Abstracts

New Mexico Geology recognizes the important research of students working in post-graduate MS and PhD programs. The following abstracts are from recently completed MS theses and PhD dissertations that pertain to the geology of New Mexico and neighboring states.

New Mexico Institute of Mining and Technology

SPATIAL VARIABILITY OF DESERT LOESS ON THE CARRIZOZO LAVA FLOW, SOUTH-CENTRAL NEW MEXICO, by *Shari L. Bauman*, 1999, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 106 pp.

The Carrizozo lava flow is an ideal isochronous (5 ka) surface to examine the influences of climate, provenance, and surface-cover types on the abundance of and physical and chemical composition of loess deposits, and the early pedogenic process occurring within the deposits. The Carrizozo lava flow is 75 km long. Its complex surface topography provides catchments for eolian material accumulation, as well as for the development of a range of surface-cover types (i.e. desert pavement, grasses and cacti, and juniper trees). The Carrizozo lava flow is surrounded by various lithologies within the Tularosa Basin, and dust transport is by southwestern prevailing winds.

Surface-cover type influences the loess composition in two ways: (1) by influencing the moisture content and thus the accumulation of chemical constituents in the soil profile during pedogenesis and (2) by preferentially trapping material. In general, higher concentrations of CaO, MgO, S, soluble salts, chloride, and calcium carbonate are found in the south and are indicative of provenance effects. Strong correlations in chemistry coupled with the prevailing wind direction suggest that the evaporite gypsum dune deposit of White Sands and the dolomitic rocks from the San Andres Mountains influence the dust composition.

The Carrizozo dust flux average of 0.54 $g/cm^2/ka$ is very comparable to those found in the southwestern United States and in similar desert environments around the world. The non-pedogenic calcium carbonate chemical composition of the Carrizozo loess is similar to the regional shale standard (NASC), local crustal composition, and to soils developing on the Potrillo volcanic field in southern New Mexico. As expected, high deviation in chemistry is observed when compared to the Carrizozo basalt composition, indicating that the soils are indeed of eolian origin and not basalt weathering products.

Furthermore, surface-cover type, provenance, and wind direction affect the abundance of and physical and chemical composition of the Carrizozo lava flow loess deposits, and the early developmental stages of pedogenesis. The Carrizozo lava flow has provided an opportunity to investigate the spatial variability associated with these factors, as well as the remarkable uniformity of the eolian material and accumulation over the last 5,000 yrs.

STRUCTURAL AND THERMOCHRONOLOGICAL CONSTRAINTS ON THE MOVEMENT HISTORY OF THE MONTOSA FAULT, CENTRAL NEW MEXICO, by *Rose-Anna Behr*, 1999, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 129 pp.

The 90-km-long Montosa fault bounds the east side of the Los Pinos and Manzano Mountains of central New Mexico. Overall fault strike is north-northeast, and dip is 55–70° west. The fault shows predominantly reverse separation and has been interpreted as Laramide in age. Local normal stratigraphic separation across the fault and normal-slip slickenlines on earlier reverse and strike-slip faults indicate that fault reactivation occurred during Neogene Rio Grande rift extension.

Lineations and kinematic indicators on minor fault planes and fold hinges were examined to constrain the direction of maximum shortening during formation of these structures and, by inference, the sense of slip on the Montosa fault. Three different directions of shortening were determined: east-west, northwest-southeast, and north-south. Other workers have reported that structures recording east-west shortening are cross-cut by those recording north-south shortening. East-west shortening would impart dextral reverse oblique-slip motion on the Montosa fault. The central portion of the fault shows strong evidence for northwest-southeast shortening, which would cause sinistral reverse oblique-slip motion on the Montosa fault. Along the north-central portion of the fault, minor planes and folds accommodated north-south shortening, which would result in sinistral reverse oblique-slip motion on the fault. East-west shortening was the most significant stage in the movement history of the Montosa fault, resulting in reverse separation, with a component of dextral strike-slip offset. The Montosa fault also shows evidence of normal reactivation during the Neogene Rio Grande rift formation.

Apatite fission tract (AFT) analysis was used to determine the thermal history of samples collected in several transects across the fault. Because the thermal history of a sample reflects the tectonic history, AFT data can be used to constrain the relative timing of faulting. AFT data from along the Montosa fault indicate that denudation in early Eocene to late Eocene time (55–35 Ma) resulted in cooling of the lower elevations of the Los Pinos Mountains. Samples from the lower elevations of the Manzano Mountains cooled in early Oligocene to early Miocene time (33–22 Ma), ascribable to exhumation following Laramide uplift and during the formation of the Rio Grande rift. The southern fault tip shows normal separation of sedimentary strata, which is attributed to reactivation during rift-related extension. Samples in this area did not cool until the late Oligocene to mid-Miocene (25–14 Ma). Broad track-length distributions suggest that all of the samples remained within the partial annealing zone (PAZ) for apatite (temperatures range from ~60° to ~120°C) for long periods of time where elevated temperatures caused fission tracks to shorten. Thermal modeling of the AFT ages and track-length distributions reveal that the samples remained in the PAZ for 10–30 m.y., then cooled quickly to surface temperatures.

AFT analysis did not show significant age variation across the fault, which indicates that faulting predated cooling; therefore, movement on the Montosa fault during the Laramide orogeny must have occurred at temperatures greater than ~120°C. Any normal fault reactivation during rift formation also occurred at temperatures greater than 60°–120° C or was too minimal to be recorded by AFT.

DEFORMATION WITHIN A BASEMENT-CORED ANTICLINE: TEAPOT DOME, WYOMING, by *Scott P. Cooper,* 2000, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 274 pp.

Teapot Dome is an asymmetric, doubly plunging, basement-cored, Laramide-age anticline. A systematic study of natural fractures within the Cretaceous Mesaverde Formation at Teapot Dome, Wyoming, indicates that lithology and structural position control outcrop fracture patterns. Lithology controls fracture, deformation band, and fault patterns in the following ways: (1) fracture intensity increases with increased cementation; (2) fracture spacing increases proportionally with bed thickness within two sandstone facies but not in carbonaceous shales where fracture spacing is inversely proportional to bed thickness; (3) coal cleats are generally oblique, by up to 20°, to fractures in sandstones; (4) most fractures in sandstone units terminate at contacts with shale layers; (5) deformation bands occur almost exclusively in a poorly cemented, high-porosity, beach-sand facies; and (6) normal faults within well-cemented sandstones are generally expressed as fracture zones, whereas the same faults within poorly cemented sandstones are diffuse zones of subparallel deformation bands.

Three primary through-going fracture sets were documented at Teapot Dome. The oldest fracture set is oblique to the fold hinge. The vast majority of these fractures strike northwest to west-northwest. A small number of these oblique fractures strike roughly north-northeast. Fractures that strike oblique to the fold hinge appear to predate folding. The most common fractures, which are found throughout the fold, are bed-normal extension fractures striking subparallel to the fold hinge. A third set consists of bed-normal extension fractures striking perpendicular to the fold hinge. In many areas this fracture set is spatially related and subparallel to northeast-striking, normal, oblique-slip faults. The normal, oblique-slip faults are common along the eastern limb, but more than 90% of these faults terminate before intersecting the western limb. Conjugate fractures, deformation bands, and faults, oriented such that they have a vertical bisector to the acute angle and striking subparallel to the axis of the anticline, are common in the southwestern limb and southern arc of the anticline. Hinge-parallel and hinge-perpendicular fractures and faults are probably broadly contemporaneous with basement-involved thrusting and folding at Teapot Dome, as suggested by their spatial relationship to the fold. Further observations suggest that fault-related, hinge-perpendicular fractures are generally the same age as hinge-parallel fractures, and that northeast-striking, normal, oblique-slip faults are oriented roughly perpendicular to the fold hinge, even where it bends, and terminate toward the southwest limb of the anticline. The oblique movement recorded on some of these northeast-striking faults may be related to differential movement across individual segments of the basement-involved thrust.

Based on the Teapot Dome natural fracture data set, a three-dimensional conceptual model

of fractures associated with basement-cored anticlines suggests significant horizontal permeability anisotropy. Depending on structural position and the interaction between fracture sets, the direction of maximum permeability can be either parallel or perpendicular to the fold hinge.

EXPERIMENTAL EVIDENCE OF HYPERFILTRATION INDUCED PRECIPITATION OF HEAVY METALS, by *Gina DeRosa*, 1999, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 126 pp.

It has long been known that clays and shales have membrane properties. A semipermeable membrane is defined as a material that will permit the passage of some molecules, but not others. When a shale membrane partially rejects solute, a concentration polarization layer (CPL) forms at the higher-pressure membrane face. Non-equilibrium thermodynamic calculations for conditions of reasonable hydraulic gradient, aquitard hydraulic conductivity, and pollutant heavy-metal concentration suggest that it should be possible for concentrations of heavy-metal solute in the CPL to reach supersaturation, resulting in the precipitation of heavy-metals. The purpose of this research was to test this concept. Eight hyperfiltration experiments were conducted with undersaturated heavy-metal solutions of varying composition. Of these eight, six succeeded in precipitation of heavy metal on the high-pressure face of the membrane. The heavy metals of interest included lead, copper, and cobalt.

In order for solute sieving to occur, there must be a head difference across the shale aquitard. Such head differences can occur as the result of rapid sedimentation of fine-grained materials or lateral tectonic compression. Head differences observed in perched and artesian aquifer systems are sufficient to drive the phenomenon. Additional theoretical calculations indicate that much lower pressure-head gradients than those used in these experiments will drive hyperfiltration in natural systems, resulting in the precipitation of heavy metals as described in this study.

The experiments demonstrate that clay-membrane induced precipitation of heavy metals can occur when undersaturated solutions pass through membranes. Mathematical analysis coupled with the findings of this study suggest that hyperfiltration may induce heavy-metal precipitation in the subsurface where contaminated aquifers are bounded by membrane-functioning shales.

TRACE-ELEMENT CONTROL ON NEAR-INFRARED TRANSPARENCY OF PYRITE, by *Jerzy Kulis*, 1999, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 271 pp.

Pyrite from various localities has been analyzed, by means of infrared microscopy, FTIR spectroscopy, bulk geochemical analysis, and electron microprobe analysis for correlations between trace-element contents and transparency in near-infrared ($\lambda \leq \sim 2.0$ µm). Additionally, FTIR spectra were taken in the temperature range from 28°C to 400°C to identify mechanisms responsible for degradation of the transparency of pyrite at high temperatures.

The transparency of pyrite at room temperature was found to be highly variable, with a sedimentary and fine-grained pyrite being mostly opaque in the analyzed spectral range. Although fluid inclusions are present in pyrite, relatively few of them are transparent enough to be suitable for microthermometric measurements, and their prevalent opacity can be attributed to the high refractive index of pyrite and the resulting refraction of IR light from the inclusion walls.

