Abstracts

New Mexico Geology recognizes the important research of students working in post-graduate M.S. and Ph.D. programs. The following abstracts are from M.S. theses and Ph.D. dissertations completed within the last 12 months that pertain to the geology of New Mexico and neighboring states.

New Mexico Institute of Mining and Technology

WATER AVAILABILITY TO VEGETATION ACROSS A SEMIARID SHRUBLAND AND GRASSLAND ECOTONE, SEVILLETA WILDLIFE REFUGE, NEW MEXICO, by *Eric W. Bhark*, 2002, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 108 pp.

The 20th century shrub invasion of semiarid grasslands in New Mexico is one example of the transition of a semiarid herbaceous to woody plant ecosystem. A key factor controlling plant productivity and reproduction in semiarid environments is water availability in the soil. We characterize the hydrologic changes resulting from the shrub invasion, specifically the hydrologic advantage that shrubs hold over grasses, to pinpoint the primary factor(s) that contribute to the invasion. Observations are based on measurements of near surface soil moisture and soil-water potential across the transition. We focus on the differences between the grass and shrub environments. Our previous research has shown that in both environments, maximum spatial soil moisture variations exist at the plant-to-interspace scale, on the order of meters. Therefore, we now focus on individual plant canopy and interspace patches. We hypothesize that the critical hydrologic difference(s) contributing to the shrub invasion exist at this scale.

During the 2001 summer monsoon season, we used the TDR (time domain reflectometry) method to measure soil water content. In both environments, TDR probe arrays are installed laterally covering the surface of eight plant canopies in total and their adjacent interspaces, using 128 probes. One array in each environment contains TDR probes inserted both at the surface and at depths. In addition, soil matric potential is measured adjacent to selected TDR probes. Soil-water potential is measured using a total of 64 heat dissipation sensors. The measurement arrays are designed to observe spatial, in both vertical and lateral orientations, and temporal movement of soil-water at the canopy-interspace scale during natural precipitation events and subsequent soil dry down. Measurements are made and recorded hourly.

We focus on initial dry soil conditions, wetting events, and subsequent dry down sequences following natural rainfall events. Results suggest that it is the time period during precipitation, when water is redistributed over the ground surface, that is most critical to plant water availability. During precipitation events, shrub canopies accumulate a greater percentage of precipitation applied to a ground surface area than grass canopies, most critically during low precipitation events on the order of millimeters. The advantage of shrubs is twofold. One, their woody structure permits significant rainfall interception and stemflow directly to the plant root zone. Two, the large shrubland bare soil patches, coupled with low bare soil infiltration rates, provide runoff during precipitation that infiltrates into more permeable canopy soils. On the contrary, the plant structure of canopies in grassland, coupled with the depressed microtopography of bare soil patches, results in formation of ponds at bare soil depressions during precipitation, increasing infiltration into bare soil where it is not readily available to grasses.

LITHOSTRATIGRAPHY AND PETROGRAPHY OF UPPER SANTA FE GROUP DEPOSITS IN THE NORTHERN ALBUQUERQUE BASIN, NEW MEXICO, by *Nathalie Nicole Brandes*, 2002, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 208 pp.

Recent geologic mapping in the northern Albuquerque Basin near Albuquerque, Rio Rancho, Zia Pueblo, and San Felipe Pueblo, New Mexico, suggests that facies of the upper Santa Fe Group are locally differentiable. Integration of these maps with paleocurrent data and studies of sand and gravel petrography supports the differentiation of these facies. Previous petrographic studies in the area concentrated on sand petrography. However, this study shows that gravel petrography is key to differentiating the facies of the upper Santa Fe Group.

Stratigraphic sections were measured in Pliocene and early Pleistocene deposits, and sand and gravel samples were collected at different locations in the northern Albuquerque Basin in order to understand the lithologic character of the Arroyo Ojito and Sierra Ladrones Formations. Deposits of the Arroyo Ojito Formation constitute the fluvial facies of the ancestral Rio Jemez/Guadalupe, Rio Puerco, and Rio San Jose that drained sedimentary, crystalline, and volcanic rocks exposed along the western and northwestern margins of the basin. Deposits of the Sierra Ladrones Formation are divided into axial fluvial (ancestral Rio Grande) deposits and piedmont deposits derived from basin margin uplifts. The ancestral Rio Grande drained areas dominated by crystalline and volcanic rocks. Piedmont streams drained crystalline and sedimentary rocks.

