deep as 500 m below the present topographic surface.

The depth of the local phreatic zone, in general, controls the depth of oxidation. Oxidizing conditions persist into the phreatic zone, although the oxygenated water at depth is very reduced compared to the near-surface water. Reducing conditions persist into the oxidized volume as well, resulting from capillary action moving reduced water along fractures. As a result of the channelized fracture flow and capillary action a vadose zone is formed in which a combination of sulfide and oxide minerals are stable.

Acid conditions are created as oxygenated ground water migrates, especially along fractures, and oxidizes sulfide minerals. The result of this is the formation of oxide and sulfate minerals that are dissolved and transported by periodic flushing into reduced rock volumes where supergene sulfide minerals form. If the local phreatic zone is lowered and if the sulfide minerals experience in situ oxidation, the result will be a geochemically thick copper oxide zone.

The copper oxide minerals that form are a function of local pH conditions within the deposit. Chalcanthite and kröhnkite, along with a series of iron oxides, occur in very acid conditions; these minerals are very water-soluble and tend to be redissolved, surrendering copper to copper oxide minerals such as antlerite and brochantite. In moderate pH conditions minerals such as neotocite, copper pitch, and cuprite are stable. Conditions favorable for malachite and azurite exist when there is a sufficient amount of reactive carbonate material in the wall rock or sufficient carbonate in solution. Chrysocolla will form if there is adequate silica in solution.

SAMPLING PROTOCOL FOR MINE WASTE ROCK PILE CHARACTERIZATION IN THE HILLSBORO MINING DISTRICT, SIERRA COUNTY, NEW MEXICO, by *Erik A. Munroe*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; *Virginia T. McLemore,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801; and *Philip Kyle*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Mine waste rock piles are anthropogenically created landforms in mining areas that are derived from open pit and underground mining methods. These waste rock piles exhibit a diverse mineralogy and geochemistry. In addition to the mineral and chemical heterogeneities, the waste rock piles contain variable grain sizes. There are 100,000s of waste rock piles in New Mexico of varying size and composition. One of the controversial problems facing scientists today is how to sample these waste rock piles quickly and economically in order to adequately assess and prioritize environmental hazards.

A sampling strategy was developed to geochemically characterize four mine waste rock piles in the Hillsboro mining district in Sierra County, New Mexico. The piles represented four different mineral deposits and include: a placer gold waste rock pile (Site A), a Laramide polymetallic vein waste rock pile (Site B), a carbonate-hosted Pb–Zn waste rock pile (Site C), and a carbonate-hosted Ag–Mn waste rock pile (Site D). The waste rock piles have highly variable grain sizes. Chemical analyses of six size fractions indicated the less than 0.25 mm mesh typically contained the highest metal concentrations. In addition to each of the grain size fractions, chemical heterogeneity is found within an entire waste rock pile. As an example, 45 samples were analyzed by XRF for each of the sample sites within a grid overlying the Laramide polymetallic vein waste rock pile (Site B). Copper values range from 460 to 2700 ppm, lead from 73 to 730 ppm, zinc from 120 to 1400 ppm, and arsenic from 4 to 76 ppm.

Each of the four waste rock piles was sampled using unique grids that conformed to their respective dimensions. To ensure equal treatment of the samples, sampling was performed using a less than 0.25 mm stainless steel sieve. Each of the waste rock piles was sampled with densities of 15, 30, and 45 samples within each of the respective grids. This study indicates that heterogeneous mine waste rock piles can be adequately sampled and chemically characterized by homogenizing samples collected from a grid containing 15–30 sample cells.

MINE WASTE ROCK PILE MINERALOGY AND GEOCHEMISTRY IN SELECT AREAS OF THE HILLSBORO MINING DISTRICT, SIERRA COUNTY, NEW MEXICO: INSIGHTS INTO METAL MOBILITY, by *Erik A. Munroe*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; *Virginia T. McLemore*, and *Nelia Dunbar*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

In New Mexico, there are at least 100,000 abandoned mine waste rock piles with widely ranging mineralogical and geochemical compositions. To better understand the environmental implications of metal mobility in regions of minimal precipitation (< 250 mm/year) a mineralogical and geochemical study was implemented for five mine waste rock piles, some of which contained sulfides, as well as the drainage systems from these areas in the Hillsboro mining district. Furthermore, this study will give insight into the mineralogical mechanisms governing metal mobility in arid environments.

The average metal content of a Laramide

vein waste rock pile is 1,200 ppm copper, 230 ppm lead, 550 ppm zinc, and 26 ppm arsenic, but a stream sediment sample directly below the area contains 190 ppm copper, 52 ppm lead, 150 ppm zinc, and 8 ppm arsenic. The mineralogical assemblage of the same Laramide vein waste rock pile consists of (in order of abundance) quartz, albite, microcline, chlorite, illite, hornblende, muscovite, pyrite, chalcopyrite, hematite, minor bornite, chalcanthite, and actinolite. The stream sediment contains igneous rock fragments, quartz, albite, chlorite, hematite, minor pyrite, calcite, gypsum, and cuprite.

Mineralogical characteristics of mineral grains and their weathering rind products were examined with the electron microprobe to examine the chemical breakdown of minerals that release metals to the environment. Several minerals have weathering rinds of different mineralogical and chemical compositions than their cores. Pyrite and chalcopyrite appear to be the most reactive to surficial weathering and tend to show the thickest weathering rinds. Chemical composition of a pyrite core/rind transect showed iron concentration increased from 46% to 66% while sulfur decreased from 54% to 2%. Chemical composition of a chalcopyrite core/rind transect showed copper concentration decreased from 33% to 3%, iron increased from 30% to 58%, and sulfur decreased from 34% to 0.3%. Sulfur lost from the system will be removed by the formation of sulfuric acid after oxidation occurs. Clays, iron oxide/hydroxide, iron sulfate, and primary texture rinds exist in the waste rock piles analyzed.

Metal ratios of mine waste rock pile/stream sediment sample are copper 6.3, lead 4.4, zinc 3.6, and arsenic 3.2. Metal mobility, therefore, can be described in the following manner: As > Zn > Pb > Cu. Supergene oxidation of galena created a cerrusite rind, which effectively shields the galena grain from further weathering and release of lead and sulfur. This may decrease the level of lead mobility depending on the overall acid producing capability of the waste rock pile. Metals present in sulfide mineral weathering rinds are in higher concentrations than those in rinds surrounding oxides or silicates. Oxides and silicates need more time and water to break down and showed at most a minimal clay rind. This indicates metal mobility is higher in the sulfide minerals, which therefore enhances metal availability to the environment.

SESSION 2—PRECAMBRIAN GEOLOGY AND VOLCANOLOGY

WHERE HAVE ALL THE OLD MICAS GONE?, by *M. T. Heizler*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801; *K. E. Karlstrom* and *M. J. Timmons*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Single crystal $^{40}Ar/^{39}Ar$ age determinations of detrital muscovites from several localities within the Precambrian Grand Canyon Supergroup yield a complex array of crystal ages. The Grand Canyon Supergroup is exposed exclusively in eastern Grand Canyon and rests with angular unconformity on top of the Granite Gorge Metamorphic Suite. The Supergroup is grossly sub-divided into the Unkar Group, which is unconformably overlain by the Nankoweap Formation, which in turn is unconformably overlain by the Chuar Group. Age constraints on these important Precambrian sediments are limited; however, the top of the Unkar Group includes the ca. 1.1 Ga Cardenas Basalts, thereby placing a minimum age on the Unkar Group. The Chuar Group is constrained to be younger than the Cardenas Basalts and older than Middle Cambrian (Tapeats Sandstone).

Muscovite from four separate samples of the Dox Formation within the Unkar Group were analyzed. Single crystal laser fusion (SCLF) analyses were conducted on 110 crystals, and additionally 19 individual crystals were incrementally heated for age spectrum analysis. Forty-seven crystals from the Tapeats Sandstone were dated with SCLF methods, and 7 grains were step heated. Fifteen muscovite crystals were also analyzed from the Sixtymile Formation, which unconformably caps the Chuar Group. The majority of the SCLF results from the Dox Formation yield ages between 1,050 and 1,200 Ma with a strong peak at ca. 1,100 Ma. The crystals from the Sixtymile Formation are typically between 1,200 and 1,400 Ma, but one grain is ~650 Ma and one ~1,000 Ma. Traditionally, the youngest detrital age is interpreted to be a maximum estimate for the sedimentary age thereby suggesting that the Dox Formation is younger than ~1,100 Ma and that the Sixtymile Formation is potentially as young as 650 Ma. Considering that the Supergroup sediments overlie Precambrian crystalline rocks with muscovite cooling ages between 1,400 to 1,600 Ma, it is intriguing that very few detrital grains yield these ages. Moreover, the grouping of ages at ca. 1,100 Ma is conspicuously near the age of the Cardenas Basalts and other 1,100 Ma intrusive rocks. These observations suggest that argon loss from the detrital muscovites may have occurred since deposition, and therefore traditional interpretations to constrain sedimentary ages may be inappropriate.

The age spectrum analyses of the single grains provide additional insight towards the meaning of the overall young SCLF results. One sample of the Dox Formation shows copper mineralization, and initial heating steps of the age spectra yield ages between 200 to 500 Ma, clearly indicating post-deposition argon loss. However, age spectra for other samples of the Dox Formation do not yield ages below ca. 1,100 Ma. Combined, these results are interpreted to record two alteration events, one at ca. 1,100 Ma and one in the Phanerozoic (?Laramide?).

The geochronologic results demonstrate argon loss since deposition but can not discern between thermal resetting versus loss associated with alteration or diagenesis. Electron microprobe analyses suggest that the muscovites from the Dox samples have been recrystallized. Additionally, the microprobe reveals that the sandstone matrix is rich in K and Fe, possibly reflecting a significant fluid influx event. This event is probably ca. 1,100 Ma and may be associated with the igneous activity that occurred at this time. Combined, the geochronological results indicate that the Dox Formation is older than 1,100 Ma and that the young (~650 Ma) ages from the Sixtymile Formation may be the result of argon loss and therefore can not be used to argue that the Sixtymile Formation is younger than 650 Ma.

QUARTZ–KYANITE PODS IN PROTEROZOIC ROCKS IN NORTHERN NEW MEXICO: SHEAR ZONE FORMATION ALONG AN OLDER HYDROTHERMAL ALTERATION HORIZON, by *Mary C. Simmons*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Large quartz–kyanite schist pods of unusual bulk composition enclosed by shells of sericite schist occur within the 1.7 Ga Vadito Group metarhyolite in northern New Mexico. These pods are discontinuous, lenticular, symmetrically zoned, and are stratiform within a map-scale sericitic horizon. Previous studies have not resolved whether the high-Al bulk compositions of the quartz–kyanite pods were the result of weathering, hydrothermal alteration, or shearing. Geochemical differences between the quartz–kyanite/sericite schist pods and the sericite-rich layer that connects them suggest more than one alteration process. This study uses geochemical, structural, and metamorphic data to evaluate the origin and tectonic evolution of the quartz–kyanite rocks.

Geochemical data from sampling traverses, mineral textures, and map patterns indicate that the quartz–kyanite pods obtained their unusual (high Al, low K, Na, Ca, Fe) compositions through hydrothermal alteration associated with volcanism. Geochemical profiles are symmetrical with depletion of Ca, Na, K, Fe and enrichment of Si toward the center of the alteration zone. Higher K and Fe compositions in the sericite-rich layer that connects the pods suggest a different alteration process. Truncation of stratigraphic map units, grain-size reduction, S–C fabrics, and asymmetric porphyroblasts suggest that this second alteration process was related to a top-to-the-south shearing episode (D_1) along a bedding-subparallel zone before D_2 (N-vergent) deformation produced map-scale folds.

Microstructural studies show that kyanite is an early (S_1) metamorphic mineral produced prior to shearing of the previously altered volcanic rock, shown by alignment and grain-size reduction of kyanite within the earliest fabric (S_1). Subsequent metamorphism and shearing may have enhanced the concentration of silica and aluminum in this zone and linked the pods of altered rock into a map-scale sericite-rich (S_1) shear zone. Other minerals that formed early in the deformational history of these rocks include staurolite, chloritoid, paragonite, and albite, indicating peak P–T conditions of up to ~550°C, ~5 kbar for S_1 fabrics.

ORIGIN OF SPHEROIDAL AND ELLIPSOIDAL FLOW(?) STRUCTURES IN THE BEARWALLOW MOUNTAIN ANDESITE, MOGOLLON–DATIL VOLCANIC FIELD, NEW MEXICO, by *James C. Ratté*, U.S. Geological Survey, P.O. Box 25046, MS-905, Denver, CO 80225

Enigmatic structures in the Bearwallow Mountain Andesite, or Bearwallow Mountain Formation, are here interpreted to be flow features. The Bearwallow Mountain Andesite is a voluminous assemblage of andesitic to basaltic lava flows that covers large areas of the Mogollon–Datil volcanic field of southwestern New Mexico. Flows were erupted from numerous polygenetic, and perhaps some monogenetic, centers best described as shield volcanoes. Many literature references to them as stratovolcanoes seem inappropriate because of their composition, low, domal profiles, and lack of appreciable interlayered pyroclastic material. The Bearwallow volcanoes erupted about 25 million years ago, and many are aligned along predominant northeast–southwest and west-northwest–east-southeast trends believed to reflect early crustal extension that preceded Basin and Range deformation in this area.

The spheroidal and ellipsoidal structures are somewhat uncommon but have been seen at widely separated localities, in lavas from different eruptive centers. They may be most easily observed in road cuts along the National Forest road leading south and east from Reserve to Negrito Creek and in cliffs along the Tularosa River about 2 mi above its confluence with the San Francisco River, in Catron County.

The structures are most conspicuous where they are spheroidal or elliptical in form, but at some places, they appear to grade into ramp structures, as commonly found at flow fronts or where flows traverse uneven topography. Where spheroidal in form, they are commonly 1–5 m in diameter, but the long axes of more ellipsoidal structures may be 10 m long.

Initially, these spheroidal and elliptical features might bring to mind filled lava tubes, but the presence of circumferential, stretched vesicles would seem to rule out that idea. Alternative explanations, gleaned from a summary search of the literature, include accretionary lava balls, lava channel fillings, lava squeeze-ups, lava coils, and structures formed by interaction of lava and water. However, none of these seem to quite fit the ellipsoidal and spheroidal structures in the Bearwallow Mountain Andesite. Then, I came across Kenneth Hamblin's excellent descriptions of lava flows and lava dams in the Grand Canyon in GSA Memoir 183. Dr. Hamblin describes ellipsoidal structures in Flows E and F of the Toroweap lava dam, and his sketch of these features, in his figure 29, closely resembles those in the Bearwallow Mountain Andesite at the Tularosa River locality. However, the features in the Toroweap basalt flows are associated with other structures that Hamblin identified as basalt pillows, some of which are 10–20 m across, and this association led him to attribute the ellipsoidal structures, as well as the giant pillows, to interaction with water, which is supported by the position of the Toroweap flows relative to the Colorado River, past and present. Where the similar structures in the Bearwallow Mountain Andesite are found, there are no obvious relationships with major pre-existing water courses, but further consideration of this possibility may be warranted.

I conclude that the spheroidal and ellipsoidal structures in the Bearwallow Mountain Andesite are probably flow structures because of the encircling, stretched vesicles, and because they appear to grade into more common flow structures such as ramped flow layers. In keeping with the interpretation as flow features, I offer the perhaps outrageous hypothesis that they might be akin to standing waves in water, but because of the much greater viscosity of andesitic and basaltic lava, they are essentially standing waves frozen in space.