Six distinct absorption features, caused by imperfections in pyrite, have been identified in the IR spectra: (1) raised baseline; (2) prominent absorption tail of the main absorption edge; (3) high-absorption area, with a steep low-energy slope, below the main absorption edge; (4) symmetric absorption peak centered at 2.0 µm; (5) asymmetric absorption peak with a maximum at ~2.0 µm, with a steeper low-energy slope; and (6) gradual increase in absorption, below the main absorption edge, with longer wavelengths. The first three absorption features have been linked to the presence of large-scale mechanical defects in pyrite (e.g., cracks, grain boundaries, solid inclusions, surface imperfections), and they might be caused by reflection, refraction, and absorption (by foreign minerals) of the incident IR light. The remaining absorption features are likely produced by crystal-lattice imperfections, which affect the electronic structure of pyrite. Strong experimental evidence indicates that Co is responsible for the symmetric absorption peak in pyrite at 2.0 µm. Theoretical calculations suggest that this peak is most likely caused by $^2E \rightarrow {}^4T_1(F)$ crystal-field transitions of a low-spin Co^{2+}, with $B \cong 0.050$ eV and $\Delta \cong 1.65$ eV. Co^{2+} occurs in a solid solution in pyrite as a stoichiometric substitution for Fe^{2+}, and it probably enters pyrite as a deep-level imperfection, close to the bottom of the energy gap of pyrite. The last absorption feature listed above correlates with As; however, there is no theoretical evidence to support that correlation.

The main absorption edge of pyrite shifts gradually toward longer wavelengths with an increase in temperature. The coefficient of this shift is equal to -0.50 meV/°C in the analyzed temperature range from 28°C to 400°C. The resulting high-temperature degradation in the IR transparency of pyrite can be minimized by keeping the thickness of a sample to a minimum and/or by increasing the spectral range of the IR detector being used.

GEOCHEMICAL CHARACTERIZATION OF GEOLOGICALLY COMPLEX MOUNTAIN FRONT AQUIFERS: PLACITAS, NEW MEXICO, by *William J. LeFevre*, 1999, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 209 pp.

Characterization of ground-water flow across geologically complex mountain-front recharge areas can be confounded by an intricate network of structural and stratigraphic controls. Standard exploration methods are inadequate because the hydrologic nature of geologic discontinuities may be difficult to discern and the collection of representative data may be prohibitively expensive. The use of geochemical techniques as a primary tool for characterizing ground-water flow and recharge in geologically complex terrain is demonstrated on the eastern margin of the Albuquerque Basin at the north end of the Sandia Mountains in New Mexico, where structural and stratigraphic controls produce hydrologic discontinuities and aquifer compartmentalization. The regional distribution of geochemical parameters such as radioisotopic dating, stable isotope analyses, major ion analyses, ground-water temperature, and dissolved oxygen concentration, differs significantly from the distribution predicted by a standard basin model and illustrates the heterogeneity and complexity of ground-water flow in the study area.

Local scale analysis of the geochemical results from ground-water, surface-water, and precipitation sampling permits the identification of recharge areas, discharge areas, preferential ground-water flow pathways, and barriers to ground-water flow. Comparison of stable isotope analyses on ground water and precipitation suggests that most ground water is recharged in the Sandia Mountains by infiltration of precipitation and runoff that is produced by winter-type storms originating over the northern Pacific Ocean. The Madera Limestone that caps the Sandia Mountains produces ground water that is typical of recharge areas and has a low temperature, low TDS concentration, and high dissolved oxygen concentration (Madera-type water). Madera-type water is also produced by isolated Mesozoic aquifers between the mountains and the Albuquerque Basin, and downgradient of basin-bounding faults, suggesting that some faulted and compartmentalized aquifers have a good hydraulic connection to the Madera Limestone, and also that local infiltration of surface water is a significant source of recharge to the basin-fill aquifer. An evaporation-altered stable isotope composition and a high tritium concentration in Madera-type ground water near Las Huertas Creek and other arroyos suggest that ground water from the mountains is redistributed across the study area, and to the Albuquerque Basin, by ephemeral arroyos and Las Huertas Creek, and that infiltration from Las Huertas Creek is the single most important source of ground-water recharge within the study area. Mesozoic aquifers between the Sandia Mountains and the Albuquerque Basin generally produce ground water with higher temperatures, higher TDS concentrations, and higher dissolved oxygen concentrations than the Madera Formation, suggesting that ground-water flow from the Sandia Mountains to the Albuquerque Basin is generally blocked by basin-margin faults and by tilted and rotated fault blocks that orient the bedding planes of sedimentary units normal to ground-water flow. Several instances of Madera-type water produced by Mesozoic aquifers suggest that ground-water flow across basin margin faults is permitted where permeable sandstone formations are in fault contact with the Madera Limestone and at the highly faulted junction of the Placitas fault zone and the San Francisco fault . Anomalous ground-water ages and temperatures, stable isotope compositions, and dissolved oxygen concentrations along the San Francisco fault suggest that this fault, and other faults in the Madera Limestone, may act as discrete ground-water flow paths.

The results of this thesis illustrate that geochemical techniques can be a valuable primary tool for characterizing ground-water flow through geochemically complex mountain front aquifers. Measurements of the stable isotope and major ion composition, temperature, and dissolved oxygen concentrations were the most useful parameters measured during this study, and prior knowledge of the geology was critical to the hydrogeologic investigation.

PROBABILISTIC SEISMIC HAZARD IN NEW MEXICO AND BORDERING AREAS, by *Kuo-wan Lin*, 1999, PhD dissertation, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 194 pp.

Presented in this dissertation is a catalog of magnitude 2.0 or greater earthquakes for New Mexico and bordering areas for the time period 1962–1998. This catalog contains 925 events (215 inside the Socorro Seismic Anomaly [SSA]) and covers the region longitude 101° west to 111° west and latitude 31° north to 38° north. Significant contributions to this catalog came from Los Alamos National Laboratory, U.S. Geological Survey, University of Texas at El Paso, University of Texas at Austin, and Texas Tech University. The unique features of this catalog include reassignment of magnitudes using a duration scale tailored to the region, and relocation of epicenters using the SEISMOS program. A major factor in improving locations was the development of an innovative subroutine that calculates a reliable first estimate of the epicenter for input into the SEISMOS program. The subroutine is based on a modified G matrix and fuzzy logic. Inclusion of it in the location process avoids problems encountered when using data from small aperture networks or when confronted with earthquake phase readings containing large errors, both rather frequent occurrences with the catalog events.

Probabilistic seismic hazards for the region based on the catalog are presented in maps of 10% and 2% probability of exceedance in a 50-yr period. The hazard maps show moderate to low seismic hazards for the region, with the highest level of ground acceleration, ~ 0.18g, inside the SSA (10% probability of exceedance in a 50-yr period). Along the major population corridor of the state from Albuquerque to Santa Fe, the peak ground acceleration is ~ 0.08g, which generates Modified Mercalli Intensity (MMI) VI effects. The magnitude contribution curves for selected areas show that earthquakes with magnitude 4.5–5.5 contribute the most to seismic hazards. Structural damage is not expected to modern buildings from earthquakes in this strength range but non-structural damage can be significant.

Sensitivity studies for the probabilistic seismic hazard analyses indicate that the hazard estimates for New Mexico are stable. Among controlling factors, the maximum likelihood slope B in the recurrence model is the most important factor for estimating rates for earthquakes in the magnitude range 4.0–6.5. A recurrence relationship based on preinstrumental data 1868–1961 for the SSA is in reasonably good agreement with the rate based on instrumental data 1962–1998. The recurrence rates based on active faults in the Rio Grande rift and the SSA suggest that the active faults in these regions do not significantly affect hazard estimates for a short return interval of 500 yrs.

TRANSPARENCY AND MICROTHERMOMETRY OF PYRITE-HOSTED FLUID INCLUSIONS, by *Shannon E. Logan* (nee *Lindaas*), 1999, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 55 pp.

Pyrite, a common gangue mineral, is often associated with ore minerals within sulfide ore deposits. In the past, fluid inclusion microthermometry has been limited to transparent minerals. Unlike most transparent gangue minerals, pyrite is a sulfide, and as such, it may give a closer approximation than quartz, calcite, or fluorite to physical conditions at the time of ore deposition. Analysis of opaque minerals, such as pyrite, using a near-infrared camera, can broaden the sample base when applying microthermometry to the study of ore genesis.

Ninety-three doubly polished pyrite thick sections were made from 35 deposits worldwide. Pyrite transparency was quantified and intramineral features were identified using a near-infrared camera and microscope. Microthermometric analyses were made on 55 fluid inclusions within the pyrite sections.

Pyrite transparency is dependent on the formation environment and careful sample preparation. Pyrite-hosted fluid inclusions and available microthermometric measurements are scarce; of the 55 fluid inclusions found, 24 yielded salinity measurements, and 10 yielded homogenization temperatures. Microthermometric analysis on pyrite-hosted fluid inclusions is possible; however, workable fluid inclusions are limited to specific depositional environments.

AN ATTEMPT TO DATE FLUID INCLUSIONS IN QUARTZ: IMPLICATIONS FOR THE ^{40}AR/^{39}AR METHOD, by *Sarah A. W. Lundberg*, 1999, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 212 pp.

The primary aim of this work was to investigate the possibility of dating fluid inclusions in quartz veins from the Capitan pluton, south-central New Mexico with the ^{40}Ar/^{39}Ar method. Because quartz is such an abundant vein mineral, the ability to use the ^{40}Ar/^{39}Ar method to date quartz would allow a wide range of ore deposit systems to be dated. Vein quartz from Capitan is considered to be deposited from primary magmatic waters and is cogenetic with vein adularia, which provides a tight constraint on the age of the quartz veins. The fluid inclusion populations are exceptionally well characterized. The inclusions have been shown to be remarkably abundant, highly saline, and relatively large. Samples of different grain sizes from several prospect pits were analyzed using furnace, laser, and in vacuo crushing as argon extraction methods. ^{40}Ar/^{39}Ar age spectra from vein adularia show argon loss profiles. The plateau ages obtained from the adularia range from 25.80 ± 0.22 to 31.60 ± 2.00 Ma, which agree well with the known age of the pluton. Ages determined from ^{40}Ar/^{39}Ar analysis of quartz exhibit a wide range of behavior. In addition to anomalous old ages typical of samples containing excess ^{40}Ar (^{40}Ar$_E$), anomalously young ages were observed in seven samples. The young ages were measured at the high temperature degassing steps, which implies they are a result of material contained within the quartz, rather than some form of contamination. In vacuo crushing of the quartz released up to 83% of the ^{39}Ar. A substantial part of the ^{40}Ar$_E$ was removed, but some remained in the samples after crushing. The remaining ^{40}Ar$_E$ in the samples, measured by post in vacuo crush step-heating, resulted in ages older than the emplacement age of the pluton. The ^{40}Ar$_E$ appears to be distributed throughout the quartz, not associated with one phase in particular, and was very difficult to quantify. As a result of the distribution of the ^{40}Ar$_E$, the quartz yielded relatively high precision plateau ages in the high temperature steps, which are as old as 81.7 ± 4.1 Ma. The Cl/K ratios measured during ^{40}Ar/^{39}Ar analysis are remarkably homogeneous and agree well with the results from the crush-leach analysis, obtained for the vein quartz (Campbell et al., 1995), which implies that the bulk quartz, as opposed to sylvite or feldspar, is being measured during ^{40}Ar/^{39}Ar analysis. Quartz was thought to be a neutral substrate, which would not contribute to the argon budget of the inclusions. This was not the case. The quartz was found to be heterogeneous on the micron level, containing many small solid inclusions of salts and other K-bearing phases. Complexity of K and Ar distribution in the quartz prohibits reliable dating of the fluid inclusions in Capitan quartz.