Arroyo Ojito Formation gravels are typically moderately to poorly sorted, occur in horizontally stratified, laterally discontinuous beds and are primarily composed of volcanic tuff and fine-grained red granite with subordinate Pedernal chert, sandstone, and basalt. Ancestral Rio Grande gravels are generally moderately to well sorted, occur in thin, planar to cross-stratified beds, and are composed of rounded to well-rounded metaquartzites and diverse igneous clasts. Granite and sedimentary clasts are relatively sparse. Piedmont gravels contain abundant sedimentary clasts, especially limestone, and coarse-grained, pink porphyritic granite deposited in horizontally stratified, clast- and matrix-supported beds.

Sand composition of all lithofacies ranges from subarkose and arkose to feldspathic litharenite. Arroyo Ojito Formation sands are subarkose to lithic arkose and occur in planar stratified to low-angle cross-stratified beds. Arroyo Ojito Formation sands contain more chert and granite grains than the ancestral Rio Grande deposits. Ancestral Rio Grande sands were deposited in planar stratified to trough cross-stratified beds and contains abundant volcanic grains. Volcanic grains are rare to nonexistent in piedmont sands in the study area. Piedmont sands were deposited in planar stratified to low-angle and trough cross-stratified beds. Paleocurrents for the ancestral Rio Grande deposits are dominantly to the south. Paleoflow in the Arroyo Ojito Formation was south-southeast, whereas piedmont paleoflow was generally to the west.

The results of this study show that the three lithofacies assemblages in the northern Albuquerque Basin can be confidently differentiated by integrating studies of stratigraphy, gravel and sand petrography, and paleocurrents.

GEOCHEMISTRY, GEOLOGY, AND GEOCHRONOLOGY OF THE VICTORIO MINING DISTRICT, LUNA COUNTY, NEW MEXICO—LINKING SKARN AND PORPHYRY SYSTEMS TO CARBONATE-HOSTED LEAD-ZINC REPLACEMENT DEPOSITS, by *Kelly M. Donahue*, 2002, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 186 pp.

The Victorio mining district, southwestern New Mexico, hosts three types of mineral deposits that are spatially related (from the central zone to outer zone): porphyry molybdenum, W-Be-Mo skarn/vein, and carbonate-hosted Pb-Zn replacement deposits. Through geochronology, fluid inclusion microthermometry and gas analysis, and stable isotope analysis a genetic model was developed showing the genetic relationships between the three types of mineral deposits.

The fluid inclusions from the porphyry deposit have a homogenization temperature range of 208–315°C and salinities between 2.0 and 11.9 eq. wt% NaCl. The fluid inclusions from the skarn deposits have a range of homogenization temperatures from 180° to 350° C and have salinities 2–22.5 eq. wt% NaCl. The carbonate-hosted replacement deposits are slightly lower in temperature and salinity than the skarn and porphyry deposits with a range of homogenization temperatures of 105–289° C and salinities <2–5 eq. wt% NaCl.

The fluid inclusion and stable isotope analyses indicate an alteration continuum between the porphyry molybdenum, skarn, and carbonate-hosted replacement deposits. The sulfur and oxygen isotope data from sulfide and silicate samples and fluid inclusion gas analyses point to a probable magmatic source for the skarn and porphyry mineralization. The sulfide isotope data from the carbonate-hosted replacement deposits also suggest a magmatic component. The carbon and oxygen values from carbonate and silicate samples for the carbonate-hosted replacement deposits indicate a moderate to high degree of interaction between the mineralizing fluid and the host rock.

The mechanisms responsible for the shift in mineralization style between high-temperature porphyry and skarn deposits and low-temperature carbonate-hosted replacement deposits are most likely boiling and mixing of meteoric and magmatic waters. There is evidence for boiling and fluid mixing in all three mineral deposits, which caused a decrease in temperature and salinity, an increase in pH, and an increase in oxidation state of the mineralizing fluids.

The geochronological results for the Victorio Granite and the skarn alteration minerals indicate that all three mineral deposits formed from one magmatic source at about 34.9 Ma. However, there is no direct evidence that the mineralization of the three deposits was one continuous event. It is more likely that mineralization took place over an extended period of time with episodic events of brecciation, boiling, fluid mixing, and mineral precipitation as a result of the intrusion of the Victorio Granite.