Finally, I hope others will find an opportunity to see these interesting flow(?) structures in the Bearwallow Mountain Andesite and look for new evidence to confirm their origin.

CHARACTERISTICS AND ORIGIN OF MELTED XENOLITHS AT VULCAN CONE AT THE ALBUQUERQUE VOLCANOES, by *Kathleen E. McLeroy* and *Gary Smith*, Department of Earth and Planetary Science, University of New Mexico, Albuquerque, NM 87131

Melted xenoliths are present at Vulcan cone, highest of the middle Pleistocene Albuquerque volcanoes. The inclusions at Vulcan cone are light colored, are more than 90% glass, and, in many cases, are extremely vesicular. Petrographic examinations show that the inclusions are about 15–30% rounded quartz grains and glass (locally hydrated to unidentified zeolites) and vesicles.

XRF analyses indicate a SiO_2 content of 84%. This composition is unreasonable for an igneous protolith but, along with the other oxides, is consistent with an arkosic sandstone (70% quartz, 13% K-feldspar, 17% plagioclase [An 28]).

The basalt is not quenched where it is in contact with the exotic melt, leading to the conclusion that the magma had reached thermal equilibrium. In places the melts have thoroughly mingled, and a hybrid liquid appears to have formed. We have found no reference to similar extremely melted sedimentary xenoliths, suggesting unusual conditions for their formation.

Our hypothesis is that extreme melting was a consequence of wet-melting at sufficient depth that the pore water was not expelled but participated in the melting reactions and was incorporated into the newly formed melt. The extreme vesicularity of the ejecta affirms a high dissolved volatile content for the melted xenoliths. Mingling of the two melts also suggests similar viscosity at some point in their combined history, despite striking contrast in silica content. This might also be explained by a high water content for the felsic melt. To test this idea we are currently calculating the viscosity of the two melts for different water contents. These water contents will be compared to experimental haplogranite water solubility data to estimate a depth of melting. This depth will be compared to the inferred stratigraphic section beneath the volcanoes for consideration of potential protolith horizons.

EFFECTS OF SHALLOW BASALTIC INTRUSION INTO SILICIC TEPHRA, GRANTS RIDGE, NEW MEXICO, by *Giday WoldeGabriel*, wgiday@lanl.gov, *Gordon N. Keating*, and *Greg A. Valentine*, Earth and Environmental Sciences Division, Los Alamos National Laboratory, Los Alamos, NM 87545

A shallow basaltic intrusion into chemically homogeneous silicic tephra at depths of <200 m was investigated as part of a natural analog study on the effects of subsurface disposal of high-level radioactive waste. This is an attempt to understand the effects of intrusions into unsaturated zeolitic tuffs that will potentially host high-level radioactive waste. Moreover, the extent of man-made hydrothermal system that could develop from radioactive decaying in a shallow repository is evaluated.

A localized aureole up to 10 m wide developed around a 150-m wide, 2.6 Ma basaltic plug at Grants Ridge, New Mexico. The plug intruded into nonwelded, pumice-rich compositionally homogeneous tuff and volcaniclastic sediments of similar age (3.3 Ma). Color variation (pinkish to orange), strong local contact welding, brecciation, and stoping characterize the host rock within the contact zone. Despite the high-temperature basaltic intrusion, there is no indication for extensive convective heat transfer and pervasive hydrothermal circulation and alteration. The proportion of volcanic glass, loss on ignition (LOI), fluorine, iron, and some trace- and rare-earth-element contents in the host rocks are depleted near the intrusion. Conversely, the degree of devitrification and the potassium content are higher along the contact. Vapor-phase expulsion of elemental species as fluoride, chloride, hydroxide, sulfide, and carbon oxide complexing may have been responsible for the depletion of the elements during the devitrification of silicic glass at near- solidus temperature related to the basaltic intrusion.

The results of finite-difference numerical modeling of the intrusion as a dry, conduction-dominated system agree well with geochemical and mineralogical data. Contact welding of the host rocks apparently occurred at temperatures >700°C under a density-driven lateral load of approximately 1 MPa, corresponding to the observed depth below the former ground surface of <200 m. Other physical changes in the first 10 m of host rock, represented by partial devitrification and color changes, apparently occurred at temperatures of 500–600°C, which probably persisted for up to 55 yrs after the emplacement of the basaltic plug. Devitrification is generally enhanced by the presence of aqueous fluids; however, the abundance of volcanic glass within a short distance (~ 10 m) from the plug is consistent with our inference that the limited water-rock interaction in the nonwelded ignimbrite and fallout was caused by intrusion into unsaturated environment. Our study appears to suggest that basaltic intrusion into nonwelded unsaturated tuffs has localized contact metamorphic effects and insignificant hydrothermal alteration.

SESSION 3—RIFT-RELATED MAGMATISM, SEDIMENTATION, AND TECTONICS

THE LOBO HILL ALKALIC COMPLEX, TORRANCE COUNTY, NM: CAMBRIAN MAGMATISM IN THE NEW MEXICO AULACOGEN, by *N. J. McMillan*, nmcmilla@nmsu.edu, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003; and *V. T. McLemore,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

New analyses of alkalic igneous rocks and carbonatites from the Lobo Hill alkalic complex near Moriarty, NM, provide new evidence for a widespread, early Paleozoic, alkalic igneous event in New Mexico. The complex consists of brick-red, fine-grained syenitic and carbonatitic dikes that intrude the Precambrian basement and clearly crosscut the Precambrian foliations. Previous attempts at radiogenic isotope dating of the Lobo Hill complex were unsatisfactory; however, a new $^{40}Ar/^{39}Ar$ age determination on biotite from a syenite yields an age of 518 ± 5.7 Ma. Syenites have aphanitic porphyritic textures, with altered plagioclase phenocrysts set in felty to intergranular groundmasses; the rocks are almost devoid of ferromagnesian minerals. Textures formed during rapid cooling indicate that the $^{40}Ar/^{39}Ar$ date can be interpreted as the age of emplacement and cooling at shallow depths. Na_2O and K_2O concentrations are highly variable. K_2O/Na_2O ratios vary from 0.34 to 2.96; two samples from the top of the complex have K_2O/Na_2O of ca. 130, have late-stage fluorite and high concentrations of Rb, Pb, Th, and Zn, and record metasomatism at the fringes of the system. Incompatible trace elements Y, Zr, and Nb increase with increasing SiO_2 in the suite, while Ba and Sr decrease, suggesting that fractional crystallization of feldspar was the dominant differentiation process.

The Lobo Hill alkalic complex is one of several similar intrusions of Cambro–Ordovician age in New Mexico and Colorado. Although many of these complexes lack modern age determinations, the well-dated suites include the Florida Mountains alkali feldspar granite in southern New Mexico (503 ± 10 Ma, U–Pb zircon, Evans and Clemons, 1988, AJS, 288:735–752; 491 ± 5 Ma, $^{40}Ar/^{39}Ar$ hornblende, Ervin, 1998, MS thesis, NMSU); the Lemitar carbonatites (449 ± 16, K–Ar biotite, McLemore, 1983, NMGS Guidebook, 34:235–240) in central New Mexico; and a volcanic rock from a depth of about 2,800 m in an oil test well near Tularosa (541 ± 21, K–Ar whole rock; Loring and Armstrong, 1980, Geology, 8:344–348). The chemistry of these rocks and in some cases the short time interval between intrusion and deposition of the overlying Ordovician sedimentary rocks suggest that they were all generated during continental rifting. Thus, we propose that an aulacogen, similar to the Southern Oklahoma aulacogen, existed in New Mexico during Cambrian and Early Ordovician time.

ORIGIN OF THE SYENITIC ROCKS OF THE RED HILLS, SOUTHERN CABALLO MOUNTAINS, NEW MEXICO, IN THE LIGHT OF FIELD, PETROGRAPHIC, AND GEOCHEMICAL STUDIES ACCOMPANIED BY THE COMPARISON WITH TWO PETROGENETIC MODELS, by *S. Pandurang,* spandura @nmsu. edu, *N. J. McMillan,* Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003; and *V. T. McLemore,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

The brick-red, silica-depleted, microcline microperthite syenites of the Red Hills at the Caballo Mountains occur within the Precambrian granites in the form of elongated bodies. The syenites are studied with the aim of determining the petrogenesis with the aid of field studies, petrography, and geochemistry. Field studies include sample collection across a zone of metasomatism and from individual syenite bodies (some containing granite xenoliths). The syenites are being analyzed for major elements and trace elements.

Field observations, petrographic analysis, and literature survey indicate that the petrogenesis of the syenites can be tested by two models. In Model 1 the syenites are magmatic with accompanying metasomatism and formed in a failed rift during Cambrian–Ordovician time (Ervin, S. D., and McMillan, N. J., 1997, Ann. G.S.A. Meeting, Abs. with Prog., p. 231; McLemore, 1986, 37th N.M.G.S. Field Conf. Guidebook, pp. 151–159). Model 2 suggests that the syenites are late-stage hydrothermal alteration products of the granite accompanied by quartz dissolution and replacement (metasomatism) by secondary K-feldspars. Unfortunately, the syenites are devoid of datable minerals, and all the rocks are significantly altered, precluding age determinations.

Modal analysis across two zones of metasomatism (29 samples) indicates an abrupt change in composition across the syenite/granite contact accompanied by a decrease in quartz from 40–0 % and increase in microcline from 1–94%. Petrographic studies of the Red Hills syenite have shown that the alteration of the syenites can be distinguished from that of the granites, based on the changes in primary mineralogy and the type of secondary vug filling (Cathelineau, M., 1986, Journal of Petrology, v. 27: 4, pp. 945–965). Thus, preliminary data support a magmatic origin for the syenites.

ARC ABANDONMENT AS A CAUSE FOR PASSIVE CONTINENTAL RIFTING: COMPARISON OF THE JURASSIC MEXICAN BORDERLAND RIFT AND THE CENOZOIC RIO GRANDE RIFT, by *Timothy F. Lawton* and *Nancy J. McMillan,* Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003

Two rift systems, the late Mesozoic Borderland rift that includes the Bisbee and McCoy Basins and the Cenozoic Rio Grande rift, in the southern Cordillera of North America formed along the inner flanks of former continental-margin arcs. Both rift systems were initiated when arc magmatism abandoned its former inboard extent as a result of retrograde motion of the subducted slab. Similarities in the tectonic and geochemical stratigraphy preceding and during crustal extension of each rift system suggest a three-phase magmatic-depositional model for the formation of passive continental rifts above a foundering subducted slab. Phase 1: Continental margin arc magmatism during normal subduction weakens the continental crust. This phase is represented in the Borderland rift system by the Mount Wrightson Formation and related calc-alkaline volcanic successions, and in the southern Rio Grande rift by the Rubio Peak and Palm Park Formations. Phase 2: Incipient retrograde motion of the slab, or "slab foundering," initiates mantle return into the wedge-shaped volume between slab and overlying continental lithosphere, causing crustal extension, lithospheric melting, and deposition of conglomerate in nascent rift basins stratigraphically above and adjacent to the extinguished arc. Caldera-related silicic volcanism and coeval extrusion of lithosphere-derived basalt and basaltic andesite define a bimodal "ignimbrite flare-up." This phase is represented in the Borderland rift system by an assemblage of outflow and intracauldron tuffs informally known as the "quartz porphyries" (for example, the Cobre Ridge Tuff and Canelo Hills Volcanics) and in the southern Rio Grande rift by the Bell Top Formation. Mafic volcanism, represented in southern New Mexico by the Uvas basaltic andesite, block faulting, and extensional sedimentary-basin formation continue after the end of silicic volcanism. Phase 3: Decompression-induced partial melting of convecting asthenosphere in the mantle wedge creates basalts with ocean-island chemical affinities intercalated with alluvial or marine sedimentary rocks in extensional basins. This phase is represented in southern Arizona by the Glance Conglomerate, Crystal Cave Formation, and interbedded volcanic rocks, and in southwestern New Mexico by newly discovered marine and volcanic strata beneath the Lower Cretaceous Hell-to-Finish Formation. In the Rio Grande rift system, phase 3 is recorded by the Santa Fe Group, including the Hayner Ranch, Rincon Valley, and Camp Rice Formations.

DEVELOPMENT OF A MAJOR RIFT TRANSFER ZONE (EMBUDO FAULT): INSIGHTS INTO THE EVOLUTION OF THE NORTHERN RIO GRANDE RIFT IN NEW MEXICO, by *Paul Bauer,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801; *Keith I. Kelson,* William Lettis and Assoc., 1777 Botelho, Walnut Creek, CA 94596; and *Peggy Johnson*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Three major fault systems intersect in the Taos area of northern NM: 1) the repeatedly reactivated, N-striking, 5-km-wide Picuris–Pecos fault system (PPF); 2) the Holocene, eastern, rift-bounding Sangre de Cristo fault zone (SdCF); and 3) the Embudo fault zone (EF), which is the transfer zone between the San Luis and Española rift basins. The mountain front zone between Pilar and Cañon provides preeminent exposures of the termination of a major rift transfer fault. New, detailed (1:12,000 and 1:6,000 scale) mapping of bedrock, rift fill, surficial deposits, and the faults that cut them all, provides important controls on the geometry and kinematics of Laramide to Holocene tectonism.

The southern end of the SdCF (Cañon and Hondo sections of the SdCF) is a 20-km-long, arc-shaped fault zone that defines the Taos embayment. The SdCF continues north (Questa section) into Colorado along a relatively linear range front. The transition between the NE-striking, left-oblique normal EF and the N-striking, normal Cañon section is a smooth curve that cuts the PPF in a structurally complex zone near Talpa. South of the EF/SdCF, the volcaniclastic Picuris Formation (34–18 Ma) of the Miranda graben is cut by strike- and oblique-slip faults of the PPF. The PPF projects northward across the Taos Valley to align with the Questa section. The Taos graben, identified primarily by geophysics and drillholes, is a buried, N-trending, 13-km-wide, 5,000-m-deep graben. The Taos graben is the major rift feature in the southern San Luis Basin. The eastern edge of the graben (Town Yard fault) lacks Quaternary expression but is aligned with the PPF to the south and the Questa section of the SdCF to the north.

A preliminary conceptual geologic model of the Taos Valley is as follows. The PPF and SdCF are reactivated pre-Laramide faults. The Miranda and Taos grabens were originally parts of an oblique-slip, Oligocene-to-Miocene basin. The PPF and Questa section of the SdCF represent the exposed eastern edge of the graben. The Town Yard fault is the buried intermediate section of the graben. Sometime after 18 Ma, rift kinematics changed, and the EZ-Cañon/Hondo section severed the PPF, leading to its extinction. As the rift widened and extension slowed, the Taos graben was abandoned, and faulting migrated eastward to form the Taos embayment.

This model explains a variety of geologic, hydrogeologic, and physiographic features of the Taos Plateau, including the Rio Grande gorge, intrabasinal faults such as Los Cordovas faults, Pliocene basalts, broad basinal warps, hot springs, ground-water flow, and asymmetric drainages.

MOUNTAIN-FRONT GEOLOGY OF THE TESUQUE QUADRANGLE, SANTA FE COUNTY, NEW MEXICO, by *Claudia I. Borchert*, cloudya@unm.edu, and *Gary Smith*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM, 87131

Our research in the Tesuque quadrangle, Santa Fe County, New Mexico, has produced insights to controversial stratigraphic and structural relationships along the Sangre de Cristo Mountain front.