ELECTROKINETIC ION TRANSPORT THROUGH UNSATURATED SOILS: THEORY AND APPLICATION, by *Earl D. Mattson*, 1999, PhD dissertation, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 305 pp.

Previous studies of electrokinetic ion and water transport have generally disregarded its application to remediation of unsaturated soils due to a lack of theoretical understanding, numerical predictive capabilities, and suitable electrodes. The research focus of this dissertation is on the electromigration of ions in unsaturated soils. Electrokinetic transport theory, three-dimensional numerical model development, comparison of model predictions to experimental results, and a surfactant-coating procedure for the anode electrode casings are all described in the dissertation.

An electromigration transport model was developed based on a modified Nernst-Planck equation describing the electromigration and diffusive flux of ions in a porous medium and on the equation of continuity. A steady-state electric potential field was assumed, an assumption valid for highly buffered soils or when the electrode electrolysis reactions are neutralized. The model also assumed that advective water movement through the soil due to either electric or hydraulic potentials was negligible. The transport and continuity equations were implemented in the model using public domain ground-water flow (MODFLOW) and transport (MT3D) numerical codes that were modified to allow prediction of ion transport due to an electric potential field.

Effective ionic mobility and diffusion parameters for porous media were calculated using a tortuosity function based on a closed-form solution of an equation describing electrical conductivity dependence on moisture content. The effect of ionic strength on ionic mobility was estimated using the activity coefficient calculated by the Davies equation.

One-dimensional laboratory experiments that measured anionic dye electromigration rates as a function of moisture content were used to verify the model. Laboratory experiments were conducted using a 10-mA, constant-current condition. Predicted red dye No. 40 migration rates matched the experimental data very well. Both the numerical simulations and the experimental results showed a maximum electromigration velocity at moisture contents less than satura-

tion. This maximum is believed to be due to competing effects between current density and tortuosity.

A six-month field demonstration was conducted to examine ion electromigration through heterogeneous unsaturated sandy soils. Acetate electromigration transport in the field demonstration indicated preferential transport through soil layers exhibiting higher moisture content and electrical conductivity.

Modeling was used to assess the effects of spatial heterogeneities on electromigration transport at the field-scale. The measured soil properties of the field demonstration were conceptualized as a layered system or as a homogeneous system. The layered model had three layers where each layer was assigned a moisture content and electrical conductivity value. The homogeneous model represented a single homogeneous profile with average properties of the layered model. Numerical results from these models suggest that spatial heterogeneities in soil properties must be accounted for in order to predict electromigration transport in a heterogeneous soil profile. The numerical predictions of the layered model qualitatively matched observations from the field experiments.

A surfactant-coating procedure for ceramic electrode casings was developed that eliminates excess electro-osmotic flow from the anode into unsaturated soils. Anode porous ceramic casings were treated with hexadecyltrimethylammonium at concentrations above the critical micelle concentration. Laboratory experimental results suggested the surfactant coating formed a bilayer on the ceramic surface, reversed the zeta potential and, hence, the electro-osmotic flow direction within the treated-ceramic pores. A six-month field demonstration confirmed the stability and effectiveness of the surfactant treatment on the porous ceramic.

The results of this dissertation illustrate the importance of moisture content and its relationship to electrical conductivity on electromigration transport, and the importance of including spatial heterogeneity in electrokinetic transport models. The steady-state electric potential field assumption allowed soil spatial variability effects on electromigration to be incorporated in a three-dimensional transport model. Electrokinetic transport models assuming homogeneous soil parameters will not adequately predict ion transport pathways at the field-scale in heterogeneous soil profiles.

GEOLOGY AND GEOCHEMISTRY OF WASTE ROCK PILES IN THE HILLSBORO MINING DISTRICT, SIERRA COUNTY, NEW MEXICO, by *Erik A. Munroe*, 1999, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 144 pp.

In New Mexico, there are more than 100,000 abandoned mine waste rock piles with variable mineralogical and geochemical compositions. To better understand the environmental consequences of metal mobility in regions of minimal precipitation, a mineralogical and geochemical study was implemented for four mine waste rock piles and their drainage systems in the Hillsboro mining district.

A sampling strategy was developed to geochemically characterize four mine waste rock piles representing four different mineral deposits: 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). In addition, another Laramide polymetallic vein waste rock pile (Site E) was studied to compare physical and chemical characteristics specifically with Site B. To determine the appropriate grain size range to be sampled, six grain size fraction ranges (2–1 mm, 1–0.5 mm, 0.5–0.25 mm, 0.25–0.125 mm, 0.125–0.063 mm, and <0.063 mm) were analyzed by FAAS and XRF. The <0.25 mm grain size fraction (encompassing the three smaller grain size fraction ranges) was used to sample the mine waste rock piles because it was determined to typically contain the highest metal concentrations. Using grid patterns unique to each of the waste rock piles, three homogenized samples were obtained using sampling densities of 15, 30, and 45 sample cells. Chemical analyses by FAAS and XRF determined that these mine waste rock piles can be adequately geochemically characterized by homogenizing samples collected from a grid pattern containing 15–30 samples.

An examination of metal mobility from the waste rock piles indicates that metals are moving as mineral grains, suspended material, and dissolved material. Chemical metal mobility is higher in the Laramide polymetallic vein waste rock piles (Site B and Site E) than in the carbonate-hosted waste rock piles (Site C and Site D). This may be a result of pyrite-bearing waste rock piles (Site B and Site E) generating sulfuric acid that can increase metal availability to the environment. Site C and Site D, however, have less chemical movement due to the abundance of calcite. Physical movement of material from these sites is the primary cause for the metals in downgradient stream sediments.

Secondary mineral rinds play a major role in the release of metals to the environment. Iron sulfate, iron oxide, and iron oxyhydroxide form rinds on the chalcopyrite and pyrite. Pyrite oxidation rinds preferentially partition arsenic. Oxidation rind thickness varies depending on mineralogy, mineral residence time in the waste rock pile, and hydrothermal history associated with the different deposits. Strong precipitation events may flush out metals partitioned in the outer rinds of oxidized sulfide grains. However, hydrothermal oxidation of some mineral grains like galena may be "armored" by cerussite. This leads to a significant decrease in the lead concentration available for chemical transport in the environment. Dissolved material may precipitate soluble salts onto grains in waste rock piles and stream sediments.

Agitation tests indicate copper and zinc are preferentially partitioned in the suspended material during a simulated precipitation event. Primary clays present in the stream sediments were smectite, illite, and illite/smectite mixed-layer clays. Metal movement in a semi-arid environment is governed by local drainage characteristics, mineralogy, and grain size.

CHARACTERIZATION OF VADOSE ZONE IN-SITU MOISTURE CONTENT AND AN ADVANCING WETTING FRONT USING CROSS-BOREHOLE GROUND PENETRATING RADAR, by *Lee T. Paprocki*, 2000, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 120 pp.

The need for effective methods of containing and remediating contamination has become increasingly important as our reliance on ground water for drinking water and the occurrence of contaminated vadose zone sites has increased. Flow and transport within the vadose zone is dependent upon the in-situ moisture-content distribution, which is often inadequately characterized by sparse hydrological measurements. Cross-borehole ground penetrating radar (GPR) is a high resolution, rapid-acquisition geophysical method that can obtain detailed measurements of the subsurface. Ground penetrating radar estimates the velocity of the electromagnetic (EM) waves in the subsurface. This velocity can be converted to an image of moisture content because it depends primarily upon the moisture content (Topp et al., 1980).

At a vadose zone field site the feasibility of using cross-borehole GPR to image the two-dimensional in-situ moisture-content distribution was tested. Then, during an infiltration experiment, cross-borehole GPR was tested to see if it could accurately image the advancing wetting front. GPR measurements were taken along an 11-m profile, consisting of five boreholes, with a 3- by 3-m infiltrometer in the center that emitted water at a rate of 2.7 cm / d. Two-dimensional GPR moisture-content images were produced for preinfiltration and infiltration conditions. The GPR images were compared to neutron moisture-content measurements and to two stratigraphic columns. The neutron measurements were collected in the same five boreholes, and the stratigraphic columns were constructed from continuous core samples taken several meters from the boreholes.

Overall, the GPR two-dimensional in-situ moisture-content distribution image correlated well with the neutron-probe and the stratigraphic-column data. By taking multiple data sets, one is able to quantify the GPR repeatability error. The average traveltime error was 1.08 ns, which in a general sense translated to an average moisture-content error of ±2%. Both errors were calculated by taking two standard deviations. The overall error was highest in areas of high moisture content and low ray density. Results indicate that the GPR moisture-content figures represent a smoothly varying image that maintains the general trend of the moisture-content distribution as compared to the neutron-probe and stratigraphic-column data. Equipment failures led to inaccurate estimation of moisture content in at least two data sets. However, this study showed that cross-borehole GPR can be an effective and feasible technique for characterizing the vadose zone.

SEQUENCE STRATIGRAPHY AND SEISMIC-GUIDED ESTIMATION OF LOG PROPERTIES OF THE SECOND SAND MEMBER OF THE BONE SPRING FORMATION, DELAWARE BASIN, NEW MEXICO, by *Robin A. Pearson*, 1999 MS thesis,, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM, 124 pp.

Seismic attributes have the potential to significantly improve reservoir property predictions in interwell areas if care is taken to ensure that the results are geologically and geophysically reasonable as well as statistically significant. This study illustrates how an integrated, volume-based attribute analysis can be used to determine reservoir properties and evaluate infill drilling targets via a case study of an oil and gas field producing from the Second Sand Member of the Bone Spring Formation along the north-

ern slope of the Delaware Basin, New Mexico. The Second Sand is a stratigraphically complex submarine fan deposit, and more traditional horizon- and interval-based attribute analysis techniques have been unable to predict porosity with the desired accuracy.

Based on an integrated analysis of well logs, cores, and 3-D seismic data, a combination of high frequency sea-level changes, variations in sediment supply, and tectonic activity have resulted in a submarine fan deposit that is largely confined to a small intraslope basin and that can be subdivided into a basin-floor fan, a slope fan, and a modified lowstand wedge. The best reservoir quality is found in the slope fan. The porosity distribution was successfully predicted using a combination of five seismic attributes. Although the predicted porosity distribution is complex, it appears to be geologically reasonable with high porosities (>10%) tending to occur in what is believed to be a channel fairway, and zones of extremely low porosity being associated with faults. Three potential drilling targets were identified within the slope fan and were assigned risk factors based on the geologic setting, production history, and statistical significance. These results have implications for the way in which other attribute studies are done and for Bone Spring exploration elsewhere.

PETROGRAPHY, DIAGENESIS AND RESERVOIR QUALITY OF THE UPPER SPRABERRY FORMATION, TEXAS, by *Claudio J. Saleta*, 1999, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 196 pp.

The Spraberry Formation is part of the submarine fan and deep marine deposits of the Midland Basin. The unit consists of very fine grained sandstones, siltstones, shales, and carbonate mudstones. These rocks show different degrees of lamination, bioturbation, convolute bedding, and a complex mineralogy.