MEASURING SALINITY CHANGES IN THE VADOSE ZONE USING DOWNHOLE ELECTROMAGNETIC INDUCTION, by *Laila M. Hall*, 2003, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 259 pp.

To improve our ability to measure and predict quantities such as moisture content and soil-water conductivity in the unsaturated or vadose zone, an infiltration experiment was monitored with a dense array of geophysical and hydrological instrumentation. The geology of the site, as described from four continuous core samples, is fairly continuous layers of unconsolidated alluvial deposits, consisting primarily of fine sands but also containing a significant cobbly clay layer at 4–6-m depth. The infiltrometer consisted of a finely controlled irrigation system, which delivered local tap water to the surface at a flux of 2.7 cm d^{-1} over a 3-m by 3-m area. After approximately 1,100 days of regular infiltration events, a 6.9 g L^{-1} concentration of NaCl was added to the infiltration water, increasing the irrigation water conductivity from 80 mS m^{-1} to 1,300 mS m^{-1}.

The focus of this thesis was subsurface soil electrical conductivity measurements, collected weekly during the infiltration of the salt pulse with an EM39 probe (Geonics LTD., Mississauga, ON, Canada). Data was collected in a 16-m by 16-m area surrounding the infiltrometer, in 13 boreholes reaching an average depth of 12 m. 3D images created from these measurements showed structures of salt distribution related to the stratigraphy of the field site and to the shape of the wetted area directly under the infiltrometer. To quantify how well the EM39 was capturing the extent of the salt plume, a mass balance approach was used to compare a calculated soil-water salt mass to the known mass of salt infiltrated at the surface. Following models designed primarily for agricultural soils, the measured bulk soil conductivity (EC_a) was converted to soil-water conductivity (EC_w) using estimates of the volumetric water content (θ_w) from monthly neutron probe measurements, and the percent clay of the soil as determined by lab analysis of the continuous core samples. The result of these calculations was a close fit (r^2 = 0.98) between the calculated mass of salt in the soil-water and the known mass of salt infiltrated at the surface.

The low water content (<15% by volume) and low bulk soil conductivity (<100 mS m^{-1}) measured at the test site present more resistive conditions than previous studies of this type and were a cause for uncertainty in the calculated EC_w results. Sensitivity analysis results show that due to the low measured water content at the site, the calculated EC_w is strongly dependent on the chosen limit between immobile and mobile water content, or threshold water content, but determination of the value was possible through lab analysis of soils from the site. Errors in the calculated mass also arise during periods when the overall EC_w is low, such as during the initial stages of the salt pulse infiltration and during a tap water flush following the end of the salt pulse. Calculations were shown to be less sensitive to soil temperature and percent clay estimates. The results of this study indicate that downhole EM39 methods show much promise for characterizing water and solute distribution in the vadose zone.

SOIL SALINITY IN ARID NON-FLOODED RIPARIAN AREAS, by *Sung-ho Hong*, 2002, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 71 pp.

Soil salinity is a common problem in arid riparian areas of the arid Southwest, but the dynamics of soil salinity in these areas are not well understood. The main causes of soil salinity in non-flooded riparian areas are generally known as low precipitation, high evapotranspiration, and capillary flux from saline shallow ground water. However, some riparian areas maintain relatively low soil salinity for a long period of time with thriving salt-sensitive vegetation such as cottonwoods, whereas other areas are completely salinized and covered by salt-tolerant vegetation such as salt cedars. Is this difference in soil salinity caused by a small amount of deep infiltration sufficient to leach salts back to the ground water or by ground water dynamics that "wash" the soil profile from below? The results of this study, using the modeling program HYDRUS-1D, indicate that soil salinity is a complex process affected by a number of factors such as soil profile texture, ground water table depth and its fluctuation, ground water quality, and time period of simulation. First, a validation of the HYDRUS-1D model demonstrated that predicted apparent soil electrical conductivities of six representative soil profiles show a good correlation with the apparent soil electrical conductivities measured in the field with the Geonics EM38 ground conductivity meter. A sensitivity analysis was conducted to analyze which factors determine soil salinity under the riparian conditions of my study area. Soil texture—which determines capillary rise—is the most important predictor variable for long-term soil salinity; generally finer soil texture leads to more saline soils in this environment because of higher capillary rise. The effect of deep infiltration on soil salinity was examined. Differences in soil salinity levels among different riparian areas are not caused by a small amount of deep infiltration but by ground water fluctuations that "wash" the soil profile from below. Although evapotranspiration affects the rate of soil salinization over time, the basic processes of soil salinity have not been changed.