Volcaniclastic strata of the Bishop's Lodge Member have been variously placed within or unconformably below the Tesuque Formation. Our mapping clearly substantiates early workers' choice of including these strata within the Tesuque. The volcaniclastic layers are interbedded with and overlie characteristic arkosic, conglomeratic sandstone of the Nambé Member of the Tesuque. Within the older, arkosic strata of the Nambé Member lie several olivine basalt flows, likely similar in age to a nearby 24.9 ± 0.6 Ma basalt (Baldridge et al.; 1980, EPSL v. 51, pp. 309–21). We submit that this relationship is evidence that subsidence of the Española Basin was underway prior to 25 Ma and that the Bishop's Lodge Member correlates regionally to the Oligocene–lower Miocene Abiquiu and Picuris Formations. Previous restriction of the Nambé Member to the middle Miocene overlooked the presence of diagnostic fossils only in the upper part of the member.

The contact between the Tesuque Formation and the mostly Proterozoic rocks of the Sangre de Cristo Mountains is both faulted and depositional. Field and geophysical data do not support a single, range-bounding fault with possible Quaternary movement, an interpretation proposed by some workers for the eastern margin of the Española Basin. Near Nambé Lake, the Tesuque Formation is clearly in depositional contact upon the Paleozoic and Proterozoic rocks. Farther south, a fault along the contact juxtaposes granite and Tesuque Formation along one segment, but offsets different beds of the Nambé Member along another, demonstrating that the mountain-front faults are of comparable magnitude to the myriad, minor faults found farther west into the basin. Most Pliocene and Quaternary stream deposits close to the mountain front have not been offset, precluding significant Quaternary fault movement.

THE OLIGOCENE–EARLY MIOCENE ABIQUIU FORMATION, NORTHERN NEW MEXICO: EVIDENCE FOR RIO GRANDE RIFT INITIATION SYNCHRONOUS WITH DEPOSITION, by *Jessica D. Moore,* moss@unm.edu, and *Gary A. Smith,* Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Previous work on the western margin of the Rio Grande rift, in the area of the southern San Luis Basin and northern Española Basin, has purported that rift subsidence did not begin until middle or late Miocene (Baldridge et al., 1994, GSA Bull. 105, p. 1538; Ingersoll et al., 1990, GSA Bull. 102, p. 1280). We have found evidence for earlier onset of rift subsidence in the Oligocene–early Miocene Abiquiu Formation, which straddles the margin of the Rio Grande rift and Colorado Plateau near Abiquiu, New Mexico. Structural and stratigraphic relationships between Mesozoic strata of the plateau and the upper member of the Abiquiu Formation provide evidence for syndepositional subsidence of the Abiquiu embayment, a shallow structural bench of the rift adjacent to the deeper San Luis and Española Basins. The data presented here indicate riftward stratigraphic thickening in the upper Abiquiu Formation across rift-bounding faults.

Stratigraphic thickness between intervals, defined by vertical changes in lithofacies and clast composition, increases from the plateau to the rift. Compositional changes, evident petrographically and in mesoscale, reflect the introduction of newly erupted material from the Latir volcanic field (~60 km to the northeast in the Taos area) to the depositional system. Such Latir-derived volcanic clasts as tuff, sanidine, and quartz-bearing pumice each make their first appearance progressively higher in stratigraphic sections toward the rift, as do lithofacies transitions within the upper Abiquiu. These signs point to deposition of the upper Abiquiu Formation having taken place while the basin was subsiding along rift-bounding faults.

TECTONICS AND VOLCANISM OF THE LATE MIOCENE BEARHEAD MAGMATIC EPISODE IN THE SOUTHEASTERN JEMEZ MOUNTAINS, NEW MEXICO, by *Gary A. Smith,* Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Relationships between Neogene volcanism and faulting in the Jemez Mountains have been only poorly defined. Recent mapping indicates, however, that upper Miocene Bearhead Rhyolite magmatism was coeval with, and spatially related to substantial subsidence along NNW intra-rift faults and NE-striking reactivated basement structures along the Jemez lineament. Extrusion of Bearhead Rhyolite flows/domes and cogenetic Peralta Tuff Member pyroclastic deposits occurred mostly between 7.0–6.7 Ma. Although eroded in many places and buried to the south beneath younger fill of the Santo Domingo Basin, Bearhead–Peralta eruptive products comprise a minimum volume of 35 km^3 and may have exceeded 100 km^3. Several workers (most notably L. Justet, UNLV M.S. thesis, 1999) have suggested that the Bearhead Rhyolite may represent eruptions from a single magma chamber. Most vents are concentrated in an ~165 km^2, NE-elongated elliptical region parallel to, and just north of, a discontinuous zone of NE-striking faults, at least 30 km long, that coincides with the volcanic front of the southern

Jemez Mountains and a regional geophysical lineament. Northeast-striking faults are common north of, but are rare south of, this zone. This zone of faults and vents may more appropriately represent the southern margin of a broadly defined Jemez lineament, rather than the narrow line through the Valles caldera that is typically depicted on maps. Most Bearhead Rhyolite magmatism was focused along the margins of the Bearhead Basin, a 6.5 km-wide asymmetric, west-tilted graben that accommodated at least 700 m of volcaniclastic strata between about 7.0 and 6.2 Ma. Erosional remnants of relatively thin Peralta Tuff pyroclastic aprons are found near rhyolite vents outside of the basin, but a thick sequence of pyroclastic deposits and tuffaceous sedimentary strata accumulated within the basin, demonstrating subsidence contemporaneous with late Miocene volcanism. The restricted extent of hypabyssal rocks of the Cochiti mining district can now be explained by a footwall uplift along the NW margin of the Bearhead Basin. Pre-Miocene(?) roof pendants in mineralized intrusions suggest >1 km of uplift. Alteration in the mining district, and broadly through the southern Jemez Mountains, has been dated at 5–7 Ma (WoldeGabriel and Goff, 1989, Geology, 11:986).

All of these observations suggest that a large, late Miocene magma chamber developed along the crustal-scale boundary represented by the Jemez lineament. This magma chamber may have induced hydrothermal mineralization/alteration of a large region of the southern Jemez Mountains. Movement along intra-rift faults intersected this chamber and tapped it incrementally prior to sufficient evolution of a gas-rich cap that might have led to a single, voluminous pyroclastic eruption. Subsidence along these faults enhanced accumulation and preservation of volcaniclastic deposits recording this magmatic episode.

RESULTS OF A FIELD-BASED STREAM POWER LAW TEST ON THE RED RIVER AND RIO HONDO, NORTHERN NEW MEXICO, by *David K. Mitchell,* Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

While it has been proposed that the rate of vertical fluvial incision of a stream is proportional to stream power, no field-based tests have been conducted to validate this proposed relationship. The general form of this relationship is $dz/dt = kQ^mS^n$, where dz/dt is the vertical incision rate, k is a basin-specific constant, Q is discharge, S is the energy slope, and m and n are coefficients that scale the relative influence of discharge and slope. At least 3 different combinations of m and n values have been suggested as most appropriate for predicting rates of vertical fluvial incision, and all previous stream power law tests have substituted drainage basin area for discharge. Using a field-based approach, we determined discharge–drainage area relationships and stream power values for the Red River and Rio Hondo in northern New Mexico. These two streams both head in the Taos Range and flow west onto the Taos Plateau. Previous workers have determined approximate rates of vertical incision that allow for a field-based test of the stream power law. Field measurements of discharge for the two streams show that discharge generally increases with drainage area for these two basins, but discharge does decrease in the more alluvial stretches (developed in basin fill) downstream of the mountain front. Discharge then increases once the streams enter lower gorges incised through basalts. We suggest that the stream loses water to the relatively permeable basin fill sections, while it gains water once it intersects a regional ground-water system in the basalts of the lower gorges. Stream power maps using field-derived data indicate that unit stream power ($m = 0.5$, $n = 1$) and another variant ($m = n = 1$) best predict the rates of incision for both the Red River and Rio Hondo. Furthermore, field-based stream power maps match incision rates better than their map-based counterparts. Similarities between the map-based and field-based unit stream power distributions suggest that this may be the best form for predicting rates of vertical incision using just maps. We suggest that the similar, generally parallel profile shapes of both the modern valleys and terrace treads for both rivers (indicating constant rates of incision spatially) suggest that these streams are at grade. If so, the stream power law parameterized for unit stream power ($m = 0.5$, $n = 1$) provides a potential simple test for grade of river systems in areas where base level fall or regional tectonics cause net fluvial incision.

EVIDENCE FOR LATE CENOZOIC ROCK UPLIFT IN THE WESTERN UNITED STATES FROM THE GEOMORPHIC EVOLUTION OF THE CANADIAN RIVER, NORTHEASTERN NEW MEXICO, by *Paul A. Wisniewski*, pawis@unm.edu, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Post-Laramide rock uplift in western United States has been the subject of a longstanding debate. Central to the debate are the following questions: has the West experienced rock uplift, where have rocks come up, and what is the nature of the uplift mechanism? Workers speculate that the rugged, high topography of the Rocky Mountains reflects late Cenozoic rock uplift, generated perhaps in part by active mantle processes. Recent teleseismic data suggest that plumes of low-velocity, dynamic mantle currently buoy an almost uniformly over-thickened crust. Apatite fission-track cooling histories of various mountain chains seem to corroborate this story. Paleobotanical data, however, indicate that the Laramide Rocky Mountains stood at equal or greater elevations than the modern Rockies. These high elevations have been attributed to up-basin hydrological shifts such as those that accompany global climate change and glacial-interglacial cycles. While the presence of deeply entrenched river systems of the Colorado Plateau, Great Plains, and Basin and Range can be used to support either scenario, we believe that geomorphic evidence found in a major river system on the high plateaus of the western Great Plains argues for late Cenozoic mantle-driven, epeirogenic rock uplift.

The Jemez lineament is one of many distinct zones of high heat flow and prolific late Cenozoic volcanism identified as "fingers" of low-velocity mantle that extend beneath parts of the western United States. Regional-scale warping of the Tertiary Ogallala Formation implies Neogene–Quaternary deformation across the lineament. The Canadian River canyon, northeastern New Mexico, straddles this crust-penetrating structure and cuts through the warped Ogallala cap rock. A broad convexity in the longitudinal profile of the Canadian where it traverses the Jemez lineament provides further evidence for rock uplift. No such broad convexities exist in the profiles of other major river systems (e.g. Arkansas River, South Platte River, and the Pecos River) that drain the eastern flank of the southern Rockies. Fluvial stratigraphy of the Canadian River canyon is temporally constrained by $^{40}Ar/^{39}Ar$ dating of a basalt flow within the canyon and by radiocarbon dating of organic material found in the terrace deposits. Numerical age dates yield uniform incision rates over the past 1.5 Ma. These uniform rates coupled with nearly parallel terrace profiles suggest that incision is controlled by relatively uniform, mantle-driven rock uplift along the Jemez lineament and not by hydrologic shifts linked to climate change. These combined data provide strong evidence for late Cenozoic epeirogenic rock uplift associated with localized mantle anomalies. Rock uplift in the western United States, therefore, may be localized to regions where the crust is underlain by buoyant mantle, but not necessarily associated with areas of high elevation and high relief.

RIO GRANDE INCISION HISTORY—PRELIMINARY RESULTS, SOCORRO BASIN, CENTRAL NEW MEXICO, by *Harland L. Goldstein* and *Bruce Harrison*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Constrained within a classic continental rift zone, the Rio Grande is a major through-flowing drainage system within the southwestern United States. Although rifting began in the Oligocene, the Rio Grande was not an established axial river system until early Pliocene. Furthermore, the onset of river incision did not occur until around the middle Pleistocene. The history of Rio Grande downcutting is an important component of the evolution of continental rift zones. Although the rift zone, as well as the Rio Grande itself, has received a lot of attention, detailed incision histories have had limited attention.

This study assesses the timing of Rio Grande incision within and around the Socorro Basin in central New Mexico. The approach of this study is to use tributary terraces to reconstruct paleo-Rio Grande elevations within the rift zone. Tributary terraces are the main focus of this study because axial Rio Grande terraces are not well preserved and are often complex in that they are interfingered with alluvial fan deposits. It is assumed that the tributary terraces form in response to Rio Grande base level change. Thus, they provide a record of Rio Grande elevations. Terrace profiling will provide a means to correlate the tributary terraces to remnant Rio Grande terraces, as well as reconstruct paleo-Rio Grande profiles. Four tributary terrace sequences within the Socorro Basin will be used in this study. Soil development will be used to correlate terrace surfaces between tributaries and to establish relative ages. One numeric age has been determined for a terrace surface in Socorro Canyon. The numeric age and the carbonate profile mass of this surface will be used to calibrate carbonate accumulation rates in the study area and will provide a basis for relative age determination.

Although the timing of downcutting is a major focus of this study, the ultimate goal is to provide an explanation of the external causes of incision. That is, is downcutting of the Rio Grande a result of climatic conditions, tectonic conditions, or both?

DEPOSITIONAL ENVIRONMENTS AND PROVENANCE OF THE CENOZOIC GILA CONGLOMERATE OF THE DUNCAN AND CANADOR PEAK QUADRANGLES, SOUTHWESTERN NEW MEXICO, by *Shane V. Smith* and *Greg H. Mack,* Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003

Lithofacies distribution, paleocurrent, and provenance data are used to define the evolution of the Gila Conglomerate in the Basin and Range tectonic province of the Duncan and Canador Peak quadrangles, southwestern New Mexico. Crustal extension in this part of the Basin and Range resulted in fault-block mountains and complementary basins filled with up to 250 m of conglomerate, sandstone, siltstone, and mudstone of the Gila Conglomerate. The Gila Conglomerate is divided into upper and lower stratigraphic units that are separated by an angular unconformity. The lower unit consists of strongly consolidated conglomerate, sandstone, and mudstone, and the upper unit has unconsolidated to poorly consolidated siltstone, mudstone, and sandstone with uncommon conglomerate. Three mappable members were identified in these two units including the Wilson Mine and Nichols Canyon Members of the lower Gila Conglomerate and the Pearson Mesa Member of the upper Gila Conglomerate.

The Gila Conglomerate of the Duncan and Canador Peak quadrangles shows a two-stage evolution. The initial stage was the deposition of the late Oligocene(?) to early Miocene Wilson Mine and Nichols Canyon Members that consist of 175 m of sediment deposited on the distal edge of an alluvial fan and alluvial flat and in a lacustrine playa. Clast composition and paleocurrent directions indicate a provenance for both members to the southeast in the southern Big Burro Mountains. This initial stage was followed by uplift and tilting of the strata of these two members. The second stage was the deposition of the Pliocene to Pleistocene(?) Pearson Mesa Member, which consists of 75 m of alluvial-flat and distal to mid alluvial-fan lithofacies in a northwest-trending, northeast-tilted, internally drained half graben. Clast composition and paleocurrent directions indicate a provenance for this member to the north in the Rileys Peak area. There is no depositional record of a major through-flowing, axial-fluvial system during the time of deposition of the Gila Conglomerate in the study area that would be analogous to the modern Gila River.