The Spraberry reservoirs are naturally fractured, with very low matrix permeability that ranges from 0.1 to 1.0 md. Most of the reservoir fluid conductivity is due to the presence of a broad fracture system, wherein hydrocarbons stored in the pore space of the rock matrix flow at very low rates. The rock framework directly influences permeablilty, capillary pressure, and wettability characteristics of the reservoirs. For this reason, the interaction between rock matrix, natural fractures, and fluid flow must be well understood.

Small-scale lithofacies from thin-section and core-plug petrophysics were described for core intervals analyzed in the upper Spraberry Formation. The analysis of these lithofacies included observation of their petrographic properties as well as results from fluid-flow experiments for each lithofacies type. The Spraberry Formation contains two clean and porous sandstone lithofacies, one carbonate mudstone, and one dolomitic-cemented siltstone; two clay-rich lithofacies were also found using thin-section analysis. Among all lithofacies present, the clean and porous sandstones show good reservoir quality, whereas other lithofacies exhibit poor or total lack of porosity and permeability. The main diagenetic processes affecting the unit are as follows: quartz cementation, clay precipitation, carbonate cementation, grain and cement dissolution, and fracture formation and mineralization.

Rock properties vary gradually from reservoir rocks to non-reservoir rocks following two main trends: (1) increasing organic and argillaceous content with decreasing porosity, and (2) increasing carbonate sediments and cements with decreasing porosity. Both trends show a strong relationship to grain density, which in turn, suggests that lithological variability is an important control on reservoir properties. Water and oil saturation is also strongly controlled by lithofacies variability rather than a single water/oil contact controlled by gravity forces. The fluid distribution is probably mainly controlled by pore-throat diameter, pore-throat distribution, pore morphology, capillary pressures, and wetting behavior of the rock fluid system. In general, it is observed that the very small sizes of pores and pore throats make capillary forces strong enough to hold fluids tightly to the pore system. Thus, gravity forces are less dominant in controlling the distribution of fluid saturation. Core-plug fluid-flow data suggest that fluid distribution is controlled by the wetting behavior of the different minerals that form each lithofacies along the stratigraphic sequence. Fine-grained lithofacies such as dolostones and argillaceous siltstones show high percentages of water saturation, whereas low water saturation is associated with clean, very fine sandstones and siltstones richer in hydrocarbons.

A PORE-SCALE EXPERIMENT TO EVALUATE ENHANCED VAPOR DIFFUSION IN POROUS MEDIA, by *Thomas S. Silverman*, 1999, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 117 pp.

A pore-scale experiment was performed to determine whether the rate of water vapor diffusion through a pore throat is enhanced by the presence of liquid trapped in the pore throat. The experiment demonstrated that enhanced vapor diffusion (EVD), first presented by Philip and de Vries (1957), exists on a pore scale and does not require a thermal gradient. A diffusion cell with two vapor reservoirs bridged by a single "pore throat" was used to test EVD. Using a brine-concentration-induced vapor pressure gradient, we demonstrate that the rate of water vapor transport through a liquid-filled pore throat is enhanced relative to the flux through a gas-filled pore throat. The enhancement is shown to be a quadratic function of liquid-island length. An ancillary experiment with two parallel pore throats showed that water vapor is transported simultaneously through both gas- and liquid-filled pore throats if both are available. The vapor flux through each pore in the dual-pore-throat diffusion cell is inversely proportional to the resistance of the gas- or liquid-filled pore throat. Lastly, an isotopic tracer test was performed to compare the rates of deuterium transfer through gas- or liquid-filled pore throats. The rate of deuterium transfer to the downgradient reservoir is faster in the presence of a liquid-filled pore throat despite the slower self-diffusion coefficient of deuterium through liquid than through gas.

LABORATORY INVESTIGATION OF PERMEABILITY UPSCALING, by *Vincent C. Tidwell*, 1999, PhD dissertation, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 224 pp.

Parameterization of flow and transport models is often complicated by the inability to make measurements at the desired scale of analysis. This disparity in scale necessitates the use of some averaging or upscaling model to compute the effective media properties from the measured data. Although numerous theoretical models have been proposed, physical data with which to test these upscaling models are sparse and limited in scope. Here, we develop and employ a novel minipermeameter test system, which we call the Multi-Support Permeameter (MSP), to physically investigate permeability upscaling. The MSP allows precise, rapid, nondestructive measurement of permeability over a range of different sample supports (i.e., sample volumes). Measurements are made over different sample supports, subject to consistent boundary conditions and flow geometries, by simply varying the size of the minipermeameter tip seal. Experiments progress by collecting thousands of measurements from each face of meter-scale blocks of rock with each of five different tip seals (0.15, 0.31, 0.63, 1.27, and 2.54 cm radius), plus a single large (7.62 cm) tip seal designed to integrate over the entire sampling domain. Upscaling is manifest in the acquired data by changes in key permeability statistics with increasing sample support.

Permeability upscaling experiments are conducted on four blocks of rock, each exhibiting differing physical attributes: (1) Berea Sandstone, a faintly laminated fluvial-deltaic sandstone, (2) Massillon Sandstone, a conspicuously cross-stratified sandstone from a high-energy fluvial or near-shore environment, (3) Topopah Spring Tuff, a densely-welded, devitrified tuff, and (4) Tiva Canyon Tuff, a poorly welded tuff. Over 150,000 permeability measurements corresponding to six different sample supports have been collected from these four rock samples.

By comparing and contrasting results, we explore how traits distinguishing each rock sample influence the statistical and upscaling characteristics of the permeability. Results indicate that differences in the physical attributes of each rock sample give rise to measurable differences in the spatial permeability patterns, permeability distributions, and semivariograms. Results also yield clear evidence of permeability upscaling for each rock sample and each statistic investigated. Specifically, as the sample support increases the sample variance always decreases according to a power-law relation, the semivariogram range increases linearly, while small-scale (i.e., smaller than the minipermeameter tip seal) structural features are sequentially filtered from the permeability maps and semivariograms. Although each of the samples exhibits qualitatively similar upscaling trends, distinct differences are also evident. Differences between samples are manifest in the rate at which a given statistic upscales, the absolute change in the value of the statistic, and in the sense (i.e., increasing versus decreasing) of the mean upscaling. These differences are most evident between samples of differing genetic origin (e.g., sandstones versus tuffs).

To aid in the interpretation of the permeability upscaling, comparisons are made with a series of published theoretical models. The selected models differ according to the assumptions made about the nature of the permeability distribution, spatial structure, and uniformity/non-uniformity of the imposed flow field. Results suggest that the differences in the upscaling exhibited by the four rock samples

can be explained on the basis of the spatial patterns distinguishing each, particularly the spatial correlation of the higher permeability fraction. We also find the permeability upscaling to be strongly influenced by the non-uniform flow conditions imposed by the minipermeameter measurements. As such, these data clearly demonstrate that permeability upscaling is not an intrinsic property of a porous medium but rather depends on the characteristics of its measurement. In an effort to empirically quantify the measurement characteristics of the MSP, spatial weighting functions are calculated from the multi-support permeability data via linear filter theory.

ATR-FTIR ANALYSIS OF ADSORPTION FROM CRUDE OIL COMPONENTS ONTO MINERAL SURFACES, by *Susan M. Von Drasek*, 1999, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 208 pp.

Rock-fluid interactions, or wettability, influence both the rate and amount of oil produced by the displacement of oil by water in a conventional waterflood. Although most reservoir minerals are intrinsically water-wet, their wetting properties can be altered by complex interactions among crude oil components, brine, and reservoir minerals.

Most studies of crude oil/brine/rock (COBR) interactions have relied upon measurements that quantify the end result of exposure of high-energy surfaces to brine and oil including measurements of contact angles on smooth mineral surfaces and imbibition phenomena in porous media. Less work has focused on chemical analysis of the adsorbing species because of the difficulties posed by complex mixtures of organic compounds and small amounts of material. Reducing complexity by eliminating water or substituting model organic compounds for crude oils has failed to reproduce wettability conditions that represent those that result from COBR interactions.

Acidic and/or basic species in crude oils are expected to display the greatest tendency to interact with mineral surfaces and alter wetting. In this work, the use of an ATR-FTIR technique has been evaluated, as a potential tool, for quantifying the adsorption of species with polar functional substituents from the oil onto mineral surfaces.

Six crude oils with varying chemical properties, including a wide range of acid and base numbers, were analyzed by ATR-FTIR using a ZnSe prism. Oil selection was guided by the results of earlier studies that used traditional methods to assess their wettability-altering potential. Oil spectra by the ATR technique adequately reproduced those obtained with standard sample preparation methods, although absorbance levels were weaker. Spectra of all the oils were dominated by C–H stretching and bending of aliphatic groups with only minor differences between oils.

ATR-FTIR confirmed adsorption of organic material on mica and clay surfaces exposed first to brine, then to oil. Evidence of enrichment in aromatic or polar material was impossible to discern, however, due to the strong substrate signal in regions of particular interest and to the relatively weaker signal from the adsorbed organic material. The technique does provide significant insight into the fate of water that is present on the surfaces before exposure to oil that may prove useful in understanding the mechanisms of COBR interactions.

ARSENIC GEOCHEMISTRY OF STREAM SEDIMENTS ASSOCIATED WITH GEOTHERMAL WATERS AT LA PRIMAVERA GEOTHERMAL FIELD, MEXICO, by *David Welch*, 1999, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 91 pp.

The purpose of this study is to determine factors controlling the mobility of arsenic under natural conditions and is part of a reconnaissance study on arsenic speciation of geothermally impacted stream waters. Stream sediments and algae were collected at 20 sample locations along the Rio Salado watershed and its tributaries at La Primavera geothermal field near Guadalajara, Mexico. Sediments were analyzed by several partial extractions to determine: (1) the amount of arsenic available to the environment and its partitioning into different size fractions, (2) the species of arsenic present in sediments, (3) the sedimentary phases that are associated with arsenic, and (4) the relationship between arsenic sediment chemistry and water chemistry. In addition, Rio Grande sediments, collected near Socorro, New Mexico, were analyzed for As, Mn, Fe, and percent total organic carbon (%TOC) for comparison with La Primavera sediments. In carrying out these objectives, a modified method of ion-exchange chromatography is used for speciation of As(III), As(V), monomethylarsonate (MMA), and dimethylarsinate (DMA) in sediment extracts.

Total arsenic in sediments available to the environment ranges between 3 and 16 ppm and is highest in the silt-clay fraction. Arsenic is present primarily as inorganic forms that account for over 90% of the total; MMA and DMA are detectable in small amounts. Algae from La Primavera contains between 18 and 68 ppm arsenic (dry weight) with similar proportions of inorganic and organic forms.

The primary sedimentary phases that are associated with arsenic and control its mobility are oxides and hydroxides of iron and manganese and organic carbon. Arsenic concentration is positively correlated with manganese and %TOC and shows no direct correlation with Fe; however, evidence suggests that iron oxides are also enriched in arsenic. The positive correlation between arsenic and %TOC suggests that plants and algae may represent a significant sink in some natural settings.