COSMOGENIC NUCLIDE DATING OF OLD, HIGH PLUVIAL SHORELINES IN THE WESTERN GREAT BASIN, by *Gabrielle Kurth*, 2003, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 158 pp.

Evidence of the most recent highstand cycle of Lake Lahontan and associated paleolakes persists throughout the western Great Basin and has been studied intensively for over 100 years. In contrast, little is known about the longer-term history of the basin. Many workers agree that lake filling events were somehow related to glacial periods, when amounts of precipitation and stream runoff into lakes were higher. Two competing hypotheses have been put forth to explain the response of the western Great Basin to the forcing of Pleistocene climate changes. One is that there were large basin-filling events during oxygen isotope stages (OIS) 16, 6, and 2 with a long period of aridity after OIS 16. The second is that the basin responded in a predictable manner to global climate cycles by filling during these glacials as well as the other glacial periods in the sequence. This study tests these hypotheses by dating paleoshorelines in the western Great Basin.

Dating ancient shorelines in the western Great Basin allows for a better understanding of both the timing and the magnitudes of lake-filling events. Geomorphic and soil properties suggest that the ages of several shorelines above the latest Pleistocene level increase as a function of elevation. Shoreline deposits at three sites in western Nevada were sampled for cosmogenic nuclide (^{36}Cl) dating to test this apparent increase. Chlorine-36 results from sites near Walker Lake, in Newark Valley, and around Columbus Salt Marsh in Nevada corroborate the geomorphic and soil evidence. Furthermore, ^{36}Cl results suggest that Lake Lahontan filled to nearly the same level during OIS 2 and 4; the results also suggest large filling events occurred during OIS 6, 8, and possibly 12 or 16. From these results, we can conclude that the Lahontan Basin filled more frequently and to higher levels than previously thought and that preserved shorelines show an apparent decrease in maximum lake levels with time.

GAS PERMEAMETERS—OPERATIONS, MODIFICATION, AND DESIGN, by *Benjamin James Lechler*, 2002, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 119 pp.

Gas permeameters are widely used in the fields of hydrology, soil science, and petroleum engineering to characterize the spatial heterogeneity of hydraulic properties, in particular permeability. The spatial distribution of permeability governs fluid flow and transport, affecting such processes as contaminant migration, ground water recharge, and petroleum recovery. Laboratory scale and field-portable permeameters, based on steady or transient gas flow, are used to map the distribution of permeability. Most permeameters are optimized for use on a particular type of material (lithified rock or unconsolidated sediments) with a certain permeability range. A good field permeameter must be highly portable and allow for rapid measurement of permeability across a wide range of materials. Many outcrop studies have been performed on high-permeability, poorly consolidated sand bodies dissected by nearly vertical zones of lower permeability material (small-displacement faults or clastic dikes). The lightweight syringe-based air-minipermeameter (LSAMP) designed by Davis et al. (1994) and modified LSAMP II (Suboor and Wilson, pers. comm.) were the primary permeameters used in many

of these studies. Difficulty was encountered when attempting measurements on low-permeability materials with these devices; the measurement duration was too long.

Three studies were performed to better understand and improve permeability estimation with gas permeameters, with particular focus on increasing the amount of data that can be collected in the field (making measurements faster) with a single permeameter. The first study compares the operational characteristics of the LSAMP with those of the improved LSAMP II. The second deals with modification of the LSAMP II to increase the range (decrease measurement duration) of permeability that it can effectively measure in the field. The third study involves the development, design, and testing of a new field-portable transient pressure decay permeameter to allow for rapid estimation of permeability across a wide range of materials.