LATE QUATERNARY PALEOSEISMICITY OF THE ALAMOGORDO FAULT ADJACENT TO THE SACRAMENTO MOUNTAINS, by *D. J. Koning* and *F. J. Pazzaglia,* Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

The Alamogordo fault is a major Rio Grande rift structure in southern New Mexico along which the Tularosa Basin has been down-dropped relative to the Sacramento Mountains. This fault has displaced surfaces developed on Quaternary deposits by as much as 10 m. The timing of late Quaternary rupture events along the Alamogordo fault adjacent to the Sacramento Mountains was investigated by: (1) mapping proximal piedmont deposits along the western foot of the Sacramento Mountains, (2) describing exposures of offset Quaternary sediment and collecting 11 samples of datable material, and (3) measuring fault scarp profiles at 40 localities.

The ages of four late Quaternary surface rupture events are constrained by stratigraphic relationships and C-14 dates. South of the city of Alamogordo, two large rupture events probably occurred within a time span of a few thousand years. A limiting upper numeric age indicates that both happened shortly before 12.6 ka (radiocarbon years). The estimated average displacement associated with each of these two events is approximately 3–4 m. North of the city of Alamogordo, the youngest interpreted surface rupture event is constrained by C-14 dates to have occurred between 10.4 and 11.4 ka (radiocarbon years). South of the city of Alamogordo, the youngest surface rupture very likely occurred in the early Holocene during a period of major alluvial fan aggradation. This event probably had an average displacement of ~1 m. The alluvial fan stratigraphy suggests that these four ruptures belong to a temporal clustering phenomena that occurred over a period of ~8 ka during the latest Pleistocene and early Holocene. These four ruptures probably produced seismic moment magnitudes within the range of 6.8–7.3.

EARTHQUAKE CHRONOLOGY ESTABLISHED BY CALIBRATING A FAULT-SCARP DIFFUSION MODEL WITH A COSMOGENIC NUCLIDE: PRELIMINARY RESULTS FROM THE SOCORRO CANYON FAULT, by *John P. Ayarbe, Fred M. Phillips, J. B. J. Harrison*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *David Elmore,* and *Pankaj Sharma*, PRIME Lab, Purdue University, West Lafayette, IN 47907-1396

Determining fault-scarp chronologies is important in the assessment of earthquake hazards and to paleoseismology. In arid environments the low abundance of organic carbon often prevents ^{14}C dating of displacements; therefore, in these regions fault-scarp diffusion modeling has been applied to date scarps. A drawback to this technique, however, is that the geomorphic diffusivity is often unknown and must be estimated. Because the diffusivity of unconsolidated material can vary by three orders of magnitude a large amount of uncertainty is introduced into the calculated age of a scarp. Better estimates of a scarp age can be obtained by constraining the value of the diffusivity using a cosmogenic nuclide. Samples, collected along two vertical transects near the fault plane of the Socorro Canyon fault (central New Mexico), were analyzed for ^{36}Cl. The analyses provided vertical ^{36}Cl profiles that were used to calibrate a model that couples the accumulation of ^{36}Cl to fault-scarp morphology. The calibration of the model allowed the diffusivity to be constrained and the timing of ruptures to be assessed. Preliminary results suggest the surface was displaced around 120 ka and 44 ka. The geomorphic diffusivity is approximately 0.0004 m^2/yr.

HYDROGEOLOGIC CHARACTERIZATION OF A LARGE DISPLACEMENT NORMAL FAULT IN POORLY LITHIFIED SEDIMENT, by *G. C. Rawling* and *L. B. Goodwin,* Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

An understanding of the impact of fault zones on subsurface fluid flow is of importance in the construction of realistic groundwater flow models. While conceptual models and quantitative hydrogeologic data exist for fault zones in lithified sedimentary rock, very little work has addressed faults in poorly lithified sediments. We are developing a hydrogeologic model of fault zones in poorly lithified sediments based on the Sand Hill fault, by field mapping at a variety of scales, in situ and laboratory permeability measurements, structural analysis, and statistical treatment of the data.

The Sand Hill fault is a large-displacement (up to 600 m), basin-bounding growth fault in the Rio Grande rift west of Albuquerque, NM. The fault juxtaposes synrift sediments of the Oligocene–Miocene middle and Pliocene–Pleistocene upper Santa Fe Group. Previous work has shown that the width, structural complexity of fault zone architecture, and extent of fault zone cementation are qualitatively predictable based on the local stratigraphy. These parameters generally increase with increasing grain size of the host sediment.

This study focuses on determining the relationships between mappable fault zone structural units and fault zone hydrogeologic units identified by statistical and geostatistical measures of the permeability data. To place the permeability data in geologic context, structural study of the fault zone will emphasize identification of active deformation mechanisms and development of structures with displacement. Hydrologic, petrophysical, and structural data will be combined with classification and regression analysis to identify the primary petrophysical factors and/or tectonic processes controlling permeability.

Preliminary data suggest that highly deformed fault zone structural units have distinct hydrologic signatures, with low means and variances of permeability. These units are characterized by penetrative planar and linear fabrics and grain-scale tectonic mixing. We are employing a petrographic image analysis system to quantify fabric development and petrophysical factors related to permeability.

HYDROGEOLOGY OF THE UPPER SANTA FE GROUP ADJACENT TO THE SAND HILL FAULT, ALBUQUERQUE BASIN, NM, by *D. G. Smyth,* Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, and *S. Connell,* New Mexico Bureau of Mines and Mineral Resources, Albuquerque, NM 87106

Little is known about fault controls on fluid flow through unconsolidated sediments, although many important aquifers in the United States are found in such basins. The Sand Hill fault (SHF) is a major north-south trending, high-angle normal fault associated with the Rio Grande rift. This growth fault locally separates the synrift deposits of the upper and lower Santa Fe Group. Our project is part of a collaborative effort trying to characterize fluid flow through unconsolidated sediments in faulted basins, for the purpose of more accurate fluid flow modeling of these systems. The focus of our field study is the hydrogeology of the hanging-wall sediments associated with the SHF in the Pliocene to Pleistocene upper Santa Fe Group.

Physical characteristics of sediments, such as grain size and sorting, act as indicators of possible pathways and barriers to fluid flow. Calcic soil horizons, which are common in the Albuquerque Basin, can change the hydrologic properties of a sedimentary unit by depositing calcium carbonate around and between grains, closing off pathways for fluid flow. Our research utilizes 1:8,000 lithofacies mapping to document lateral changes and several measured sections to document vertical/temporal changes. The measured sections document lithofacies changes in greater detail than the mapping, allowing a better idea of lithologic variations within individual mappable units that may influence permeability. Calcic soils are documented as a map overlay and incorporated into the measured sections.

The lithologic units are divided into five mappable units within two major depositional environments. In the upper Santa Fe Group we document basin-scale fluvial sediments present at the time of fault propagation and fault-related syn-tectonic depositional wedge (STDW) deposits that occur as a result of unstable, fault-related, surface morphology due to fault propagation. The upper Santa Fe Group fluvial deposits are divided into three units: gravel- and conglomerate-dominated, sand-dominated, and silt- and mud-dominated units. The STDW consists of a poorly sorted colluvial wedge unit, an eolian unit, and a well-sorted, fault-parallel fluvial unit that contains reworked colluvial wedge and upper Santa Fe Group fluvial sediments. For mapping purposes the eolian and fault-parallel fluvial sediments within the STDW are grouped together as both represent well-sorted sands.

The STDW sediments are commonly associated with soil-bounded stratigraphic intervals, within the upper Santa Fe Group, representing episodic movement along the SHF. The fluvial facies acts as background sedimentation within the basin. The calcic soils represent periods of relative tectonic and landscape stability between rupture events along the SHF. To test the viability of these lithologic units as hydrostratigraphic units, permeability measurements are being undertaken using a variety of methods: air minipermeameter, grain-size analysis, and falling-head permeability.

SESSION 4—HYDROLOGY, SOILS, AND PALEONTOLOGY

PRELIMINARY RESULTS OF HYDROGEOCHEMICAL AND ISOTOPIC INVESTIGATION OF GROUNDWATER FLOW IN THE SAN BERNARDINO VALLEY, ARIZONA AND SONORA, by *S. Earman, F. M. Phillips*, and *B. J. O. L. McPherson,* Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

An ongoing study is focused on understanding the hydrogeology of the San Bernardino Valley, located in southwestern Arizona, USA, and northeastern Sonora, Mexico. Ground water from artesian wells in the center of the basin is used to provide habitat for several species of endangered and threatened fish, and the long-term viability of this supply is uncertain if water-use patterns in the valley are altered.

The San Bernardino Valley is located in the Basin and Range physiographic province. It trends north-south and is approximately 15 km wide and 35 km long. The geology and hydrogeology of the basin have not been widely investigated and are poorly understood.

Basaltic volcanism was active in the area coëvally with basin and range tectonic activities. As a result, the basin fill consists of alluvium interlayered with basalt flows. Based on drilling records from wells in the valley, some of the basalt layers are highly fractured and probably act as aquifers, while others appear intact and probably function as aquitards.

Over 40 water samples from the area have been analyzed for major ion content, δD and $\delta^{18}O$; approximately 15 are from springs and flowing artesian wells in the center of the basin, and the remainder are from springs, seeps, and creeks in the Chiricahua Mountains (the bounding range on the northwest of the valley; it is assumed to be the primary recharge area).

Based on their chemical signatures, waters from the center of the basin form two distinct groups—well waters are dominated by HCO_3^- and Na^+, while most spring waters have HCO_3^-/mixed cation compositions but show greatly elevated levels of Mg^{2+} compared to the well waters. Both well and spring waters typically have TDS and SO_4^{2-} of roughly 400 and 10 mg/L, respectively. Data from stable isotope analyses of the well and spring waters suggest that they share a common source area.

Water samples from springs near the crest of the Chiricahuas are dilute (TDS <50 mg/L), with mixed-ion composition. The waters from lower elevations on the eastern side of the range (that bounding the San Bernardino Valley) are predominately Ca^{2+}/SO_4^{2-} waters with elevated TDS (460–1,200 mg/L).

Stable isotopic data suggest that the Chiricahuas are the primary source area for waters in the basin center. The cause of decreasing TDS and SO_4^{2-} levels from the basin margin to the basin center is not understood but may be revealed by examining chemical data from water sources in intermediate areas of the basin.

SEASONAL GEOCHEMICAL RESPONSE OF A SHALLOW ALLUVIAL AQUIFER ASSOCIATED WITH A FIRST ORDER MONTANE STREAM IN NORTHERN NEW MEXICO, by *Richard M. Ortiz, Armand Groffman,* and *Laura J. Crossey,* Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Rio Calaveras, located in the Jemez Mountains of northern New Mexico, is a first order montane stream with a shallow alluvial aquifer system. The hydrogeology of the system has been well documented during the past 6 years allowing for an understanding of the seasonal dynamics. The aquifer is ideal for the examination of the seasonal response of redox processes in a dynamic near-surface environment because 1) the chemistry shows a seasonal response, 2) vadose-zone and aquifer sediments are relatively high in organic carbon (an important consideration in biogeochemically mediated systems), 3) a large biogeochemical and hydrological data base has been assembled, and 4) it is a pristine environment.

In addition to surface water sampling at the site, there are also floodplain and transect wells. These three main sampling localities add up to a combined total of 54 sampling locations. Measurements performed in the field and in the lab include pH, oxidation-reduction potential (ORP), dissolved oxygen, and major anion and cation analysis (for major and minor elements including iron and manganese).

This study compares hydrologic data (stream discharge, water-table fluctuations) with geochemical parameters (anion and cation concentrations, pH, ORP, and dissolved oxygen content). The water table fluctuates up to 0.7 m during an annual cycle with a maximum reached during spring snow melt and minimum during winter baseflow conditions. During periods of high discharge (spring snow melt), dissolved oxygen in the system is at a maximum (2–6 mg/L). Elements such as iron and manganese are predominantly present in their oxidized states and remain stationary within the aquifer system. During periods of baseflow conditions, dissolved oxygen within the system is at a minimum, and iron and manganese are reduced. Iron and manganese become mobile in the system with concentrations of iron and manganese up to 15 mg/L and 2 mg/L respectively. Understanding the dominant hydrologic pulse (snowmelt) and how it affects the geochemistry of the system allows for the application of this knowledge to perturbed systems.

THE SPATIAL VARIABILITY OF ENTISOLS ON A RIPARIAN FOREST FLOODPLAIN AS A FUNCTION OF VEGETATION AND SEDIMENT TEXTURE: IMPLICATIONS FOR SHORT-TERM PEDOGENESIS, by *Nicole M. Bailey,* nbailey@unm.edu, and *Laura Hagan,* Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

In the past, active floodplain soils were considered much too young to contain any significant amount of soil development, such that few soil studies have been conducted on floodplains to determine rates of soil formation in time scales of years or decades. This is particularly so in arid regions, where rates of soil development are generally slower than those in more humid regions. The middle Rio Grande floodplain at the Rio Grande Nature Center in Albuquerque provides an opportunity to study a unique floodplain environment, where the surface has been artificially stabilized by the Cochiti Dam construction in 1942. Soil stratigraphy in this region is characterized by a complex sequence of overbank flooding deposits and lateral accretionary deposits that have been subjected to pedogenesis for the past 57 yrs.

Eight soil pits were excavated along north-south and east-west transects of the Rio Grande in order to characterize the soil spatial variability. Soil stratigraphy, vegetation species, and vegetation density are variable along both transects. Pedogenic features such as O and A development, root diameters and densities, and degree of sedimentary structure preservation vary noticeably with changing vegetation. Typically, the better-developed soils are observed in the forested areas. Laboratory analyses revealed textural and vegetation controls on both organic matter and carbonate content. Organic carbon weight percentages are higher and penetration of organic matter is deeper in riparian forest soils than in desert patchland soils. Although weight percent calcium carbonate is less than 0.5% in both the desert patchland and riparian forest, carbonate penetration is deeper and concentrations are lower in the riparian forest soils. A positive relationship also exists between finer-grained sediments and organic content in both soils. Our findings suggest that: (1) short-term pedogenesis is surprisingly significant on the middle Rio Grande floodplain when contrasted with soils of deposits of similar age elsewhere in the region; and (2) vegetation exerts some control over the rate of incipient stages of soil development. In other words, one must consider that the apparently accelerated soil formation is largely attributable to the construction of Cochiti Dam.

CARBON DIOXIDE SOIL GAS STUDIES IN THE SEVILLETA, by *L. J. Wardell* and *B. Harrison,* Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Previous work on two opposing slopes at a Sevilleta field site inferred different paleoclimate conditions and vegetative patterns from measuring stable carbon isotope concentrations of pedogenic carbonate layers. However, calcium carbonate layers form over several thousands of years and thus represent an integrated climate signal over this time period. To better understand the short term variability we are conducting soil gas measurements periodically over at least four consecutive seasons.

By combining the seasonal trends of CO_2 flux and carbon stable isotope composition in the soil gas, we will be able to relate CO_2 production with the degree of vegetation respiration and carbonate deposition. Yearly variations will provide understanding to the degree of variability that can be expected in the more general determination of a paleoclimate condition. Differences in CO_2 production rates and concentrations within the soil on the two different slopes in the study provide information on their different vegetative growth patterns. Measurements started in spring of 1998 and are planned to continue through 1999.

Results show that these two slopes with different vegetation patterns show different patterns of seasonal behavior with respect to surface CO_2 flux and subsurface CO_2 concentrations. Little variation is observed in the isotopic composition of the subsurface CO_2. Isotopic carbon values for both slopes favor C4 vegetation. This is inconsistent with the pedogenic carbonate that indicated one of the two slopes having a near equal distribution of C3 and C4 vegetation.