Sediment arsenic concentrations showed no correlation with surface water concentrations. Though sediment-water heterogeneity may account for this lack of correlation, evidence indicates that sediment arsenic concentrations are determined by the amount of organic matter, iron and manganese oxides and hydroxides present, not the concentration of arsenic in surface waters.

Comparison of sediment-water data from the Rio Grande to that of La Primavera showed arsenic to be more mobile in La Primavera waters with relatively less being retained in the sediments. This is most likely due to lower concentrations of iron, occurring as iron oxides and hydroxides in La Primavera sediments, but could also occur if the capacity of the sediments to take up arsenic has been exceeded.

SOLUTE MIXING IN A FRACTURE JUNCTION UNDER EQUAL AND UNEQUAL FLOW CONDITIONS, by *J Sidney Wise*, 1999, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 84 pp.

I conducted a series of experiments using a physical model of a fracture junction with simple geometry. The flow conditions in the experiments included equal flow, where the flow rates in all four fracture branches were identical; unequal flow, where the flow rates in the two inflow fractures were different but the flow rates in adjacent inflow and outflow branches were identical; and forced mixing (a type of unequal flow), where water from one of the inflow branches crossed to the opposite side of the junction and mixed with water from the other inflow branch. Forced mixing occurred because the flow rate in one inflow branch was greater than the flow rate in the adjacent outflow branch, resulting in overflow to the opposite outflow branch. The goal of the experiments was to determine how the mixing behavior of a solute would be affected by the Peclet number at the junction in each of these flow conditions.

In the case of equal flow, the present work verifies the findings of Li (1995), showing that partial mixing occurs at Peclet numbers between approximately 1 and 200. Complete mixing occurs below this range, and streamline routing occurs above this range. Photomicrographs of the equal flow case illustrate the three types of mixing behavior and show that upstream diffusion occurs at low Peclet numbers. In the case of unequal flow without forced mixing, where the water from each inflow branch exits through the adjacent outflow branch, the transition between mixing states occurs at a lower range of Peclet numbers than in equal-flow conditions, so that complete mixing was not observed at a Peclet number of 1. In the case of forced mixing, the transition occurs at still lower Peclet numbers, too low to be observed in the present work.

WHOLE-ROCK OXYGEN ISOTOPE TRAVERSES ACROSS GOLD-BEARING AND BARREN STRUCTURES, LONE TREE COMPLEX, NEVADA, by *Christopher M. Young*, 1999, MS thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 104 pp.

The Lone Tree Complex includes the Lone Tree, North Peak, and Trenton Canyon deposits. These fine-grained gold deposits, hosted in Paleozoic sediments, are variations of Carlin-type deposits with ore zones being structurally controlled. Both gold-bearing and barren structures have hydrothermal alteration centered along faults that is indicated by an increase in modal percent of alteration minerals towards the structure. The alteration mineral assemblage is dominated by quartz, fine-grained white-phyllosilicates (sericite), oxidized sulfide (mainly pyrite), and locally, clays and chlorite.

Whole-rock oxygen isotope traverses across gold-bearing and barren structures record isotopic alteration resulting from deposition of alteration minerals and water-rock exchange. On a district-scale, oxygen isotopes are inconclusive at detecting ore zones. All gold-bearing traverses have depletions at the fault zone relative to background values, whereas barren traverses produced either an enrichment (North Peak) and a depletion (Lone Tree) at the fault zone. On a deposit-scale, correlation of oxygen

isotope composition and ore zones can be made. Gold-bearing structures are associated with more oxygen isotope alteration (change relative to background values) than the barren structures. At Lone Tree, North Peak, and Trenton Canyon gold-bearing quartz was isotopically lighter than the barren quartz, respectively, by 8.8 ‰, 4.1 ‰, and 9.9 ‰.

Calculated oxygen isotope composition and fluid inclusion data indicate multiple sources of fluid for deposits of the Lone Tree Complex. A regional, barren formation water is documented by temperature and salinity measurements in inclusions and calculated oxygen isotope compositions from the three deposit areas. This formation water ranges in both salinity and oxygen isotope composition, respectively, from 3.0 to 18.0 eq. wt.% NaCl and from 8.5 to 13.1 ‰, and ranges in homogenization temperature from 170° to 310°C, with the upper range resulting from mixing with a higher temperature magmatic fluid at Lone Tree.

At Lone Tree, a magmatic source for gold-bearing fluid is suggested by the range in homogenization temperatures from 280° to 400°C and salinity from 12.0 to 39.0 eq. wt.% NaCl (Kamali, 1996). Calculated oxygen isotope composition of gold-bearing fluid (6.5%) supports this conclusion. Ranges in salinity and homogenization temperature for gold-bearing and barren sample suggest mixing between the gold-bearing and barren fluids. Trenton Canyon gold-bearing fluids had calculated $\delta^{18}O$ of 0.0 ‰, indicating an evolved meteoric fluid. This meteoric fluid, ranging in homogenization temperature from 210° to 350°C and salinity from 2.6 to 5.7 eq. wt.% NaCl, can be approximated by mixing the Lone Tree magmatic fluid and a local meteoric water (from -6.0 to -9.0 ‰) established at Twin Creeks and Getchell deposits (Groff, 1996). Further mixing of this fluid with the barren formation water lowers salinity and homogenization temperatures from values expected by a true meteoric-magmatic mixing trend. Gold-bearing fluid at North Peak had calculated $\delta^{18}O$ value of 8.5 ‰. Mixing between meteoric water and regional barren formation water produces the oxygen isotope composition, along with ranges in homogenization temperature (170°–270°C) and salinity (3.7–14.0 eq. wt.% NaCl). As with the Lone Tree and Trenton Canyon deposits, salinity and homogenization temperatures at North Peak from gold-bearing and barren samples indicate mixing between the barren and gold-bearing fluids.

New Mexico State University

CONGLOMERATIC DEPOSITION WITHIN THE CRETACEOUS CORDILLERAN FORELAND BASIN: REDDICK CANYON CONGLOMERATE OF CENTRAL UTAH, by *Jennifer M. Jones*, 1999, MS thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 91 pp.

The Cordilleran foreland basin formed in Aptian through Campanian time. Clastics deposited in the basin were sourced by erosion unroofing of the Sevier orogenic belt to the west. The Sevier orogenic belt includes folded synorogenic deposits that include the Indianola Group, of which the Reddick Canyon conglomerate is part. The Reddick Canyon conglomerate is composed dominantly of large cobble to boulder-size quartzite clasts.

The Reddick Canyon conglomerate is divided into three units, 1, 2, and 3, which are defined in the stratigraphic section studied. Unit 1 is interpreted to have been deposited in a fan-delta environment. Unit 2 developed on the proximal to upper mid-fan environment. Unit 3 contains deposits that are indicative of mid-fan to distal-fan environments.

Three major controls influenced deposition of the Reddick Canyon conglomerate. The first control was lithology of source bedrock. Widely exposed Precambrian and Cambrian quartzite strata provided large resistant clasts to the depositional site. These strata are presently exposed in the upper plate of the Canyon Range thrust currently located 40 km west of the Reddick Canyon conglomerate. The second control is the tectonic evolution of thrust belt. The clasts found in the Reddick Canyon conglomerate are very large, well rounded, and as much as 1 m in diameter suggesting that 40 km of transport is unlikely. Distance from the source, overall rounding of clasts, and clast size suggest repeated recycling of clasts from the thrust belt to the basin. It is therefore likely that other as yet unknown thrusts located between the Canyon Range and the Gunnison Plateau contributed to deposition of the Reddick Canyon conglomerate. The third control was the evolution of the foreland-basin system. Decreasing stratigraphic dips upsection in a single measured section in the northern part of the study area suggest that the Reddick Canyon conglomerate records foredeep disruption and subsequent deposition in a wedge-top depozone. Disruption had not yet begun in the southern part of the study area, because no significant change in stratigraphic dips is observed there. Thus, the southern part of the study area was located in the foredeep depozone throughout deposition of Reddick Canyon conglomerate.

PROVENANCE, GEOMETRY, LITHOFACIES, AND AGE OF THE UPPER CRETACEOUS WAHWEAP FORMATION, CORDILLERAN FORELAND BASIN, SOUTHERN UTAH, by *Stonnie L. Pollock*, 1999, MS thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 117 pp.

In the southern part of the Cordilleran foreland basin, Upper Cretaceous fluvial strata of the Wahweap Formation record three major river systems with different headwaters. Exposed along the flanks of the southern High Plateaus and Kaiparowits Plateau of southern Utah, the Wahweap Formation consists of four informal members. The lower and middle members were deposited by north- and northeast-flowing meandering and anastomosing rivers that transported feldspar-rich volcanic-lithic detritus from a basement source in the Mogollon highlands and a volcanic source from the Delfonte Volcanics in southeastern California. The upper member was deposited by northeast-flowing rivers that transported sedimentary lithic detritus from Paleozoic sedimentary rocks uplifted in the Sevier thrust belt in southern Nevada. The uppermost capping sandstone member was deposited by east- and southeast-flowing braided rivers that transported quartzose detritus derived from Paleozoic and Mesozoic sedimentary rocks of the Sevier orogenic belt. Although not directly dated, the Wahweap Formation overlies the Santonian Straight Cliffs Formation and underlies the middle-late Campanian Kaiparowits Formation.

The lower, middle, and upper members were deposited in an actively subsiding foredeep setting with abundant accommodation space. The capping sandstone member was deposited in wedge-top basins that were carried by eastward advancing thrust sheets of the Sevier thrust belt. Thickness trends of the Wahweap Formation and stratigraphically adjacent units indicate that the foreland basin was partitioned during or after Wahweap deposition. The capping sandstone member thins in a downdip direction from 150 m in the Henrieville Basin to 30 m in the Kaiparowits Basin. In the updip direction it is present locally as paleovalley deposits in the Paunsaugunt Basin beneath the Eocene Claron Formation west of the Paunsaugunt fault and thicker quartzose units in the Markagunt Basin. I infer that the Paunsaugunt fault, most recently with Neogene normal offset, and other associated Neogene and Laramide structures are inverted Campanian thrust faults. Uplift along thrust-tip anticlines resulted in the formation of wedge-top basins and concomitant erosion of and partitioning of the foreland basin.

DEPOSITIONAL FACIES ANALYSIS OF THE LATE PENNSYLVANIAN, LOWER HOLDER FORMATION PHYLLOID ALGAL MOUND COMPLEXES, SACRAMENTO MOUNTAINS, NEW MEXICO, by *Mark A. Rivera*, 1999, MS thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 143 pp.

This study has focused on the delineation of intramound sequence stratigraphy in order to understand vertical and lateral mound growth patterns. Because other phylloid algal mound complexes hold million to billion barrel fields within the mid continent and southwestern U.S. and the former U.S.S.R., it is important to understand how phylloid algal mound growth is affected by change in accommodation.

Fourteen lithofacies and 10 depositional sequences were recognized and correlated within the Upper Pennsylvanian lower Holder Formation phylloid algal bioherms of the Sacramento Mountains, New Mexico. These facies include mound core phylloid algal boundstones, mound flank skeletal wackestones and packstones, and off-mound conglomerate, sandstone, siltstone, shale, and algal-peloid-rich wackestone and packstone. Detailed sequence stratigraphic correlation of 10 depositional sequences within Yucca and Dry Canyons reveals that sequence thickness and vertical facies successions vary relative to biohermal buildups.