Over 1,000 permeability measurements were collected to compare the operational characteristics of the LSAMP and LSAMP II as they apply to measurement repeatability (measurement variance at a point). The major operational differences are: (1) the LSAMP uses a hand-held tip seal, whereas the LSAMP II has a pistol grip-mounted tip seal with a gage to monitor application force, and (2) the LSAMP's tip seal must be removed between measurements to refill the syringe with air, whereas the LSAMP II has a 3-way solenoid valve and air pump that automatically refill the syringe, eliminating the need to remove the tip seal between measurements. Results suggest removing the tip seal when making multiple measurements at a point produces a significantly higher variance than not removing it, whereas the amount variability attributed to applying the tip seal by hand or with the pistol grip-mounted tip seal (monitoring application force) is relatively the same. Instrument error was also quantified and found to account for less than 2% of the total measurement variability for all materials tested, but results indicate it could be an issue at the high end of the instrument's measurement range.

Two modifications were tested to decrease the required measurement duration of the LSAMP II: (1) changing tip seal inner radius and geometric factor and (2) increasing the gas injection pressure by adding weight. Thirty measurements were made at relatively the same location on an aluminum oxide sharpening block using three different tip seal geometries (inner radii and/or geometric factor). Measurements were made on different lengths of POREX® porous plastic standards with no weight, 1 lb, and 2.5 lbs added weight. Increasing the tip seal ratio (geometric factor) for a given tip seal inner radius did not prove to have a significant effect on measurement duration. Increasing the tip seal inner radius, for a given geometric factor, significantly decreases the measurement duration, though application of this modification is limited due to practical considerations. The addition of weight proved to significantly decrease measurement duration: 5 times faster than the un-weighted duration for 1 lb, and 10 times faster than the un-weighted duration for 2.5 lb. Reduction of the measurement duration by a factor of 10 (for 2.5 lb added weight) effectively adds an order of magnitude permeability to the low end of the measurement range.

A mathematical model was developed and a prototype device was built to test the range and corresponding measurement duration of a transient pressure decay permeameter. Experiments were performed on multiple sample materials, at a range of initial tank pressures, using two different volume tanks (with and without a heat capacitor in the tank). Results suggest use of a heat capacitor in the tank is essential to dampen thermodynamic effects resulting from rapidly decaying pressure at the onset of a measurement. Derivative plots and steady-flow measurements indicate the presence of nonlinear effects, occurring at the transition to turbulent flow, in high-permeability materials at higher pressure. For data in which thermodynamic and nonlinear effects were unnoticeable, pressure decay permeability estimates agree fairly well with steady-flow measurements, but are consistently biased low. Though only tested in the laboratory, the pressure decay permeameter could significantly improve data collection in the field, allowing for rapid ($\Delta t_{measurement}$ <20s) permeability measurement across at least four orders of magnitude permeability (from 1×10^{-11} to $3 \times 10^{-15} m^2$) using a single permeameter.

CONTROLS ON THE ACCUMULATION OF HYDROCARBONS IN THE LOWER BRUSHY CANYON FORMATION, SOUTHEASTERN NEW MEXICO, by *Jason Lennane*, 2002, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 146 pp.

The lower Brushy Canyon Formation (LBC) of southeastern New Mexico consists of fine-grained clastic material deposited by turbidity currents during sea level lowstands in the Delaware Basin. Hydrocarbon production from the LBC is often unpredictable and well logs offer little assurance of pay.

Detailed descriptions of several cores taken from the LBC show a very fine grained siltstone, which is dominated by finely interbedded organic shale turbidities. The producing intervals are generally thicker, cleaner siltstones. Non-producing siltstones are generally darker in color indicating a high clay content. Further petrographic analysis of both producing and non-producing sandstones confirm observations from the core. The non-producing siltstones contain high amounts of clay and calcite cement. These components fill pore space and increase pore entry pressures, thereby reducing the ability of the rock to transmit hydrocarbons. The producing siltstones are generally clean with very low amounts of clay or calcite cement. Porosity in these productive rocks is very high, and pores are interconnected. Further research shows that it is possible to calculate the amount of clay in a siltstone from the LBC based on its gamma ray curve. Clay content of sandstones can then be quantitatively mapped at the reservoir level and at the basinal level. This technique will help identify unproduced reservoirs as well as better explain current reservoirs and traps.

GEOLOGIC MAPPING AND $^{40}AR/^{39}AR$ GEOCHRONOLOGY IN THE NORTHERN NOGAL CANYON CALDERA, WITHIN AND ADJACENT TO THE SOUTHWEST CORNER OF THE BLUE MOUNTAIN QUADRANGLE, SAN MATEO MOUNTAINS, NEW MEXICO, by *Scott D. Lynch*, 2003, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 102 pp.