AVAILABLE MOISTURE CONTROLS ON THE DISTRIBUTION OF CALCIUM CARBONATE WITHIN SOILS OF A FIRST ORDER DRAINAGE BASIN, SEVILLETA WILDLIFE REFUGE, SOCORRO, NEW MEXICO, by *D. McMahon,* Desert Research Institute, Reno, Nevada; *J. B. J. Harrison*, and *J. M. H. Hendrickx,* Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

A small first-order drainage basin developed in early Pleistocene fan gravels shows a marked contrast in vegetation between north- and south-facing slopes. The south-facing slope is characterized by a creosote-black gramma grassland, whereas the north-facing slope has black gramma-juniper woodland vegetation. There is a concomitant change in the depth and amount of calcium carbonate in the soils on the opposing slopes. Depth to calcic horizon and the average profile mass of calcium carbonate in south-facing slope soils is 5 cm and 10g/cm^2 respectively, compared to 30 cms and 15g/cm^2 for soils on the north-facing slope. Catenary relations are not strongly developed for the soils on either slope. However, a very strong catenary relationship exists in the soils of the east-facing headslope of the drainage basin. A decrease in profile mass of calcium carbonate and an increase in depth to calcic horizon occurs with lower slope soils.

The initial driving force for these contrasts is the variation in solar radiation, with the north-facing slope receiving less winter sunlight than the south-facing slope; however, the greatest differences in PET occur in the spring and fall. These differences in PET determine the nature of the vegetation communities on the opposing slopes, which in turn influences the available soil moisture. North-facing soils also have greater amounts of organic carbon and silt than south-facing soils, and these features increase the available moisture for vegetation on the north-facing slopes. CO_2 measurements throughout the year indicate that north-facing soils have a greater CO_2, flux which may be the main factor controlling the difference in profile mass of calcium carbonate between the two slopes.

SEDIMENTOLOGY OF ESTANCIA BASIN GROUND-WATER DISCHARGE PLAYAS, CENTRAL NEW MEXICO, by *T. A. Loveland,* Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

The Estancia Basin playa complex, located about 40 km east of the Manzano Mountains in central New Mexico, consists of ~87 ephemeral salt lakes (playas) and associated lunette dunes, which together encompass an area of approximately 400 km^2. The playas occupy ~12% of this area (50 km^2). The playa basins are mid-Holocene eolian deflation features cut into the latest Pleistocene lake beds, which were deposited on the floor of pluvial Lake Estancia in the center of the Estancia Basin. The lunette dunes, adjacent to and downwind from the playas, are composed of material deflated during playa basin formation, mostly gypsum and clay. These dunes are up to 1 km wide, with elevations of up to 50 m above the adjacent playa surface. Depth of post deflation playa-fill sediment in different playas ranges from 0.4–2.4 m. Radiocarbon dates from gastropod shells, taken from the base of one of the dunes, and from cysts of the brine shrimp *Artemia salina*, taken from the bottom-most sediment of one of the playas, both indicate ~7,000 yrs BP as the time of playa basin deflation.

The playas are zones of ground-water discharge for the hydrologically closed Estancia Basin (approximately 5,000 km^2). The Estancia Basin (central valley floor, town of Estancia) receives 30 cm (12 inches) of precipitation and experiences 152 cm (60 inches) of potential evaporation in an average year. Ground water discharging into the playas is rich in the dissolved ions Na^+, Ca^{++}, Mg^{++}, SO_4^{2-}, Cl^-, and HCO_3^-. Evaporative concentration of these ions results in precipitation of gypsum, calcite, halite, dolomite, and to a lesser extent bloedite, in and on the playa sediment. Playa sediment consists of 30–50% gypsum, 2–10% carbonate (calcite and dolomite), and the remainder silt and clay. Efflorescent crusts on playa surfaces are mainly halite and thenardite. Crystal morphology of gypsum crystals, which grow in the sediment at a depth of 30–40 cm, is controlled by ground-water flow (delivery of ions), temperature, salinity, and concentration of dissolved organic carbon. Growth of these sand-sized gypsum crystals results in increased hydraulic conductivity of this zone.

A few of the wettest playas are colonized at their surface by microbial communities. At the top of the sediment column, just below the halite crust, is an algal mat composed of filamentous cyanobacteria (blue-green algae). This mat excludes oxygen from the zone below where *Desulfovibrium*, an anaerobic sulfate reducer, performs dissimilatory sulfate reduction (the reduction takes place outside the cell), producing hydrogen sulfide gas. Some of the reduced sulfur combines with aqueous ferrous ions and results in precipitation of botryoidal pyrite both free and on the surfaces of growing gypsum crystals.

A DIVERSE NEW TRIASSIC FOSSIL ASSEMBLAGE FROM THE PETRIFIED FOREST FORMATION (REVUELTIAN: EARLY-MID NORIAN) NEAR ABIQUIU, NEW MEXICO, by *A. B. Heckert,* Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131; *L. F Rinehart, S. G. Lucas,* New Mexico Museum of Natural History and Science, 1801 Mountain Rd. NW, 87104 (NMMNH); *A. Downs,* Ruth Hall Museum of Paleontology, Ghost Ranch Conference Center, Abiquiu, NM 87510; *J. W. Estep, J. D. Harris, P. K Reser*, and *M. Snyder,* NMMNH

Recently, one of us (MS) discovered a prolific new locality (NMMNH locality 3845) in the badlands of the Petrified Forest Formation near Ghost Ranch, New Mexico. This locality yields fossils that represent a diverse vertebrate and invertebrate fauna. The invertebrate fauna consists primarily of conchostracans, although a possible decapod crustacean was also discovered at the site. The vertebrate fauna consists of both fish and abundant tetrapods. A partial, articulated fish skeleton represents a semionotid, and numerous scales have also been recovered from the site. The tetrapod fauna is dominated by archosaurs, including indeterminate phytosaurs, the aetosaur *Desmatosuchus haplocerus*, a coelophysoid theropod dinosaur, and another, larger theropod; a distal humerus of a possible cynodont? was also recovered. Plants are represented by nondiagnostic woody debris.

Stratigraphically, the site is high in the Petrified Forest Formation, approximately 60 m below the Entrada Sandstone. Tetrapod biochronology, based on the presence of the aetosaur *Typothorax* and the phytosaur *Pseudopalatus*, indicates a Revueltian (early-mid Norian, approximately 210–218 Ma) age for the Petrified Forest Formation in this area.

Tetrapod bones from locality 3845 are extremely well preserved and occur primarily in a bonebed of greenish-gray intraformational conglomerate that fines upward into sandy mudstone of similar colors. Conchostracans are preserved in close association with tetrapod bones. The fish skeleton was found approximately 1.5 m above this horizon in laminated mudstone above a similar, fining-upward sequence. The decapod? was found in a spoil pile at the site but was probably originally close (<1 m) to the bone-bearing horizon.

Coelophysoid theropod material recovered thus far includes elements of the pelvic girdle and the hind limbs as well as a partial tooth. The presence of two proximal left tibiae and fibulae indicates the presence of at least two individuals. An aberrant tetrapod specimen consists of a fused tibia-fibula-astragalus-calcaneum that is also fused proximally. This probably represents a large (>3 m body length) theropod with an as-yet-undetermined pathology.

Particularly important aspects of this site are: (1) the abundant and highly diverse faunal elements, including aquatic invertebrates, fish, and both semi-aquatic and terrestrial tetrapods; (2) the exceptional preservation that characterizes all taxa found at the site; (3) the 10+ m extent of the fossiliferous horizons; and (4) the relatively rare taxa, including decapods?, dinosaurs, and cynodonts? found at the site.

CARBONATE HILL MEMBER OF THE U-BAR FORMATION: KEY TO CORRELATION OF THE LOWER CRETACEOUS SECTION IN SOUTHWESTERN NEW MEXICO, by *Spencer G. Lucas* and *John W. Estep*, New Mexico Museum of Natural History and Science, 1801 Mountain Rd. NW, Albuquerque, NM 87104

Lower Cretaceous strata exposed in southwestern New Mexico (Hidalgo, Luna, Grant, Sierra, and Doña Ana Counties) are assigned to the Hell-to-Finish, U-Bar and Mojado Formations of the Bisbee Group. A lack of regional stratigraphic studies (most have focused on a single mountain range), the relative rarity of biostratigraphically useful fossils, and the apparently rapid lateral facies changes in parts of the Lower Cretaceous section have hindered the development of convincing regional correlations. However, a lithologically and biostratigraphically distinctive interval of the U-Bar Formation, the Carbonate Hill Member, is present in all outcrop areas of the U-Bar Formation in southwestern New Mexico. It thus provides a sound basis for the correlation of U-Bar sections throughout the region.

Zeller (1965, NMBMMR Memoir 16) introduced the term "oyster-limestone member" of the U-Bar Formation in the Big Hatchet Mountains for the same lithostratigraphic unit that Gillerman (1958, NMBMMR Bulletin 57) had already named the Carbonate Hill Limestone. The Carbonate Hill Member of the U-Bar Formation is 60–610 m thick and consists mostly of dark-gray to black, bioclastic limestone (packstone) characterized by numerous bivalve or gastropod shells and interbedded with calcarous shale, calcarenite, and minor limestone-pebble conglomerate. It yields late Aptian ammonites (e.g., *Kazanskyella spathi*, *Acanthoplites berkeyi*, *Hypacanthoplites immunitis*) in the Peloncillo and Big Hatchet Mountains. At all outcrops, a diverse assemblage of bivalves from the Carbonate Hill Member includes species of *Quadratotrigonia* that indicate a late Aptian age. At some outcrops, the large, late Aptian–early Albian foraminiferan *Orbitolina texana* is present in the Carbonate Hill Member.

The Carbonate Hill Member of the U-Bar Formation crops out in the Big Hatchet, Little Hatchet, Animas, Peloncillo, Victorio, and East Potrillo Mountains and at Eagle Nest in the West Potrillo Mountains. It thus provides the basis for a first order correlation of U-Bar Formation outcrops throughout southwestern New Mexico.

A NEW TYRANNOSAURID (DINOSAURIA: THEROPODA) PARTIAL SKELETON FROM THE UPPER CRETACEOUS KIRTLAND FORMATION, SAN JUAN BASIN, NEW MEXICO, by *Thomas E. Williamson,* New Mexico Museum of Natural History and Science, 1801 Mountain Rd. NW, Albuquerque, NM 87104; and *Thomas D. Carr,* Royal Ontario Museum, 100 Queen's Park, Toronto, Ontario M5S 2C6 Canada

A partial skeleton of a large tyrannosaurid (NMMNH P-27469) from the Upper Cretaceous (upper Campanian) Hunter Wash Member, Kirtland Formation represents only the third relatively complete tyrannosaurid to be collected from New Mexico. Previously reported partial skeletons of tyrannosaurids from Upper Cretaceous strata of New Mexico include OMNH 10131, a skull and skeleton referred to *Aublysodon* cf. *A. mirandus* from the Fruitland or lower Kirtland Formation, and NMMNH P-25049, a partial skeleton of an immature tyrannosaurid from the Farmington Member, Kirtland Formation that has been referred to *Albertosaurus* but probably represents a new species of *Daspletosaurus*. The new specimen is tentatively identified as an *Albertosaurus* based on the relatively uninflated ectopterygoid. A more precise and certain identification must await further preparation of the specimen.

NMMNH P-27469 is estimated to be from 40% to 60% complete. It is largely or completely disarticulated and includes portions of the skull including portions of both dentaries, a maxilla, and an ectopterygoid, and postcranial elements including numerous vertebrae and ribs, a partial femur, and most of the left pelvic girdle. It also shows evidence of pathologies including a possible puncture wound of a palatal bone (ectopterygoid) with related infection of the bone and nearby periosteal tissue and a rib that shows a healed fracture.

The new tyrannosaurid specimen was collected from the Bisti/De-na-zin Wilderness Area under an excavation permit issued by the Bureau of Land Management (BLM)—the first permit of its kind to be issued on any federally designated Wilderness Area.

TWO NEW PLIOCENE (BLANCAN) VERTEBRATE FAUNAS FROM THE ALBUQUERQUE BASIN, NORTH-CENTRAL NEW MEXICO, by *G. S. Morgan* and *S. G. Lucas,* New Mexico Museum of Natural History and Science, 1801 Mountain Rd. NW, Albuquerque, NM 87104

Ten sites from the Albuquerque Basin in north-central New Mexico have produced vertebrate fossils of Blancan (Pliocene) age. Five of these are unpublished sites discovered within the past 5 yrs, and five of the sites were known previously. Two of the new sites, the Loma Colorado de Abajo fauna from Rio Rancho in Sandoval County and the Belen fauna from near Belen in Valencia County, contain age-diagnostic species of mammals. The Loma Colorado de Abajo fauna is composed of three species. A small land tortoise (cf. *Hesperotestudo*) is identified from a shell fragment; the ground squirrel *Spermophilus* sp. is known from a partial skull; and the primitive pocket gopher *Geomys* (*Nerterogeomys*) is represented by one complete and one partial skull and a mandible fragment. The Loma Colorado *Geomys* is indicative of a Blancan age but does not permit a more precise placement of this fauna within the Blancan. The Belen fauna includes six species: the partial skeleton of a colubrid snake; a partial mandible of the talpid *Scalopus* (*Hesperoscalops*) sp.; a mandible of the geomyid *Geomys* (*Nerterogeomys*) *paenebursarius*; a metatarsal of the horse *Equus calobatus*; a partial metapodial of a small antilocaprid; and a complete set of mandibles with right and left m2-m3 of the gomphotheriid proboscidean *Stegomastodon mirificus*. The Belen mole mandible represents the first record of the family Talpidae from New Mexico in either the fossil or modern fauna and the westernmost occurrence of the genus. *G.* (*N.*) *paenebursarius* is restricted to late Blancan faunas, *E. calobatus* occurs in the late Blancan and Irvingtonian, and *S. mirificus* is found in the middle Blancan through the early Irvingtonian. The overlapping range zone for these three species is late Blancan. The three other new sites from the Albuquerque Basin, two in the vicinity of Los Lunas in Valencia County and one near Veguita in northern Socorro County, each consist of only one species of mammal. A tooth of the typical Blancan camel *Hemiauchenia blancoensis* occurs in one of the Los Lunas sites, and several postcranial elements of either the large camel *Camelops* or a giant camelid (*Blancocamelus* or *Gigantocamelus*) were identified from the second Los Lunas site. The Veguita site has a maxilla with a complete dentition of the large horse *Equus scotti*, a species typical of middle Blancan through early Irvingtonian faunas.

The presence in many of the Albuquerque Basin faunas of mammals that occur in middle Blancan and younger faunas excludes an early Blancan (3.7–4.5 Ma) age for most of these sites. Several of these faunas appear to be late Blancan in age (1.8–2.5 Ma) based on the few age-diagnostic species present, although the absence of Neotropical immigrant mammals (e.g., ground sloths, glyptodonts, capybaras, and porcupines) from all Albuquerque Basin Blancan faunas may be significant. The arrival of these immigrants from South America at about 2.5 Ma characterizes most late Blancan faunas from the southwestern United States, suggesting that some Albuquerque Basin Blancan faunas may be middle Blancan in age (2.5–3.7 Ma).