Variation in facies patterns, both laterally and vertically, has been attributed to the variable growth of mound core boundstones in response to generation and destruction of short-term accommodation space. Vertical relief of abnormal subaerial exposure surfaces developed on top of individual phylloid algal mounds indicates potential sea-level fluctuations of 54 m and possibly as high as 100 m. Furthermore, estimates of sequence durations for Late Pennsylvanian time suggest that these fluctuations occurred for a period of 400,000 yrs. Therefore, lower Holder bioherm complexes experienced changes in accommodation of at least 54 m that

were glacioeustatically controlled and short term.

Bioherm accretion varied as a function of both spatial (lateral) location relative to mound core buildups, and evolutionary (nucleation, acme, and mature phases) positions. Sequences accumulated during the nucleation stage of mound growth developed during late stages of falling sea level (LHST to VLHST) and display a "catch-down" character. Acme stage sequences developed during sea level rise (TST to EHST) and display a "keep-up" phase of deposition followed by a "catch-down" phase of deposition. Sequences developed during the acme evolutionary phase are characterized by (1) vertical aggradation of mound core boundstone, (2) abrupt vertical and lateral facies transitions ("Non-Waltherian"), and (3) significant syndepositional topography. Mature stage sequences grew atop significant bathymetric relief and are characterized by deposition of late highstand rise to early fall, "catch-down" sequences.

DEPOSITIONAL ENVIRONMENTS AND PROVENANCE OF THE CENOZOIC GILA CONGLOMERATE OF THE DUNCAN AND CANADOR PEAK QUADRANGLES, SOUTHWESTERN NEW MEXICO, by *Shane V. Smith*, 1999, MS thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 103 pp.

Lithofacies distribution, paleocurrent, and provenance data are used to define the evolution of the Cenozoic 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 315 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 consists of 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, which consist of 240 m of sediment deposited in distal alluvial-fan, alluvial-flat, and lacustrine environments. 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 Riley Peaks area. There is no evidence of an ancestral Gila River during the time of deposition of the Gila Conglomerate.

FIELD, PETROGRAPHIC, AND ISOTOPIC DISCRIMINATION OF SHALLOW, AUTHIGENIC CARBONATE OF THE PLIO–PLEISTOCENE PALOMAS BASIN OF SOUTHERN NEW MEXICO, by *Leandro Treviño, Jr.*, 1999, MS thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 78 pp.

In the Plio–Pleistocene Palomas half-graben of southern New Mexico, shallow authigenic carbonate is commonly found in both the footwall-derived and hanging wall-derived facies of the Palomas Basin. Site investigation and sample collection on a basin-wide scale has resulted in the identification of nine types of shallow, authigenic carbonate that can be classified into four categories. Pedogenic or soil carbonate is found on the hanging wall- and footwall-derived alluvial fans. Carbonate that precipitates at or near the water table consists of nodular mudstones found in the hanging wall-derived alluvial fan and the axial fluvial system; nodules and tubules in eolian sand and gully bed cementation are common to the hanging wall- and footwall-derived alluvial fan. Carbonate precipitating at or near the land surface produces groundwater carbonate with capillary fringe restricted to the hanging wall- and footwall-derived alluvial fans; thick shallow ground-water carbonate and calcareous root mats are found only in the hanging wall-derived alluvial fan. Concretions, found only in the axial fluvial system, and sparry cement, found in all environments within the basin, develop below the water table.

Subtle but discernible changes in the vertical fabric, presence or absence of peds, root traces, and bounding surfaces help differentiate among different forms of carbonate. In the case of non-pedogenic carbonates, the base of the indurated carbonate bedding is sharply defined and parallel to the overall bedding, resulting in a laterally extensive sheet-like deposit. In contrast, pedogenic carbonate exists as nodular or massive horizons with gradational bases. Unless eroded before burial, pedogenic carbonate is overlain by an argillic B horizon characterized petrographically by clay coatings (argillans) around grains and/or peds.

Stable carbon isotopes further differentiate carbonate in footwall-derived alluvial fan strata and associated axial-fluvial fan strata from that in hanging wall-derived strata. This is likely the result of vegetation differences or the presence of Paleozoic carbonate rocks in the catchment and as clasts in the footwall-derived detritus. Stable oxygen isotopes help differentiate among different forms of carbonate on the footwall fan.

STRATIGRAPHY, SEDIMENTOLOGY, AND PROVENANCE OF THE GILA CONGLOMERATE NEAR LAKE ROBERTS, NEW MEXICO, by *Gregory J. Wheeler*, 1999, MS thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 125 pp.

Southwestern New Mexico has experienced middle and late Cenozoic crustal extension in the Basin and Range and southern Rio Grande rift. In addition, there is a narrow Transitional Zone between the Basin and Range/Rio Grande rift and the largely undeformed Colorado Plateau that has also experienced late Cenozoic crustal extension. The most studied and best-understood province is the Rio Grande rift, which is generally considered to have developed in two stages. By comparison to the southern Rio Grande rift, there has been very little research directed toward understanding the extensional history of the Transitional Zone, primarily because of a lack of detailed geologic maps and few studies of the syntectonic/synvolcanic sedimentary unit, the Gila Conglomerate. Thirty-six outcrops, four standard petrographic thin sections, and one stratigraphic column of the Gila Conglomerate were analyzed in the Lake Roberts area. From this study, the Lake Roberts, Purgatory Chasm, Meerschaum Canyon, Skates Canyon, and Turkey Cienega Canyon members were classified as a part of the Gila Conglomerate near Lake Roberts, New Mexico.

The analysis of the stratigraphy and sedimentology of the Gila Conglomerate has provided the pieces necessary for understanding the evolution of the Sapillo Basin through time. Early, middle, and late stages have been identified for the Sapillo Basin. The early stage of the Sapillo Basin corresponds to those members of the Gila Conglomerate that directly overlie the Bearwallow Mountain Basalt, including the Lake Roberts, the lower part of the Meerschaum Canyon, and Skates Canyon members. During its early stage, the Sapillo Basin was a half graben, bordered on the north by the Copperas Peak fault and Buck Hannen and Loco Mountains, which constituted the footwall. The principal difference between the early and middle stages of the Sapillo Basin was progradation into the basin of the Purgatory Chasm member. The late stage of evolution of the Sapillo Basin corresponds to the time of deposition of the Turkey Cienega Canyon member.

This study also showed that the east-trending Copperas Peak fault north of Lake Roberts was active during the deposition of the Gila Conglomerate. The paleocurrent direction, clast shape and size, and sedimentary structures of the Meerschaum Canyon member reveal that this fault was active during deposition of the Gila Conglomerate.

University of New Mexico

EVALUATION OF AQUIFER RECHARGE USING A MASS-BALANCE MODEL AND CONSERVATIVE TRACERS, SANDIA NATIONAL LABORATORIES/KIRTLAND AIR FORCE BASE, ALBUQUERQUE, NEW MEXICO, by *Jerry K. Bird*, 1998, MS thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 115 pp.

Recharge in arid and semi-arid climates is difficult to evaluate with traditional soil-physics and water-budget calculations that can provide estimates off by as much as an order of magnitude. The use of conservative tracers is an accepted method of evaluating mixing processes, residence time, recharge source, and recharge volume. This study uses the mass-balance model NETPATH and the conservative tracers Cl^-, Br^-, and ^2H to investigate potential recharge at Sandia National Laboratories/Kirtland Air Force Base

(SNL/KAFB), Albuquerque, New Mexico.

NETPATH is a U.S. Geological Survey model developed to evaluate mixing percentages of two or more initial waters and the mass-balance changes required along suspected hydrologic flow paths. I modeled mixing scenarios in four specific study areas at SNL/KAFB to evaluate ground-water flow. Single species conservative-tracer models were used to identify potential mixing proportions for well and spring pairs located near known or suspected preferential pathways. These pairs were also evaluated by NETPATH mass-balance models. Modeling scenarios that produce similar results with NETPATH and conservative-tracer models are considered the most robust. Although this type of modeling does not provide unique solutions, it can be used in conjunction with other hydrologic investigations to evaluate mixing processes occurring in an aquifer.

My results do not provide quantitative recharge estimates; however, they do provide qualitative evidence for mixing within the aquifer. Recent pumping has heavily perturbed local ground-water flow. The geochemical signatures observed in the study area may be reflective of the regional flow system prior to anthropogenic influences, but cannot be confirmed with this data set. Some results support other workers who have suggested that a concentrated, deep-basin water is upwelling near the basin-bounding fault system and mixing with a dilute recharge water in the basin. The source of this dilute water cannot be specified, but modeling results suggest that recent river and/or arroyo recharge as well as alluvial mountain-front recharge are possibilities. One simple model suggests that mixing of two sources east of the fault system will produce the geochemical signature observed in wells completed in the regional aquifer west of the faults.

SYNCHRONOUS PLUTONISM, METAMORPHISM, AND DEFORMATION OF THE 1.65 GA MANZANITA PLUTON, MANZANITA MOUNTAINS, NEW MEXICO, by *Cynthia L. Brown*, 1999, MS thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 82 pp.

The 1.65 Ga Manzanita pluton and its aureole record an interaction of Paleoproterozoic plutonism, deformation, and metamorphism in New Mexico. Field observations and microscopic analysis indicate that the pluton was emplaced during regional northwest-southeast shortening. Synchronous plutonism and contact metamorphism are indicated by an increase in temperature from regional metamorphic greenschist grade rocks to contact metamorphic amphibolite grade rocks. Peak contact metamorphic temperatures and pressures of 600°–620°C and 2–3 kbar are shown by assemblages with Fe-rich andalusite + K-feldspar + biotite + quartz + white mica + oxides. Synchronous deformation and metamorphism are indicated by contact metamorphic mineral-matrix relationships including the growth of garnet before, during, and after development of the regional S_2 foliation, sillimanite that is both randomly oriented and aligned along S_2, and hornblende that is dynamically recrystallized along S_2. Synchronous plutonism and regional deformation are indicated by parallel magmatic and solid-state fabrics; dynamic recrystallization of feldspar indicating high-T solid-state deformation; variably deformed dikes and veins that cross-cut and are also folded by regional foliation; and dike orientations consistent with a regional kinematic framework of northwest-southeast shortening.

Recent radiometric dating constrains the timing of synpluton tectonism. The Manzanita pluton has been dated by U–Pb–zircon techniques at 1,645 ± 16.0 Ma. In addition a post-S_2 rhyolite dike to the south of the pluton cooled through 300°C at 1,428 ± 2.0 Ma, determined by $^{40}Ar/^{39}Ar$ techniques. Hornblende in the contact aureole of the pluton yields variable $^{40}Ar/^{39}Ar$ ages of circa 1.40 Ga and 1.67 Ga; variable ages are interpreted as hornblende growth at 1.65 Ga and reheating at 1.40 Ga to 400°–500°C.

ZIRCON DISSOLUTION, by *Katheryn B. Helean*, 1998, MS thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 132 pp.