Geologic mapping and $^{40}Ar/^{39}Ar$ geochronology in the west-central San Mateo Mountains of southwestern New Mexico indicate that the Nogal Canyon caldera (source of the 28.4 Ma Vicks Peak Tuff) is larger than previously proposed and was a topographic high until at least 27.4 Ma. Approximately 42 km^2 located north of the previously proposed caldera margin were mapped at 1:24,000 using the southwest quarter of the Blue Mountain quadrangle and the three adjacent quadrangles as base maps. In this area, more than 690 m of Vicks Peak Tuff with no exposed base is overlain by 550 m of mineralogically similar rhyolite lavas. Several granite porphyries intrude the Vicks Peak Tuff, and several rhyolite dikes intrude the rhyolite lavas. Overlying this sequence is the 24.4 Ma Turkey Springs Tuff (70 m–110 m). Samples from each rock unit in this study area were collected for $^{40}Ar/^{39}Ar$ geochronological analysis. A total of 32 samples were analyzed using the single crystal laser fusion method on sanidine. Most samples yielded a tight, single population of sanidine crystals and a high precision age ($2\sigma < \pm 0.7\%$). The ages of the Vicks Peak Tuff, rhyolite lavas, and silicic intrusions overlap within 2 σ error and show that they erupted and intruded during a brief (<0.42 Ma) episode of activity that occurred between 28.58 and 28.16 Ma.

Spatial and temporal relationships between the Vicks Peak Tuff, rhyolite lavas, and granite porphyries indicate that they came from a common magma system and that the rhyolite lavas and granite porphyries are associated with the development of the Nogal Canyon caldera. The thickness of the Vicks Peak Tuff and rhyolite lavas in this study area suggests that they are intracaldera facies, thereby suggesting that the northern margin of the Nogal Canyon caldera is actually north of the field area. The estimated diameter of the caldera is 25 km, and the estimated total volume of the Vicks Peak Tuff is 1,816 km^3.

Notably missing from the stratigraphic sequence in this study area is the 27.4 Ma South Canyon Tuff, a 700 km^3 regional ignimbrite that erupted from a caldera less than 10 km to the north. This suggests that the Vicks Peak Tuff, rhyolite lava, and granite porphyry intrusions formed a topographic high during the 27.4 Ma eruption of the South Canyon Tuff such that the South Canyon Tuff was not emplaced or was completely eroded in less than 3 m.y. This high may be due to resurgent uplift of the caldera floor after caldera collapse.

RADAR DETECTION OF BURIED LANDMINES IN FIELD SOILS, by *Timothy W. Miller*, 2002, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 124 pp.

The contrast in the dielectric constant between a landmine and the surrounding soil is one of the most important parameters to be considered when using ground penetrating radar (GPR) for landmine detection. For most geologic materials the dielectric constant (relative permittivity) lies within a range of 3–30, with dry sand at the lower end of this range at about 3–5. Nonmetal-

lic antitank landmines have dielectric constants within a range of about 3–10 depending on the type of material they are composed of and the presence of minor metallic components. Metallic landmines have a much higher dielectric constant, approaching infinity because they are conductors of electricity. In previous work, a MATLAB model was developed that is able to predict whether or not field conditions are appropriate for use of GPR instruments. In this study the predictions of this model are validated using GPR in different field soils and at various soil-water contents. Three soils were chosen based on their sand, silt, and clay contents. To vary the water content of the field soils, a sprinkler system was designed to uniformly water the study areas. Time domain reflectometry (TDR) probes were used to measure the soil-water content at each site, and GPR profiles were collected under dry, intermediate, and wet field-soil conditions. GPR data from the sand and silt soils provide convincing evidence that increasing the soil-water content above a nonmetallic landmine improves detections. Data for the clay soils suggest that under elevated soil-water conditions detections of buried landmines are not improved; instead radar images in these soils become worse with increasing soil-water content. Data suggest that detections of metallic landmines also degrade with increasing soil-water content. The field data are in agreement with the model predictions.

CARBON-13 IN HYDROLOGICALLY CLOSED SYSTEMS—EXPERIMENTATION AND MODELING, by *Alyssa Joy Olson*, 2002, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 188 pp.