POSTER SESSION

A PROBABLE DECAPOD CRUSTACEAN FROM THE UPPER TRIASSIC PETRIFIED FOREST FORMATION OF THE CHINLE GROUP, NORTH-CENTRAL NEW MEXICO, by *L. F. Rinehart* New Mexico Museum of Natural History and Science, 1801 Mountain Rd. NW, Albuquerque, NM 87104; *A. B. Heckert,* Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131; and *S. G. Lucas,* New Mexico Museum of Natural History and Science, 1801 Mountain Rd. NW, Albuquerque, NM 87104

New Mexio Museum of Natural History and Science (NMMNH) locality L-3845 in the Petrified Forest Formation of the Chinle Group (Rio Arriba County, NM) yields fossils representing a rich fauna of vertebrates (fish and reptiles) and invertebrates (mostly conchostracans) of early-mid Norian (~218–210 Ma) age. We discuss here a probable decapod crustacean (NMMNH P-29041) found in the spoil pile at the site. The specimen is in matrix of slightly sandy mudstone that contains poorly sorted, texturally mature sand- to gravel-size clasts of very fine grained mudstone. Location of the specimen and rock color indicate that it probably originated in one of several fining-upward sequences between 0.3 and 1 m above the main bone-bearing layer.

The decapod specimen is dorsoventrally compressed, preservation is only fair, and, due to its fragility, preparation is proceeding slowly. The specimen measures 48 mm long by 19 mm wide exclusive of legs and antennae. No clear indication of eyes is seen in the present state of preparation; however, two pairs of antennae are present; one pair is apparently very long. Of the five pairs of legs, the first pair are slender and apparently bear small chelae. Limb pairs two, three, and four are robust uniramous pereiopods, and the legs of pair five terminate in small paddle-like structures. The wide, flat body, reduced abdomen, and lack of a caudal fan indicate the animal is probably of the brachyurous (short-tailed) type, which includes the crabs. The type and sequence of thoracic limbs is typical of swimming crabs. However, only the ventral surface is exposed, so the carapace, whose morphology is particularly diagnostic of the Malacostraca, is not visible. However, based primarily on the presence of five pairs of thoracic limbs, we tentatively assign it to the Decopoda.

Decapod crustaceans first appear in the Late Devonian. Ten families of decapods are known from the Triassic; four of these are found in North America, and two are known from the Chinle Group. Therefore, this specimen is particularly important because it sheds light on a rarely preserved aspect of the Chinle fauna and thus provides insight into the fresh-water ecosystems of the Upper Triassic.

GEOLOGY AND TAPHONOMY OF THE PETERSON SITE, NEW MEXICO'S MOST EXTENSIVE LATE JURASSIC DINOSAUR QUARRY, by *Rodney Peterson, Ronald Peterson, N. V. D'Andrea, Spencer G. Lucas,* and *Andrew B. Heckert,* New Mexico Museum of Natural History and Science, 1801 Mountain Rd. NW, Albuquerque, NM 87104

The Peterson site, NMMNH locality 3282, is the most extensive Jurassic dinosaur locality yet discovered in New Mexico. Located in Bernalillo County near Cañoncito, it is a mass burial assemblage of dinosaur bones in the Brushy Basin Member of the Morrison Formation. The bone-bearing horizon at the site is a 1.1- to 3-m-thick, trough-crossbedded sandstone approximately 25 m below the base of the Jackpile Member of the Morrison Formation. Discovered in 1963, the site has been regularly excavated since 1989 and has yielded more than 100 dinosaur bones, but it is far from completely excavated. Dinosaur taxa from the site include a large allosaurid theropod, a diplodocid sauropod and other(?) sauropods.

The dinosaur bones at the Peterson site are mostly disarticulated and partially articulated limb bones, vertebrae, and ribs with a general NW–SE alignment that parallels the paleocurrent as indicated by SE-dipping trough crossbed axes. This provides strong prima facie evidence of fluvial transport and hydraulic concentration of the bones. However, clay balls associated with the bones, the large size of the bones, and their evident lack of abrasion suggest that transport distances were relatively short. Some bones at the site are tilted on bedding planes with a dip of about 8° down to the NW, suggesting they may have been mired on a bar or levee margin.

The Peterson site thus is a fluvially transported and winnowed lag deposit of large dinosaur bones, mostly of sauropods. It thereby resembles taphonomically most of the large dinosaur bone quarries known from the Morrison Formation in the western United States. The Peterson site also supports recognition that deposition of the Brushy Basin Member took place on riverine floodplains, not in a large, shallow lake.

A PARTIAL SKULL OF A PACHYCEPHALOSAURIAN DINOSAUR FROM THE UPPER CRETACEOUS KIRTLAND FORMATION, SAN JUAN BASIN, NORTHWESTERN NEW MEXICO, by *Thomas E. Williamson,* New Mexico Museum of Natural History and Science, 1801 Mountain Rd. NW, Albuquerque, NM 87104

A partial skull (NMMNH P-27403) from the Upper Cretaceous (upper Campanian) De-na-zin Member, Kirtland Formation, San Juan Basin, represents a pachycephalosaur (Dinosauria: Pachycephalosauria). Previous identifications of Pachycephalosauria from the San Juan Basin have been questionable or erroneous and were based only on isolated teeth. Therefore, this represents the first certain report of Pachycephalosauria in New Mexico.

The skull of P-27403 includes most of the fronto-parietal dome as well as most of the right supraorbital II, the right postorbital and postfrontal, the right squamosal, and much of the basicranium. The new specimen differs from all previously described pachycephalosaur taxa in North America. The skull lacks a distinct squamosal shelf as is seen in *Stegoceras* and *Stygimoloch* and exhibits derived "pachycephalosaurine" features such as closed supratemporal fenestrae, a high dome, and marked anteroventral rotation of the occiput that unite it with *Prenocephale* and *Pachycephalosaurus*. The new specimen further resembles *Prenocephale prenes* from the Nemegt Formation, Mongolia, in its possession of a single row of low conical nodes along the posterior and lateral margins of the squamosal.

The new pachycephalosaur specimen is a new member of the Willow Wash local fauna that also includes the dinosaurs *Parasaurolophus tubicen*, *Naashoibitosaurus ostromi, Pentaceratops sternbergi*, and a new genus and species of Ankylosauridae. The new pachycephalosaur specimen increases the distinctiveness of the Willow Wash local fauna compared to near contemporaneous faunas of western North America. This marked faunal difference supports the argument for relatively strong provinciality among terrestrial faunas during the Late Cretaceous of western North America.

NEWLY DISCOVERED SKULL OF THE PROBOSCIDEAN *GOMPHOTHERIUM* FROM THE MIOCENE OF THE ESPAÑOLA BASIN, NEW MEXICO, by *Spencer G. Lucas, Andrew B. Heckert,* and *Gary S. Morgan,* New Mexico Museum of Natural History and Science, 1801 Mountain Rd. NW, Albuquerque, NM 87104

A nearly complete skull of the primitive proboscidean *Gomphotherium*, New Mexico Museum of Natural History (NMMNH) P-28972, was collected just east of Española, Rio Arriba County, in the area Galusha and Blick (1971, American Museum of Natural History Bulletin 144) referred to as "First Wash." This skull is from the Miocene (late Barstovian–early Clarendonian) Pojoaque Member of the Tesuque Formation. This is also the type horizon of *Mastodon productus* Cope, 1875, now referred to as *Gomphotherium productum* and supposedly the only Miocene proboscidean taxon from New Mexico.

NMMNH P-28972 has complete tusks and M2-3. The right tusk is worn, but the left tusk is unworn, indicating "right handedness" in this Miocene proboscidean. The M2's are worn, but the M3's are little worn and not completely erupted. Assignment of NMMNH P-28972 to *Gomphotherium* is justified by its relatively bunodont upper cheek teeth, which have single trefoils, and its M3 with four lophs. Size of the M3 (length = 135 mm, width = 65 mm) is relatively small for *Gomphotherium* but within the size range of a very polymorphic species, *G. productum*, as conceived by Tobien. We, however, are skeptical of the validity of so variable a species and note that the newly collected *Gomphotherium* skull falls into the size range of a small species of Santa Fe Group gomphotheres that should be called *G. productum*. A large size group of Santa Fe Group *Gomphotherium*, however, may better be termed a separate species for which the name *G. pojoaquensis* (Frick) is available.

CONTINUITY OF TRIASSIC STRATA AND UNCONFORMITIES ACROSS THE RIO GRANDE RIFT, NORTH-CENTRAL NEW MEXICO, by *Spencer G. Lucas, Andrew B. Heckert,* and *John W. Estep*, New Mexico Museum of Natural History and Science, 1801 Mountain Rd. NW, Albuquerque, NM 87104

Middle Triassic strata of the Moenkopi Formation and Upper Triassic strata of the Chinle Group are readily correlated from the Colorado Plateau eastward across the northern Rio Grande rift to the southern High Plains of eastern New Mexico. Lithostratigraphic and biostratigraphic data thus provide the basis for a detailed correlation of Triassic strata from Fort Wingate on the west to Lamy on the east. This correlation demonstrates the continuity of Middle and Late Triassic deposition across northern New Mexico and that:

1. There is substantial (tens of meters of) stratigraphic relief across three pervasive unconformities: Tr-1, Tr-3, and J-2. These are tectonosequence boundaries that correspond to significant tectonic reorganizations of the Triassic–Jurassic depositional basins. Thus, the Tr-1 erosional surface represents the hiatus from Permian to Middle Triassic time (at least 30 million years) and is overlain by Moenkopi fluvial deposits. Tr-3 is the unconformity between early Middle Triassic (Moenkopi) and early Late Triassic (Chinle) rocks (about a 10 million year hiatus), and this surface is overlain by initial fluvial deposits of the Chinle Group. J-2 is the erosional surface between latest Triassic and Middle Jurassic strata (about a 45 million year hiatus) overlain by Entrada eolianites.

2. There is much less regional stratigraphic relief on the Tr-4 unconformity. This is consistent with the fact that the Tr-4 unconformity is an intrabasinal unconformity that represents a relatively short temporal hiatus close to the Carnian–Norian boundary

3. The nature of the Tr-5 (= J-0) unconformity is difficult to evaluate using these data because in most of the sections the youngest Triassic strata pre-date the Tr-5 unconformity. Nonetheless, the varying thicknesses of the Painted Desert Member of the Petrified Forest Formation and its correlatives may in part be due to erosion beneath the Tr-5 unconformity.

THE LOWER CRETACEOUS SECTION AT EAGLE NEST, LUNA COUNTY, NEW MEXICO, by *John W. Estep* and *Spencer G. Lucas,* New Mexico Museum of Natural History and Science, 1801 Mountain Rd. NW, Albuquerque, NM 87104

Lower Cretaceous strata exposed at Eagle Nest in Luna County (sec. 34 T27S R5W) overlie Permian limestone and are overturned to the southeast. The Lower Cretaceous section here is at least 400 m thick and is assigned to the Hell-to-Finish and U-Bar Formations of the Bisbee Group. The Hell-to-Finish Formation disconformably overlies Permian strata (probably Colina Limestone) and is 175 m thick. The lower third of the Hell-to-Finish Formation (about 50 m thick) consists of interbedded cobble conglomerates (clasts are Paleozoic limestone and chert up to 15 cm in diameter) and red-bed mudstones. The upper two-thirds are interbedded red-bed mudstone, calcareous shale, calcarenite, nodular (pedogenic?) limestone, limestone-cobble conglomerate, and sandstone.

We place the contact of the Hell-to-Finish and U-Bar Formations at the base of a 5-m-thick ledge of bivalve packstone. Above this bed, U-Bar strata are interbedded bivalve and gastropod packstones, calcareous shale, and calcarenites. The exposed U-Bar Formation at Eagle Nest is about 230 m thick, if a 75-m-thick covered interval about 25 m above its base is included, but no top of the U-Bar Formation is exposed here. About 100 m below the top of the U-Bar Formation at Eagle Nest, at NMMNH locality 3755 (UTM 3533302N, 279207E, zone 13, NAD 27), fossils of *Quadratotrigonia* and other bivalves indicate a late Aptian age. Lithology and biostratigraphy thus support assignment of the exposed U-Bar section at Eagle Nest to the Carbonate Hill Member. The upper Aptian Carbonate Hill Member of the U-Bar Formation is present at all U-Bar sections in southwestern New Mexico and thus provides an important basis for regional correlation of the Lower Cretaceous.

GEOCHEMISTRY OF HOST ROCKS, VEINS, REPLACEMENTS, AND JASPEROIDS IN THE HILLSBORO DISTRICT, SIERRA COUNTY, NEW MEXICO, by *Virginia T. McLemore*, ginger@gis.nmt.edu, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801; *M. T. Heizler* and *Erik A. Munroe,* Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801

New geochemical, geochronological, and geological data, combined with earlier studies, have provided a refinement of the evolution of the mineralization in the Hillsboro (Las Animas) district in central New Mexico. Laramide (polymetallic) vein, placer Au, carbonate-hosted Ag–Mn, Laramide skarn, and porphyry-Cu deposits are found in this district. Past production has been predominantly from the Laramide veins, although minor production has occurred from the carbonate-hosted deposits. During 1877–1982 an estimated 270,000 troy oz Au (lode and placer), 78,000 troy oz Ag, 24 million lbs Cu, and 153,387 lbs Pb were produced. The Copper Flat porphyry-Cu deposit in the central part of the district was discovered in 1975. Quintana Minerals Corp. produced approximately 7 million lbs of Cu in March–June 1982, prior to closure of the open-pit mine. Alta Gold Co. is applying for mining permits to reopen the Copper Flat mine.

The geology of the Hillsboro district is dominated by Cretaceous andesite flows (75.4 ± 3.5 Ma, $^{40}Ar/^{39}Ar$), breccias, and volcanoclastic rocks that were erupted from an andesite volcano. The Copper Flat quartz monzonite porphyry (74.93 ± 0.66 Ma, $^{40}Ar/^{39}Ar$) intruded the vent of the volcano. The unmineralized Warm Springs quartz monzonite (74.4 ± 2.6 Ma, $^{40}Ar/^{39}Ar$) is south of the Copper Flat porphyry. A third altered, unmineralized quartz diorite crops out in the northern part of the district. These two intrusions most likely represent small, satellite stocks that intruded along fracture zones on the flanks of the volcano. Latite and quartz latite dikes intruded the andesite and Copper Flat porphyry and radiate outwards from the Copper Flat porphyry. A $^{40}Ar/^{39}Ar$ plateau age of 70.21 ± 0.20 Ma of a latite dike is distinctly younger than the andesite and quartz monzonite and could represent the true cooling age or was reset by younger hydrothermal activity. The igneous rocks are part of a differentiated comagmatic suite. The andesites are metaluminous and alkaline; the quartz monzonites and latites are peraluminous and alkaline to subalkaline. The linear variation in Nb/Zr, Zr/TiO_2, V/TiO_2, and various major elements suggests that the igneous rocks are comagmatic. Alteration of the igneous rocks consists of locally intense silicification and K-metasomatism. Large jasperoid bodies have replaced limestones belonging to the El Paso Formation, Fusselman Dolomite, and Lake Valley Limestone in the southern part of the district. The Sugarlump Tuff (35 Ma) unconformably overlies some of the jasperoids, indicating jasperoid formation prior to formation of the Emory caldera.

The Copper Flat porphyry-copper deposit consists of Cu, Au, Mo, and Ag disseminations and quartz veins in a breccia-pipe in the quartz monzonite stock. It is predominantly a low-grade hypogene deposit that is concentrated within a breccia pipe containing pyrite, chalcocite, chalcopyrite, azurite, malachite, and cuprite. Copper Flat has reported reserves (Dec. 31, 1997) of 56,549,000 tons of ore grading 0.432% Cu, 0.14 ppm Au, 2.19 ppm Ag, and 0.014% Mo.