Zircon, $ZrSiO_4$, has been proposed as a host phase for excess weapons Pu. The chemical durability of zircon must be quantified so that the performance can be assessed. One consequence of immobilizing radioactive elements in the structure of zircon is that the structure loses atomic-scale periodicity due to self-irradiation caused by α-decay events. A unique aspect of zircon is that natural analogues exist for all stages of the expected structural degradation, from crystalline to amorphous, hydrous zircon. Previous studies of crystalline zircon failed to quantify the dissolution rates in water using static test methods. A high-temperature Soxhlet extractor, therefore, was designed to measure the forward rate of zircon dissolution at temperatures in the range of 120°–250°C. The forward dissolution rates for zircon based on the Si release rates are : 4.1×10^{-4} g m^{-2} day^{-1} at 250°C, 1.7×10^{-4} g m^{-2} day^{-1} at 200°C, and 7.1×10^{-5} g m^{-2} day^{-1} at 120°C. The Arrhenius activation energy for the zircon dissolution reaction is 23 kJ/mol. The dissolution of amorphous, hydrous "gel-zircon" was measured using a static test method. The forward dissolution rate for "gel-zircon" based on the U release profile is 8.5×10^{-3} g m^{-2} day^{-1} at 90°C. Using the Arrhenius relationship, the forward dissolution rate for crystalline zircon was extrapolated to 90°C from the data collected in this study. The forward dissolution rate for crystalline zircon at 90°C, 4.6×10^{-5} g m^{-2} day^{-1}, is two orders of magnitude lower than the forward rate for "gel-zircon." Based on these data, zircon would make a chemically durable host phase for excess weapons Pu. A 100 μm zircon crystal would survive 150,000 yrs in an open aqueous system at 90°C.

PROTEROZOIC MULTISTAGE (~1.1 AND ~0.8 GA) EXTENSION IN THE GRAND CANYON SUPERGROUP AND ESTABLISHMENT OF NORTHWEST AND NORTH-SOUTH TECTONIC GRAINS IN THE SOUTHWESTERN UNITED STATES, by *J. Michael Timmons*, 1999, MS thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 66 pp.

The Grand Canyon Supergroup records a prolonged history of intracratonic rifting and sedimentation in rift basins during two or more distinct tectonic/depositional events in the late-Meso and Neoproterozoic. Mesoproterozoic Unkar Group deposition took place between 1.2 and 1.1 Ga during northeast-southwest extension on domino-style normal faults during Grenville northwest-directed contraction. The Neoproterozoic Chuar Group was deposited in a north-south rift basin, synchronous with movement on the Butte fault during east-west extension. Syntectonic sedimentation is documented by sedimentary patterns and sedimentary structures, including growth syncline and intraformational faults, within the Chuar Group. Neoproterozoic faults locally reactivate and cross-cut older Mesoproterozoic faults. Laramide monoclines have northwest and north-south segments that reactivate Unkar- and Chuar-age structures and are used to infer extent of each extensional event. We suggest that 1.1 Ga northwest structures and 0.8 Ga north-south structures have persisted into the Phanerozoic as important regional grains that influenced subsequent tectonism.

STREAM POWER AND INCISION OF FIVE MIXED ALLUVIAL-BEDROCK STREAMS, NORTHERN NEW MEXICO, by *David K. Mitchell*, 2000, MS thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131.

The validity of modeling fluvial bedrock incision rates with the stream power law is evaluated on five northern New Mexico streams: the Rio Pueblo de Taos, Rio Hondo, Red River, Comanche Creek, and Jemez River. Fluvial terraces within these basins provide an excellent spatial and temporal record of fluvial bedrock incision. The stream power law follows the general form, $Z = kA^mS^n$, where Z is the incision rate, k is a constant that incorporates bedrock erodibility, A is drainage area (a proxy for discharge), S is channel gradient, and m and n are exponents that scale the relative importance of discharge and slope to incision. Five versions of the stream power law, with different m and n values and/or slight modifications to the general law, are tested. This study represents one of the first rigorous tests of the stream power law with field-measured discharge and slope data.

Stream power models generally reproduce field-measured incision rates within ≈10–20%. No single version of the stream power law consistently outperforms other models, although tributary junction analysis suggests an m/n ratio of 0.4, similar to the ratio of 0.5 for a unit stream power (m=0.5, n=1) or shear stress (m=0.33, n=0.66) model. Stream power models calculated using map-measured data match known incision rates as well as field-parameterized stream power models. Thus, substituting drainage area for discharge, a common technique of the map-based metric approach, may be valid because drainage area may represent the cumulative effects of many discharge events over geologic time. Stream power models reproduce incision rates measured over hundred-thousand-year time scales better than incision records from shorter or longer time scales. Shorter-term records (10^4–10^5 yr) are sensitive to local variabilities such as migrating knickpoints, whereas drainage-basin characteristics likely have changed for longer-term (10^6 yr) records.

Channel widths, valley-bottom widths, and controls on channel gradient and discharge generation are examined in the context of the parameters of the stream power law. Channel widths vary nearly as a function of the square root of

discharge. This relationship is similar to the relationship known for purely alluvial streams and those used in bedrock stream power models. Discharge-area relationships show that local geologic controls on discharge can cause significant differences in discharge production between adjacent basins. A comparison of New Mexico gage data with Washington State gage data shows that local geologic controls on discharge generation are more significant in semiarid New Mexico.

A discharge threshold that controls the effect of rock type on channel gradients is quantified. Above this threshold sufficient discharge is generated to maintain incision in the face of base-level fall, regardless of rock type. The discharge of threshold underscores the difficulty in calibrating the proportionality constant *k*, which likely varies spatially in response to rock-type changes and temporally in response to changes in discharge generation.

A combination of field and laboratory geomorphic, sedimentologic, and sedimentary petrographic methods are employed to document the sources of basin-fill sediment, the character and relative amount of sediment produced on local hillslopes through time, the hillslope weathering and transport processes occurring through time, and the role that rock type has played in regional landscape evolution. Results of these studies indicate rock type is the dominant control on sediment yield and landscape development in tectonically inactive, dry landscapes. Hillslope processes and products in the study area have been consistent through time, but process rates have varied greatly, indicating that orbital-scale climate cyclicity can be, but is not always, well expressed in the stratigraphy of continental basins.

A LONG-TERM RECORD OF CLIMATE-CONTROLLED HILLSLOPE SEDIMENTATION, by *Joel L. Pederson*, 1999, PhD dissertation, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 235 pp.

Rare exposures of buried hillslopes and colluvium are found in the upper Miocene and Pliocene basin-fill records of two extensional basins in southeastern Nevada. Study of the stratigraphy, sedimentology, and petrology of these hillslope deposits, along with the Quaternary record and modern slopes of the study area, produces a long-term record of variable hillslope-sediment production and delivery to piedmonts as a function of climate change. Though rare, ancient colluvium exists in the stratigraphic record, and its study is the most direct method of linking hillslope processes to basin depositional systems. Results enhance our ability to interpret the sedimentologic record, particularly in terms of climate controls, and clarifies the applications of arid-environment geomorphic research to sedimentology and basin analysis.

The upper Miocene and Pliocene Muddy Creek Formation and Pliocene Panaca Formation of southeastern Nevada are analogous in their role as late-stage (post-tectonic) basin fill deposited prior to basin integration and incision. The Muddy Creek Formation exposed in Table Mesa Basin consists of three members defined by sharp changes in depositional style. The lower member, dominated by internally-drained spring travertine and saline lacustrine deposits, underlies a relatively sharp, undulating contact with mostly extrabasinally-derived red, siliciclastic alluvium of the middle member. The middle member of the Muddy Creek Formation coarsens upward at its top in a gradational contact with the locally-derived coarse fluvial upper member, which, in turn, is truncated at its top by QTg gravel deposited after external drainage was established. The Panaca Formation consists of distal deposits of pond and littoral/marsh environments and medial and proximal alluvial-slope, fluvial, eolian, and colluvial deposits. Alluvial-slope deposits account for much of the exposed fill in the Panaca Basin, and its fine-grained, roughly parallel-bedded, and commonly massive character probably led to previous interpretations of these deposits as lacustrine.

A petrologic weathering index for sand, clay-mineral data, and stratigraphic relations all indicate that, in the Neogene, episodes of greater production and delivery of colluvium from hillslopes in the study area were marked by more intense chemical weathering and thus greater effective moisture. Strata that record only limited colluviation, less intense weathering, and piedmonts dominated by eolian processes very likely correspond to drier conditions. The climate-driven hillslope and piedmont landscape changes evident in these older stratigraphic records corroborate the conceptual model developed by Quaternary researchers for arid environments. Quaternary models of arid landscape change can therefore be used to interpret the stratigraphic record at least back into the Miocene, but though the mode of response is consistent through the record, the magnitude of sedimentologic response has varied greatly.

A HIGH-RESOLUTION PETROGRAPHIC STUDY OF THE CRETACEOUS FERRON SANDSTONE, COYOTE BASIN, UTAH: INTEGRATING PETROLOGY AND PETROPHYSICS, by *Karen N. Roche*, 1999, MS thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 110 pp.

A high-resolution petrographic study is combined with laboratory measurements of porosity and permeability to characterize a fluvial-channel deposit in the Upper Cretaceous Ferron Sandstone. Thin sections were made of samples from four wells and five outcrop transects within a study volume 40.00 m × 16.5 m × 12.50 m deep. Five distinct sandstone units were defined for this volume, all of which are represented in the sampling. Thin-section macroporosity values range from 18.4% to 1.6% in outcrop samples and from 14.8% to 0.4% in core samples. Porosity determined from petrographic examination differs significantly from laboratory determinations. In most cases the petrographically determined measurements were approximately half of the volume of the bulk laboratory determination. The thin-section porosity counts suggest that up to half of the measured bulk porosity in some of the sandstones is comprised of interstitial clays, which lower the effective porosity of those units. Thin-section macroporosity values are found to correlate very well ($r^2 = 0.80$) with Hassler cell permeability values in core samples. The porosity measurements performed in the laboratory do not correlate as well with the Hassler cell permeability measurements ($r^2 = 0.59$).

The most significant factor in terms of porosity reduction is calcite cement. The degree of cementation is highly variable, ranging from 19.0% to 0.2% in outcrop samples and 20.8% to 0.4% in core samples. Authigenic, pore-filling kaolinite also contributes to porosity reduction. Incipient quartz overgrowths are present but do not contribute significantly to porosity reduction.

The differences between core and outcrop samples are due to weathering effects. The most important difference is the porosity (and therefore permeability) increase in the outcrop samples due to the dissolution of calcite cement.

STRATIGRAPHIC CYCLICITY AND MUD MOUND FORMATION IN MIDDLE CAMBRIAN DEEP-WATER CARBONATES, MARJUM FORMATION, HOUSE RANGE, WESTERN UTAH, by *Anna C. Snider*, 1999, MS thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 126 pp.

The Middle Cambrian Marjum Formation (~400 m thick) in the House Range of western Utah is composed of deep-water carbonates, which were deposited in the axis of the House Range embayment. Within the Marjum Formation, there are three scales of cyclicity recognized, including (1) limestone-marl rhythmites (~5 cm thick), (2) rhythmite-mound cycles (3–30 m thick), and (3) large-scale sequences (145–190 m thick).