Information about Quaternary paleoclimatology has been dominated by marine and ice core records, but these data do not provide direct information on mid-latitude continental paleoclimate. However, one source of continental records is sediments deposited in closed-basin lakes. Data on $\delta^{13}C$ and $\delta^{18}O$ measured in calcite from closed-basin lake sediments suggest a relationship, or covariance between these isotopes. As the $\delta^{18}O$ becomes enriched so does the $\delta^{13}C$ during the hydrologically closed periods of the lake's history. Covariation of $\delta^{13}C$ and $\delta^{18}O$ has been considered diagnostic of closed-basin lacustrine sediments, but the mechanism of this covariation remains controversial. The main factors that affect $\delta^{18}O$ in a closed-basin lake are vapor exchange and hydrologic balance. On the other hand, the mechanisms for $\delta^{13}C$ variation in closed lacustrine basins are not clearly understood. Several hypotheses, including vapor exchange, hydrologic balance, lake productivity, and CO_2 degassing have been put forward to explain $\delta^{13}C$ variation, but none have been tested experimentally.

This work involves experimentally determining the effects of CO_2 degassing on carbon isotope evolution. The hypothesis is that in alkaline lakes, the exchange of CO_2 with the atmosphere, as a function of lake volume, dominates the carbon isotope dynamics. Verification of this hypothesis will allow the carbon isotope history of such lakes to be modeled, thereby enhancing the value of the paleoenvironmental records obtained from lacustrine carbonates.

In a series of simple experiments, we approximated a closed-basin lake using three chemically different solutions: a deionized water control, a Na-HCO_3 solution, and a Ca-Na-HCO_3-Cl solution. The solutions were allowed to evaporate in three large tanks. Once the final evaporation point was reached, deionized water was added in a series of five steps until returning to the original volume.

The dissolved inorganic carbon $\delta^{13}C$ and $\delta^{18}O$ measurements in both the Na-HCO_3 and Ca-Na-HCO_3-Cl solutions indicated different covariant trends during different stages of the experiment. The calcite that precipitated in the Ca-Na-HCO_3-Cl solution also showed a covariant trend for these isotopes. The final $\delta^{13}C$ values in both solutions confirmed the absence of biological productivity. The covariation observed in both solutions was a direct result of the geochemical evolution of the solution. The ^{18}O isotopes showed an evolution consistent with Rayleigh distillation. The ^{13}C isotopes, however, appeared to be driven mostly by CO_2 exchange with the atmosphere, which could be calculated with a carbon exchange and degassing model rather than with Rayleigh distillation.

PALEOCLIMATIC CONDITIONS DURING THE LAST GLACIATION INFERRED FROM COMBINED ANALYSIS OF PLUVIAL AND GLACIAL RECORDS, by *Mitchell A. Plummer*, 2002, Ph.D. dissertation, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 324 pp.

Late Pleistocene glacial and lacustrine fluctuations preserved some of the best and most dramatic evidence of climate change on the continents. Unfortunately, paleoclimatic interpretation of those records has long been hampered by the mutual dependence of both hydrologic systems on temperature and precipitation, that is—glaciers and closed-basin lakes increase in size in response to decreased temperature as well as increased precipitation. Researchers have therefore typically relied on uncertain assumptions about one of these variables in order to infer changes in the other. In this study, we show that reconciliation of glacial and lacustrine records by itself provides a means of constraining both temperature and precipitation. This is possible because each system has different relative sensitivity to those primary climatic variables. To convert the geologic record of changes in the glacial and lacustrine records to paleoclimatic constraints, we used physically based models of the glacial and lacustrine systems to identify combinations of climatic conditions that could reproduce the changes preserved in the geologic record. The glacier model is a spatially distributed snow- and energy-balance model loosely coupled to a vertically integrated 2-D glacier flow model. It specifically addresses the need for a model that can reproduce not only the larger, easily estimated shapes of the last glacial maximum, but also the much more complex ice distributions of the latest Pleistocene. We used a Thornthwaite water balance model to estimate the sensitivity of the lacustrine system to climate change, as it is dominated by climatically induced changes in evapotranspiration and runoff. Applying this dual-system modeling approach to the glacial-pluvial record in the Owens Valley, we find that temperatures were ~6°C colder during the last glacial maximum (LGM) but had warmed by about 4°C from that low by ~13 ka, well before the onset of the Holocene. More significantly, we conclude that LGM precipitation was probably no more than 25 to 50% greater than today and that the increased precipitation continued, with intermittent dry periods, until the end of the Pleistocene.