Many workers in the district have recognized district zoning. The Copper Flat porphyry-Cu deposit forms the center. Propagating outward radially from the Copper Flat porphyry are Laramide Au–Ag–Cu veins hosted by many of the latite dikes. Chemical analyses range from 8–64,600 ppb Au, <0.2–590 ppm Ag, 40–57,337 ppm Cu, <1–475 ppm Mo, 57–8,906 ppm Pb, and 138–17,026 ppm Zn. Carbonate-hosted replacement deposits (Ag, Pb, Mn, V, Mo, Zn) are found in the southern and northern parts of the district, distal from the center. Chemical analyses range from <5–99 ppb Au, 1–<50 ppm Ag, 131–173 ppm Cu, 2–140 ppm Mo, 30–>10,000 ppm Pb, and 123–>20,000 ppm Zn. Collectively, the evidence suggests that the deposits found in the Hillsboro district were formed by large, convective hydrothermal systems related to the Copper Flat volcano and subsequent intrusion of the quartz monzonite and latite dikes.

A VOLCANO REVISITED: A PRELIMINARY REPORT OF THE GEOLOGY OF LOS LUNAS VOLCANO, CENTRAL NEW MEXICO, by *Kurt Panter,* kpanter@western.edu, Western State College, Gunnison, CO 81231; *Bruce Hallett*, bhallett@golder.com, Golder Associates Inc., Edgewood, NM 87015; *Dave Love,* dave@gis.nmt.edu; *Chris McKee*, xrf@gis.nmt.edu, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801; *Rebecca Thompson*, fsbeckyt@western.edu, Western State College

Preliminary results show Los Lunas volcano is a polygenetic center composed primarily of intermediate lavas with subordinate pyroclastic lithologies. Los Lunas is one of six principal Pliocene–Pleistocene volcanic centers erupted within the Albuquerque Basin—an extensionally formed depression within the Rio Grande rift system. Los Lunas volcano is currently being mapped under the U.S. Geological Survey's National Cooperative Geologic Mapping Program. Approximately 70 samples have been collected for geochemistry and $^{40}Ar/^{39}Ar$ geochronology.

Based on volcanic stratigraphy, landscape morphology, and two previous $^{40}Ar/^{39}Ar$ dates, Los Lunas volcano is considered to have at least two main periods of eruptive activity. The older center, a low-lying jumbled mass SW of the 5,955-ft central summit, consists of four volcanic units. The youngest of these units is an extensive flow complex of dacitic lavas dated at 3.88 ± 0.01 Ma (Love et al., 1994). These flows are massive and generally faulted into large blocks. Many of the flows have a lower medium dark-gray base that is heavily fractured into thin (~5 cm) lensoids, possibly a texture resulting from cooling and/or shear stress. In other locations, the lava bases exhibit thick (up to 4 m) flow breccias. Underlying this flow to the south is a pyroclastic breccia and lapillistone and an underlying, coeruptive flow. Both flows are tilted and faulted along with underlying sediments and are, in places, overlain by eolian and fluvial sand and gravel lithofacies. A black dacitic ash, up to 2 m thick, which is overridden and deformed by the extensive upper flow, is exposed within a prominent NW–SE canyon separating the old and young centers. Several dacitic intrusives occur as isolated hills to the south and southeast of the volcano and are believed to be age-correlative with the older center.

The younger volcano of the Los Lunas complex forms the central edifice with two prominent lava lobes that extend to the E and SE from the summit. The volcano consists of at least five eruptive units (four lavas and one pyroclastic deposit) and has been faulted and uplifted 150 m above the surrounding topographic top of basin fill. All of the units are trachyandesite in composition, and one lava has been dated at 1.22 ± 0.01 Ma (Love et al., 1994). The oldest unit is a massive chocolate-brown flow that forms a laterally continuous (but faulted) lava and eruptive edifice along the top of the pre-eruptive surface on the west, north, and northeast sides of the young volcano. The flow is generally less than 8 m thick but is ponded to the north (18 m) and on the SW edge (20 m) of the volcano. Crustal xenocrysts are common within the chocolate-brown flow. It is overlain by a light grayish-red flow on the east side. The next youngest lava forms a small isolated outcrop to the west of the main summit. A 2–5-m-thick, red, scoriaceous pyroclastic fall, consisting of individual bombs and lapilli agglutinate, mantles both chocolate-brown and high western lava. All three units are cut by a prominent N–S-trending fault exposed north of the summit and which displaces the units as much as 30 m down to the east. The youngest unit is a light-gray to brown flow(s) originating from a central vent near the summit. This unit forms extensive flow lobes to the E and SE of the summit.

Preliminary results from major and trace elements (XRF analysis) reveal some important differences between the two volcanoes. Although the dacitic compositions of the older volcano appear more evolved (12–18% *Q*-norm) relative to the younger trachyandesite volcano (3–8% *Q*-norm), the range in Mg#'s (100*Mg/Mg+Fe) are roughly equivalent (44– 51). In addition, highly incompatible trace elements such as Ba, Th, and Nb have significantly lower concentrations in the dacites relative to trachyandesites—all of which suggest a fundamental petrogenetic difference between the two volcanoes.

Reference

Love, D.W., Reynolds, C.B., Hallett, B., Lozinsky, R.P., and Niemyjski, T., 1994, Sedimentation, deformation, and erosion related to Los Lunas

volcanoes, central New Mexico (abs.): New Mexico Geology, v. 16, no. 3, p. 57.

MIDDLE PROTEROZOIC METAMORPHISM AND DEFORMATION IN THE PECOS COMPLEX, NEW MEXICO, U.S.A., by *Erwin A. Melis*, eamelis@nmt.edu, *Laurel B. Goodwin*, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801; and *Matt Heizler*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

The regional significance of ca. 1,400 Ma deformation of Proterozoic continental crust in the southwestern United States is controversial. Some workers have proposed that metamorphism and deformation were restricted to the margins of ca. 1,400 Ma plutons. Others suggest that ca. 1,400 Ma deformation and metamorphism were regional in extent. Our work supports the latter interpretation but indicates that strain was distributed heterogeneously in New Mexico during Middle Proterozoic deformation.

The Pecos complex of northern New Mexico provides an ideal site to study Proterozoic deformation and metamorphism, as it includes dated granitoid plutons of three distinct ages: ca. 1,718 ± 5 Ma (Yavapai orogeny), 1,650 Ma (Mazatzal orogeny), and ca. 1,480 Ma. All three plutons exhibit a generally easterly striking, south-dipping, solid-state foliation; where present, a stretching lineation plunges shallowly. Locally developed kinematic indicators in both the oldest and youngest intrusions record dextral strike-slip shear. The foliation is variably developed in all three plutons; much of the youngest pluton is not foliated. Definitive evidence of older structures has not been found; however, intrafolial folds in one locality and variations in orientation of the foliation in the older plutons suggest that an older foliation may have been overprinted. Deformation was accompanied by amphibolite-facies metamorphism. Local retrogression of hornblende to actinolite appears to have largely postdated deformation.

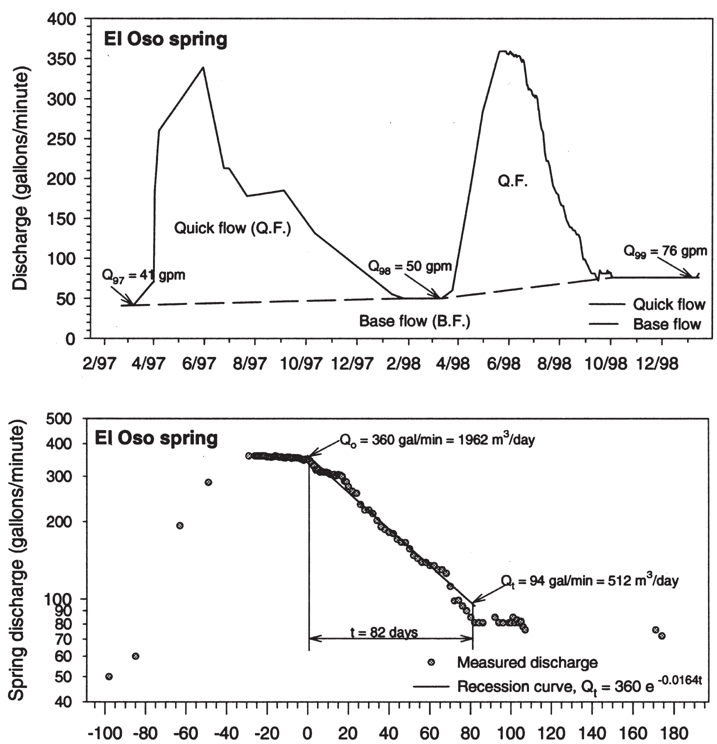
$^{40}Ar/^{39}Ar$ dates on hornblende fall within the range of 1,372 ±1 0 Ma. Cooling through the closure temperature of hornblende (~500°C) therefore postdates intrusion of the ca. 1,480 Ma granitoid. The timing of dextral strike-slip shear, which occurred under amphibolite-facies conditions, therefore is bracketed by dates on intrusion and the cooling of hornblende. We thus have evidence of a regionally extensive, ca. 1,400 Ma fabric in the Pecos complex. It is significant that this fabric formed at least in part through strike-slip shear, since previous models of this deformation event emphasized either regional shortening or extension. This work suggests that deformation was regional in extent, that strain was distributed heterogeneously, and that current models are inadequate to explain the kinematics of the structures we observe in the field.

PRELIMINARY STUDIES OF THE RECENT SOIL-GEOMORPHOLOGIC HISTORY OF A FLUVIAL SYSTEM, RIO CALAVERAS, JEMEZ MOUNTAINS, NEW MEXICO, by *Ivan Erchak* and *Tim Gere*, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

The disciplines of pedology and geomorphology have been integrated with great success, helping to illuminate processes of landform development during the Quaternary. In this research we show that the recent history of the fluvial system in a small drainage basin can be understood by coupling the detailed descriptions of soils with geomorphic and other field criteria. While many soil-geomorphologic studies have been conducted on the Pajarito Plateau, located on the east flank of the Jemez Mountains of northern New Mexico, relatively few have been conducted on the Jemez Plateau, located on the west flank. The study area is part of the Rio Calaveras drainage, which is cut into the Bandelier Tuff and located approximately 3 km west-northwest of the Valles caldera. Fluvial landforms that dominate the inner valley at the site are shown to have developed within the past 700 yrs. Two distinct, laterally continuous geomorphic surfaces are observed. The upper surface is a fluvial terrace, located between 2 and 3 m above the current stream level, and the lower surface is the current floodplain, located about 0.5 m above the active channel bed. Each of these surfaces exhibits different degrees and types of soil development, which we conclude are both time and space dependent. The ages of the soils and associated surfaces were derived in part by establishing ages through preliminary dendrochronological studies of the trees on the surfaces. The initial stages of pedogenesis occur rapidly in many environments (Birkeland, 1984), and therefore rates of soil development on the surfaces are reflected in time-dependent soil features. On such a short time-scale, spatial dependence is also very important to consider. For example, the presence of a single tree has greatly influenced local soil development. Studying and interpreting the history and evolution of late Holocene fluvial systems such as this one requires an interdisciplinary approach involving geomorphology, sedimentology, pedology, and ecology. This research is the first stage of a larger project to be conducted as a part of Master's thesis at the University of New Mexico. This study should help better define the geomorphic framework in which the hydrologic system is operating, thereby providing valuable input to ongoing hydrogeoecologic studies of nutrient cycling related to a seasonally fluctuating water table.

A DOUBLE-POROSITY MODEL OF GROUND-WATER FLOW IN THE MADERA FORMATION BASED ON SPRING HYDROGRAPHS AND AQUIFER TEST ANALYSES FROM PLACITAS, NEW MEXICO, by *Peggy Johnson*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

The Madera Formation forms a carbonate aquifer of regional significance for groundwater development in the Sandia Mountains east of Albuquerque, New Mexico. Characterization of carbonate aquifers is problematic due to the localized nature of groundwater flow in fractured limestone. Spring hydrographs and aquifer test data indicate that ground water in the Madera aquifer moves as combined diffuse flow and fracture flow. Aquifer test drawdown data fit a dou-



ble-porosity model and show that ground water is primarily transmitted through large fractures, but the majority of aquifer storage is attributable to the limestone matrix. Fracture transmissivity ranges from 170 to 200 m^2/d. Total storativity, for both fractures and matrix, is 0.20–0.25. The fractures transmitting the bulk of spring discharge are associated with faults in the Madera Formation. Spring hydrographs from fault-controlled springs near the village of Placitas may provide a potentially valuable source of data on Madera aquifer hydraulic properties, including effective porosity, transmissivity, storage, water budgets, and recharge. Hydrograph separation and recession curve analysis yield preliminary estimates of dynamic storage and recharge for three Placitas village springs. Further work is required before the full potential of spring hydrograph data can be utilized as a regional aquifer characterization tool in the Madera Formation.

ORIGAMI LEADS TO OROGENY: USE OF THREE-DIMENSIONAL PAPER MODELS FOR GEOSCIENCE EDUCATION FROM MINERALOGY TO EARTHQUAKES, by *David W. Love, Jan Thomas,* and *William C. Haneberg*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Basic geometric forms such as cubes, octahedra, rhombohedra, and tetrahedra may be made by folding flat paper or envelopes, both reasonably priced starting materials. These may be used to help visualize solid forms in crystallography and mineralogy, and numbers of them may be used to create unit cells. Tetrahedra in particular are easy to make by folding and cutting small envelopes. Tetrahedra may be linked to build silicate and carbonate crystal models.

A ring of six tetrahedra may be linked along two sides of each to form a hexaflexagon. Spillhaus and the GeoLearning Corporation (Sheridan, Wyoming) have produced hexaflexagons with illustrated geographic, geologic, and astronomic themes on each side printed on stiff paper (Spillhaus copyright, 1985). These models are also reasonably priced and require assembly. As an alternative, we have combined the rapid production of tetrahedra from envelopes with various geological themes printed in color on hexagons to produce customized hexaflexagons covering the topics of earthquakes, plate tectonics, and geology of New Mexico.

Illustrations showing how to make a tetrahedron and hexagonal illustrations that can be printed and mounted on the sides of hexaflexagons are available at the New Mexico Bureau of Mines and Mineral Resources earthquake education Web site (http://tremor.nmt.edu/). The files are currently available as downloadable and printable .gif files and may be available as higher resolution .pdf files in the near future.

DRILL CORE, CUTTINGS, AND GEOLOGICAL RESOURCES AVAILABLE AT THE NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES, by *E. R. Fleming, G. K. Hoffman,* and *A. S. Read,* New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

The core and cutting library archives at the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) make available representative samples from rock formations in different parts of New Mexico. Drill cuttings from 15,000 wells and more than 1,000 different cores are stored at the NMBMMR. The core library consists of five warehouses, a processing area in each building, equipment for slabbing core, and microscopes for the examination of cuttings. The library is an important source of geological and engineering information regarding exploration for, and development and preservation of, oil and natural gas, water, coal, uranium, metallic and industrial minerals, and carbon dioxide in New Mexico. An excerpt from the database of archived core is shown in Table 1. This data will be available on the NMBMMR web site at http://geoinfo.nmt.edu.