Rhythmites are composed of thin rhythmically interbedded, laterally continuous, limestone and marl layers. Limestone layers are composed of dark, laminated pelletal lime mudstone (~3 cm thick), and marl layers (~2 cm thick) are composed of laminated, argillaceous, dolomitized, pelletal lime mudstone; both lithologies contain rare agnostid trilobites and sponge spicules. Fine-grained carbonate and siliciclastic material in rhythmites is detrital in origin and was deposited in quiet, dyserobic waters, below storm-wave base. Alternations of limestone and marl layers are interpreted as the result of millennial-scale paleoclimatic fluctuations, which influenced changes in fluvial/ eolian influx and/or changes in the location or intensity of storms.

Rhythmite-mound cycles (3–30 m thick) are composed of limestone-marl rhythmites overlain by stromatactis-bearing carbonate mud mounds (0.5–1.5 m thick at crest). Mud mounds are composed of bioturbated pelletoidal lime mudstone with sparse trilobite wacke/packstone lenses and abundant spar-filled stromatactis-like structures. Mud mounds were precipitated in situ in deeper waters with some contribution from detrital carbonate and terrigenous sediment. Lime mud and pelletoids precipitated from highly alkaline waters produced by bacterial decay of siliceous sponges and microbial mats. The mud mounds are interpreted to have developed during a 10^4–10^5 year sea-level rise when the carbonate "factory" retrograded and the supply of fine, detrital carbonate material to the basinal regions decreased. During sea-level fall/lowstand, an increase in detrital carbonate influx due to carbonate factory progradation resulted in deposition of limestone–marl rhythmites.

Three large-scale siliciclastic-carbonate sequences (145–190 m thick) are recognized in the Wheeler Shale and Marjum Formations and are composed of shale and marl-dominated rhythmite facies grading into carbonate-dominated intervals. These sequences correlate to time-equivalent shallow-water carbonates that exhibit similar scale sequences interpreted to have formed in response to 3rd-order (1–3 m.y.)

eustatic sea-level changes. This across-platform correlation suggests the Wheeler–Marjum sequences were also formed in response to eustatic changes.

DEXTRAL TRANSCURRENT DEFORMATION OF THE EASTERN MARGIN OF THE COLORADO PLATEAU (USA) AND THE MECHANICS OF FOOTWALL UPLIFT ALONG THE SIMPLON NORMAL FAULT (SWITZERLAND/ITALY), by *Timothy F. Wawrzyniec*, 1999, PhD dissertation, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Two independent studies employ kinematic analysis of minor-fault populations to address large-scale tectonic problems. The first addresses the nature of transcurrent deformation along the eastern margin of the Colorado Plateau. The work is based on a combined fault kinematic and paleomagnetic investigation of rocks affected by faulting during the Laramide orogeny and younger Rio Grande rifting. The second evaluates the mechanics of footwall uplift along the Simplon low-angle normal fault in the Alps, by combining a fault kinematic study with fluid inclusion analysis of kinematically referenced fluid inclusion arrays.

Chapter 1 proposes a new model to describe the tectonic history of the eastern margin of the Colorado Plateau. The margin extends from southern New Mexico to northern Colorado and has experienced both Laramide-style deformation and Rio Grande rift extension. Limited age information on minor fault populations indicates that the eastern margin of the plateau has experienced a prolonged history of dextral transpression followed by dextral transtension.

Chapters 2 and 3 address the nature of extension along the Simplon low-angle normal fault (southern Switzerland and northern Italy). Structural and fluid-inclusion analysis indicates that at least part of the footwall of the Simplon shear zone experienced footwall uplift via a rolling hinge mechanism, and that the observed style of deformation and the transition from ductile to brittle deformation during the exhumation of mid-crustal rocks is in part influenced by the composition of syn-kinematic fluids. Specifically, faulting at mid-crustal depths is associated with the occurrence of carbonic fluids. Different wetting characteristics of carbonic versus aqueous fluids probably influenced the mechanical behavior of the rocks during exhumation. A comparative analysis of the Simplon shear zone with the Brenner shear zone (Chapter 3), a low-angle extensional structure located in the eastern Alps, reveals remarkable similarities. The uniformity of structural style along these two structures is likely due to (1) external tectonic controls, and (2) introduction of carbonic fluids into these shear zones at mid-crustal depths to aid in formation of a sub-vertical simple shear rolling hinge to accommodate footwall uplift during extensional unloading of the footwall rocks.

A FLUVIAL RECORD OF ROCK UPLIFT ALONG THE JEMEZ LINEAMENT, GREAT PLAINS OF NORTHEASTERN NEW MEXICO, by *Paul A. Wisniewski*, 1999, MS thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 118 pp.

Post-Laramide rock uplift in the western United States has been the subject of a long-standing debate, fueled in part by deep fluvial incision into the world's second largest orogenic plateau. Studies of late Cenozoic landscape evolution in the Rocky Mountains have focused on deeply incised fluvial systems, which have been touted as critical evidence for post-Laramide epeirogeny. Debate persists about whether this plateau achieved its current elevation during the Laramide orogeny or more recently in the late Cenozoic. The latter of these models has broad implications for the mechanisms that uplift rocks after compression and crustal thickening has ceased. Efforts to elucidate a rock uplift signal from fluvial systems are complicated by numerous non-tectonic mechanisms, such as climate change, that also drive river incision and have typically contributed little to our understanding of post-Laramide rock-uplift processes.

This study presents new incision data from a well-constrained reach of a Rocky Mountain front–Great Plains river that is uniquely situated to isolate the effects of post-Laramide rock uplift. The Canadian River of northeastern New Mexico is one of four major Great Plains rivers draining the eastern slope of the Rocky Mountain front. This river has carved a deep (~300 m), narrow canyon through Mesozoic strata at a location where its profile is broadly convex and crosses the Jemez lineament, a well-known, northeast-trending line of late Cenozoic volcanism. The numerically dated (^{14}C and $^{40}Ar/^{39}Ar$) fluvial terrace and volcanic stratigraphy in this canyon reach constrain rates of fluvial bedrock incision. Incision is maximized in the canyon reach where it has been relatively steady at ~0.06 mm/yr (60 m/m.y.) over the past ~4.5 Ma. Canyon reach terraces are correlated to produce paleo-long profiles that are increasingly convex with profile age and converge to the modern channel profile both upstream and downstream of the canyon reach. Similar terrace profiles are currently unknown for well-studied streams in the adjacent Rio Grande rift where rates of incision can be greater by a factor of three. These observations of the study area are best explained by invoking a slow but steady rate of rock uplift during the late Cenozoic beneath the Canadian River along a northeast-trending axis coincident with the Jemez lineament. Recently acquired geophysical data, including upper mantle velocity structure, suggest that hot asthenospheric mantle is rising diapirically beneath the southern Rockies and is subsequently funneled along compositional and structural heterogeneities at the base of the lithosphere. The Jemez lineament has long been recognized as one of these heterogeneities, and the Canadian River incision data likely indicate rates of rock uplift for the mantle processes acting at its base. If rates of incision and rock uplift for the Canadian River are representative for the southern Rockies in general, then they place constraints on the timing and degree of high-standing topography for the western Cordillera.

MULTIPHASE THERMAL MODELING IN VOLCANIC AND CONTACT METAMORPHIC TERRANES, by *Gordon N. Keating*, 2000, PhD dissertation, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131.

This dissertation presents the results of unique numerical models of hydrothermal systems in unsaturated pyroclastic rocks. A simple one-dimensional, radial conductive finite-difference heat-flow model is demonstrated to be an adequate tool for investigating possible thermal conditions in a limited contact metamorphic aureole that developed around a large mafic intrusion in unsaturated, silicic host rocks at Grants Ridge, New Mexico. A modified version of the Los Alamos National Laboratory code, FEHM, is presented that has a unique capability of simulating multiphase (air + H_2O) flow under the high-temperature conditions near intrusive The modified equations of state (EOS) for water and air are valid in the ranges $10° < T < 1500°C$, $0.00123 < P < 1000$ MPa, and $10° < T < 1500°C$, $0.00123 < P < 22$ MPa, respectively.

Two applications of the FEHM code are presented. A two-dimensional model of multiphase flow near a magmatic intrusion was constructed to characterize the cooling history of part of a late-Miocene mafic intrusive complex at Paiute Ridge, Nevada, USA. The results of the model were combined with paleomagnetic data to estimate that the rate of change of the transitional part of the geomagnetic field during a reversal was 0.06–0.13 degrees/year.

Multiphase cooling processes in cooling ash-flow tuffs (ignimbrites) were investigated using a set of FEHM models. The results of these models identify important factors in the cooling history, including the presence of a saturated zone in the shallow substrate, geometry of the substrate-ignimbrite interface (e.g., buried valleys), and welding zonation and fumarole structures within the ignimbrite. In addition, the models shed light on conditions that may give rise to the development of secondary explosions in ignimbrites. Finally, the model results indicate that superheated vapor from the boiling zone at the base of the ignimbrite, flowing upward through the core, may provide the necessary water mass in the upper zones of the ignimbrite to account for reported oxygen-isotope exchange in the Bishop and Chegem Tuffs, rather than requiring high meteoric infiltration on the surface of the ignimbrite, as previously proposed.

Geographic Names

U. S. Board on Geographic Names

Cañada del Agua—arroyo, 0.8 km (0.5 mi) long, heads 3.5 km (2.2 mi) southwest of Rainsville at 35°58'10"N, 105°14'48"W, trends southwest 1.6 km (1 mi) before joining Cañon del Agua, 1.6 km (1 mi) north-northwest of the community of La Cueva; Spanish name meaning "little valley of water"; Mora County, NM; T20N R16E, NMPM; 35°57'21"N, 105°15'16"W; USGS map, Mora 1:24,000 (mouth of feature).

Montoya Pasture—flat, 4.8 km (3 mi) by 4 km (2.5 mi), elevation 2,057 m (6,749 ft), in Gila National Forest/Gila Wilderness, located southeast of the confluence of Diamond Creek and the East Fork Gila River, 8 km (5 mi) east of the Gila Cliff Dwellings National Monument; named for Donaciano Montoya, who homesteaded and ranched in the area in the early 20th century; Catron County, NM; T12S R13W, NMPM; 33°14'30"N, 108°09'05"W; USGS map, Gila Hot Springs 1:24,000 (central point); *not* Montoya Ranch.

Perra Peak—summit, elevation 3,586 m (11,765 ft), in Carson National Forest, 1.6 km (1 mi) south-southwest of Lobo Peak, 2.3 km (1.4 mi) north of Gallina Peak, 4.5 km (2.8 mi) east-northeast of Kiowa Village; Spanish name meaning "female dog"; Taos County, NM; sec. 4 T27N R13E, NMPM; 36°35'54"N, 105°33'03"W; USGS map, Arroyo Seco 1:24,000.

Puerto del Venado Alazán—gap, 0.8 km (0.5 mi) west of State Route 21, 2.5 km (1.6 mi) west of Rainsville, 4.2 km (2.6 mi) north-northeast of La Cueva; Spanish name meaning "port of the red elk"; Mora County, NM; T20N R16E, NMPM; 35°58'43"N, 105°14'14"W; USGS map, Rainsville 1:24,000.

—Dave McCraw
NMBMMR Correspondent