Additional resources at the NMBMMR include a number of different types of information related to the core and cuttings in its repository. The Subsurface Library contains well records, drillers' logs, electric and other geophysical logs, sample logs, and descriptions. Source-rock analyses, biostratigraphic data, petroleum-exploration maps, geologic maps, production data, petroleum-related publications, field and pool data and maps, and a number of core analyses and drill-stem test records are also available. The Geologic Information Center (GIC) is a specialized library and archive focusing on geologic data relating to New Mexico's mining, milling, petroleum industries, and water resources. The GIC also contains unpublished mine reports, maps, and all NMBMMR open-file reports. Recently a coal library has been established to store geophysical logs, chemical analyses, maps, and reports from coal-exploration projects in New Mexico. The NMBMMR also houses information on the state's water resources, including information for use in developing and protecting water supplies, evaluating water-quality and pollution problems, operating and reclaiming mines, and utilizing geothermal resources. Some National Uranium Resource Evaluation (NURE) data are available at the NMBMMR, along with various geologic maps, reports, and logs.

Professional staff are available for consultation on the different resources provided at the NMBMMR. For a complete overview of the NMBMMR's resources visit our web site at http://geoinfo.nmt.edu.

Table 1—Excerpt from District Core Archive Table

District/Field/ Basin name	Company name	Twp	Rng	Sec	Type	Total wells
Willow Creek	Perry, Knox & Kaufman	18N	12E	27	Lead/Zinc	6
District Total Number of wells						6
Zuni Mountains	Conoco Metallics	11N	12W	6	Uranium	2
District Total Number of wells						2
Albuquerque Basin	Shell Oil	8N	2E	16	Oil & Gas	1
District Total Number of wells						1

Two abstracts from the poster session (nos. 6 and 7) were the catalyst for a letter to *New Mexico Geology*. Abstracts 6 and 7 are printed below, followed by the letter and a response from the abstracts' authors.

JURASSIC STRATIGRAPHY IN THE TIJERAS SYNCLINE, BERNALILLO COUNTY, NEW MEXICO, by *Spencer G. Lucas, John W. Estep*, and *Orin J. Anderson*, New Mexico Museum of Natural History and Science, 1801 Mountain Rd. NW, Albuquerque, NM 87104

Jurassic strata are intermittently exposed along the western, northern, and northeastern limbs of the Tijeras syncline (Cedar Crest–Sandia Park areas, Bernalillo County). The singlemost complete and well-exposed section crops out in the NW⁄SW⁄ sec. 31 T11N R5E and well represents the outcrop belt. Here, the Jurassic strata are 169 m thick and are (ascending): (1) Dewey Bridge Member of Entrada Sandstone, 11.5 m of mostly reddish brown, ripple-laminated, fine sandstone that disconformably overlies red-bed mudstones of the Upper Triassic Petrified Forest Formation of the Chinle Group; (2) Slick Rock Member of Entrada Sandstone, yellow, coarse, trough-crossbedded sandstone about 10.5 m thick; (3) Luciano Mesa Member of Todilto Formation, 2.2 m of thinly laminated, kerogenic limestone; (4) Tonque Arroyo Member of Todilto Formation, 20.5 m of massive, white gypsum; (5) Summerville Formation, 31 m of red, ripple-laminated sandstone, massive gypsiferous sandstone, and cyclically bedded, variegated siltstone, shale, and nodular limestone; (6) Salt Wash Member of Morrison Formation, 21 m of fine to coarse, trough-crossbedded feldspathic sandstone with lenses of clay-pebble conglomerate and red-bed mudstone; (7) Brushy Basin Member of Morrison Formation, 32 m of mostly covered, smectitic, green claystone with some thin lenses of nodular limestone and fine-grained sandstone; (8) Jackpile Member of Morrison Formation, 32 m of trough-crossbedded kaolinitic sandstone overlain by the Oak Canyon Member of the Cretaceous Dakota Formation. The Jurassic section in the Tijeras syncline thus is very similar to that exposed nearby in the Hagan Basin and at Galisteo Dam, though thinner. The unit mapped in the Tijeras syncline by Ferguson et al. (1996, NMBMMR Open-file Digital Map OF-DM-1) as the Bluff Sandstone is actually the Salt Wash Member of the Morrison Formation.

THE INTERTONGUED DAKOTA–MANCOS (CRETACEOUS) SECTION IN THE TIJERAS SYNCLINE, BERNALILLO COUNTY, NEW MEXICO, by *Spencer G. Lucas*, *Orin J. Anderson,* and *John W. Estep,* New Mexico Museum of Natural History and Science, 1801 Mountain Rd. NW, Albuquerque, NM 87104

The oldest Cretaceous strata exposed in the Tijeras syncline (Cedar Crest–Sandia Park area, Bernalillo County) belong to the intertongued Dakota Formation and Mancos Shale of Cenomanian (early Late Cretaceous) age. Previous workers interpreted this stratigraphic interval as either: (1) undifferentiated Dakota Formation directly overlain by undifferentiated Mancos Shale (Kelley and Northrop, 1975, NMBMMR Memoir 29) or (2) lower Dakota Formation overlain by a covered interval followed by a thin sandstone interval probably correlative with the Twowells Tongue of the Dakota Formation (Molenaar, C. M., 1983 *in* Mesozoic paleogeography of the west-central US: RMS-SEPM; Ferguson et al., 1996, NMBMMR Open-file Digital Map OF-DM-1). However, detailed stratigraphy of this interval and its correlation to nearby, better exposed sections in the Hagan Basin and at Galisteo Dam support a different interpretation of the Dakota–Mancos section in the Tijeras syncline.

The critical outcrop is along Gutierrez Canyon in the SE⁄NW⁄ sec. 29 T11N R6E. Here, the section is: (1) about 10 m of trough-crossbedded quartzarenitic sandstone, with a bioturbated uppermost 0.6 m, of basal Dakota Formation disconformably overlying Upper Jurassic Jackpile Member of Morrison Formation; (2) a 31-m-thick interval of gray shale that forms a mostly covered slope; (3) a 7-m-thick bioturbated sandstone cuesta; (4) a mostly covered 63-m-thick interval of dark-gray shale with numerous thin bentonite beds; (5) the Bridge Creek Member of the Greenhorn Formation, a 3.7-m-thick limestone with the index bivalves *Pycnodonte newberryi* and *Mytiloides mytiloides* at NMMNH locality 4105 (UTM 379273E, 3890240N, zone 13, NAD27). By correlation to the Hagan and Galisteo sections, units 1–2 = Oak Canyon Member of Dakota, unit 3 = Cubero Member of Dakota and unit 4 = Graneros Shale. Stratigraphic position, lithology, relative thicknesses, and position relative to the Greenhorn confirm that in the Tijeras syncline the upper Dakota sandstone interval is Cubero, not Twowells.

April 30, 1999
Dear *NMG*,

This letter is in response to a discussion with Spencer Lucas at the 1999 NMGS spring meeting at a poster session where Lucas et al. (1999a,b) reported significant findings regarding the Mesozoic stratigraphy of central New Mexico. The findings where presented in two abstracts focused on Cretaceous and Jurassic stratigraphy. Since two of the abstracts deal directly with areas recently mapped and described in detail by New Mexico's STATEMAP program, I feel compelled to respond to some of the statements that I believe are misleading and incorrect.

Cretaceous

Lucas et al. (1999a) report the discovery of the critical outcrop for reinterpreting the stratigraphy of the intertongued Dakota–Mancos section in the Tijeras syncline. The outcrop they describe is merely another exposure of the *Mytiloides mytiloides*-bearing black micrite bed that we identified and described at two other nearby localities (Ferguson et al. 1996, p. 4). An excerpt from our report is included.

> The most continuous exposure of Mancos Shale is near the head of Arroyo San Antonio, along the eastern half of the boundary between secs. 25 and 36 T11N R5E. In this gully, the oldest exposed rock is a dark-gray shale with a 20–60-cm-thick black micrite bed containing the bivalve *Mytiloides mytiloides*. This limestone is overlain by at least 100 m of black, noncalcareous shale with abundant septarian nodules as much as 1 m in diameter. Above the septarian nodule shale is a shale sequence with several thin- to medium-bedded calcareous sandstone beds. These sandstone beds, which also are preserved in the next gully to the north, contain abundant bivalve fragments and the ammonite *Prionocyclus novimexicanus* (sample F-95-54).
>
> The Mancos shale is also exposed along the headwaters of Gutierrez Canyon in the east limb of the Tijeras syncline. Incomplete exposures here suggest a similar stratigraphic sequence to that along Arroyo San Antonio. A *Mytiloides mytiloides*-bearing black micrite (sample F-95-49) is present just above the uppermost Dakota Formation exposure. Farther downstream a medium-bedded calcareous sandstone contains fragments of the ammonites *Prionocyclus novimexicanus* and *Scaphites whitfieldi* and the bivalve *Inoceramus rotundatus* (sample F-95-52). The *Scaphites whitfieldi* indicates a late Turonian biostratigraphic age for this interval, and, based on precise laser-fusion radiometric ages from sanidine phenocrysts in bentonites elsewhere in the western interior basin, an absolute age of between 90.21 ± 0.72 Ma and 88.34 ± 0.60 Ma (Obradovich, 1993). Kauffman et al. (1993) reported an age of 89.4 Ma for the *Scaphites whitfieldi* (T12) biozone.

Based on the "discovery" of this limestone, Lucas et al. (1999a) reinterpret a thin and discontinuous, bioturbated sandstone approximately 63 m below the limestone as the Cubero Member of the Dakota Formation, and not the Twowells Tongue. They cite stratigraphic position relative to the black micrite bed, lithology, and relative thickness of the intervening shales as evidence for the correlation. At least three tongues of Dakota Formation occur within Mancos Shale of central New Mexico, with the Twowells Tongue being the youngest and the Cubero Member being the oldest. All of the Dakota Formation sandstones underlie the Greenhorn Formation (which includes the *Mytiloides mytiloides*-bearing black micrite bed), and all consist chiefly of bioturbated, marine, quartz-rich sandstone, although the Twowells is generally coarser grained (Owen and Siemers, 1977). It seems that the only evidence Lucas et al. (1999a) have for suggesting this reinterpretation is the relative thicknesses of the intervening shales, a criteria that most geologists would find equivocal considering that the next available outcrops that include this sequence are nearly 30 km to the north. Ferguson et al. (1996) mapped the sandstone in question as upper Dakota Formation and merely suggested that it might correlate with the Twowells Tongue. The sandstone may indeed be the Cubero Member, but until definitive biostratigraphic evidence is presented, I suggest that this thin and relatively minor sandstone remain as we mapped it, an informal unit.

Jurassic

Lucas et al. (1999b) report the discovery of the most complete and well-exposed section of Jurassic rocks in the Tijeras syncline at the south end of a north-striking hogback near the Cedar Crest Post Office (NW⁄SW⁄ sec 31 T11N R5E), an area mapped in detail by Ferguson et al. (1996). I agree that the section is well exposed, but the outcrops are cut by numerous faults, and they lie in an exceptionally structurally complex area adjacent to the Tijeras fault. There may be structural repetitions or omissions of the section depending on where it is measured, and as a structural geologist I would (and have) cautioned against using any section of strata along this hogback for determining thicknesses of units.

The section is also not representative of the Jurassic sequence in Tijeras syncline as is suggested by Lucas et al. (1999b). In particular, the sandstone body that directly overlies the Summerville Formation is atypical. This sandstone, which Lucas et al. (1999b) identified as the Brushy Basin Member of the Morrison Formation, thickens to the north and changes character into a medium- to thick-bedded, planar-laminated and cross-stratified, moderately to well-sorted, feldspathic sandstone (Ferguson et al., 1996). I agree that the sandstone identified as Brushy Basin Member by Lucas et al. (1999b) is sedimentologically and compositionally more akin to the Morrison Formation and that the map ought to be revised in this small area. I think, however, that issuing the statement, "The unit mapped in the Tijeras syncline by Ferguson et al. (1996) as the Bluff Sandstone is actually the Salt Wash Member of the Morrison Formation," is wrong and misleading.

The sandstone mapped by Ferguson et al. (1996) as Bluff Sandstone in most areas of the Tijeras syncline was distinguished from the overlying Morrison Formation by its "higher degree of sorting, its lack of mud-chip clasts, and the less-altered (pinkish-colored) nature of its feldspar sand grains." Although very poorly exposed, the sandstone also displays abundant eolian sedimentological features such as large-scale, planar-tabular to wedge-planar cross-stratification, and planar laminations reminiscent of sub-critically climbing translatent ripple stratification. An eolian body in this part of the section would correlate with the Bluff Sandstone, an important eolian unit of the interior Colorado Plateau, and is significant because it would represent an eastern outlier of this lithofacies on paleogeographic maps.

A suggestion

The advancement of science depends to a large degree on accumulated knowledge and information and on the ability of scientists to tap into these resources. A scientist who starts from the beginning on every project would never get very far. Although it is sometimes difficult to acquire obscure maps and reports about an area, it is always in the best interest of the field scientist to be aware of what has already been done. I discovered during my discussion with Dr. Lucas that he had not read our map or report on the Sandia Park quadrangle (Ferguson et al., 1996) before his field investigations. It was also clear that at the time of our discussion, he still had not read our report. Although I applaud his effort and his important discovery of another index fossil in the Mancos Shale, I find that his methods leave much to be desired. Our mapping program was directed principally at the structural complications of the Sandia Mountains, but we also made a serious effort to identify important biostratigraphic features, and we invested a great deal of time integrating this information into our maps and reports.

Sincerely,

Charles A. Ferguson
Arizona Geological Survey
416 W. Congress, #100
Tucson, Arizona 85701

REPLY TO FERGUSON

May 3, 1999

Ferguson et al.'s (1996) geologic map of the Sandia Park quadrangle presents a Jurassic-–Cretaceous section strikingly different from the much better exposed Jurassic–Cretaceous sections in the nearby Hagan Basin (20–25 km to the north) and at Galisteo Dam (40–45 km to the north-northeast). However, our recent field studies indicate that the Jurassic–Cretaceous section exposed on the Sandia Park quadrangle is strikingly similar and thus readily correlated by lithostratigraphy and, where available, by biostratigraphy to the sections in the Hagan Basin and at Galisteo Dam.

Thus, the upper tongue of the Dakota on the Sandia Park quadrangle is the Cubero Tongue (Lucas et al., 1998, 1999a). And, the sandstone above the Summerville Formation is the Salt Wash Member of the Morrison Formation, not the Bluff Sandstone (Lucas et al., 1999b). As in the Hagan Basin and at Galisteo Dam, this sandstone in the Sandia Park quadrangle has fluvial bedforms and pebbly rip-ups; it lacks eolian bedforms.

Ferguson et al.'s map of the Sandia Park quadrangle contains numerous other mistakes with regard to the Jurassic–Cretaceous section, which include: (1) locally, Dakota strata are mapped as Morrison; (2) the map fails to identify several readily mappable units of the Mancos Shale interval—the Greenhorn, Carlile, Juana Lopez, D-Cross, Tocito, and El Vado; (3) locally, slump blocks of Mesaverde sandstone are mapped as a Turonian marine sandstone; and (4) the Mesaverde Group is mapped as units that lack regional significance; Lee (1912, 1917) presents a more stratigraphically useful interpretation of the Mesaverde Group here.

These aspects of the mapping of Ferguson et al. (1996) will be detailed and corrected by us in an upcoming publication. Furthermore, the Second Day fieldtrip of the 50th NMGS Fall Field Conference this September will examine the Jurassic section on the Sandia Park quadrangle, so interested parties will have a chance to evaluate the Jurassic stratigraphy firsthand.

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