A COMPARISON OF SEPARATION TECHNIQUES APPLIED TO NATURAL WATER SAMPLES PRIOR TO ANALYSIS, by *Dennis Romero*, 2002, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 226 pp.

After observing that studies involving filtration effects on natural water samples yielded results similar to those of geological membrane experiments, we conducted a series of laboratory and field experiments to examine this similarity. During the lab phase, we synthesized dilute sodium chloride and multi-component aqueous solutions mixed with varying amounts of sodium-saturated bentonite to simulate natural water samples with low concentrations of total dissolved solids (TDS) and high levels of total suspended sediment (TSS). We subjected these synthetic solutions to filtration, centrifugation, and dialysis before chemical analysis. We observed a decrease of as much as 24% in major ion concentrations after filtration. We also noted that TDS concentrations for samples subjected to dialysis and centrifugation were within 2–8% of their actual concentrations. During the field phase, we obtained water samples from the Rio Puerco and Rio Grande following large runoff events to examine the effects of different solid-liquid separation methods on the concentration of dissolved species in the samples. We filtered the field samples collected and analyzed major ion concentrations in the filtrate. We observed that the concentrations of chemical species in the filtrate as a function of volume filtered varied by as much as 8%. We concluded that, under certain circumstances, hyperfiltration might be occurring during the filtration of natural water samples. We believe this phenomena may be caused by the rapid accretion of sediment onto a 0.45 µm filter, and, although much more prevalent for trace metals, can occur for some major cations and anions. We also concluded that the solid-liquid separation techniques of centrifugation and dialysis show promise for the treatment of aqueous sample before chemical analysis.

In addition to examining chemical variations of aqueous solutions as a function of filtered volume and as a function of solid-liquid separation method, we measured and analyzed filtration rates for each experiment using the filter cake model developed by chemical engineers during the early 1900s. We noted that plotting inverse flow rates versus cumulative volume filtered for each experiment yielded a linear relationship, just as described by the filter cake model. We were also able to calculate values for the resistance of the filter medium used (R_m), as well as the resistance from the accretion of sediment onto the filter (α). Although we noted some problems associated with using the filter cake model to predict the behavior of natural water samples subject to filtration, we concluded that it may be possible to extend the filter cake model to adequately describe and predict clogging rates associated with filtering natural water samples.

CONCATENATION OF A REACTIVE TRANSPORT MODEL TO SIMULATE CO_2 SEQUESTRATION IN GEOLOGIC MEDIA, by *Tristan Paul Wellman*, 2002, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 162 pp.

Majority opinion within the science community is that anthropogenic greenhouse gases contribute to global warming. Of the greenhouse gases, CO_2 plays a significant role in trapping heat near the surface of the earth. Technology is available to capture CO_2 emissions from energy plants, and these captured emissions can be sequestered in deep basin repositories. However, determining the viability, risks, and optimal locations of sequestering CO_2 in geologic media requires modeling the complex interactions between the injected CO_2, matrix, and pore fluid under site specific pressure and temperature conditions. Previous studies consisted mainly of simulating flow and transport of CO_2 in subsurface environments. Realizing the importance of chemical processes, we assembled the TR-T reactive transport model, which in addition to flow and transport simulates the impact of fluid-mineral interactions on CO_2 mobility. The TR-T simulator is an assemblage of the CO_2 flow and transport module TOUGH2-EOSCO2 and TRANS, a multicomponent geochemistry module. Whereas the main goal of this project was to create the base version of the TR-T simulator, we have begun comparing TR-T predictions to results from laboratory experiments. Comparisons to laboratory experiments provide a means to assess the accuracy of the TR-T simulator. The experiments also offer information to parameterize the TR-T model for specific media. Model predictions show excellent agreement to results from the first completed experiment. Awaiting additional results, we performed a suite of bench-scale sensitivity simulations to determine the effects of varying brine pH and alkalinity, and rock type. Our analysis indicated that varying brine pH and alkalinity resulted in a 0–5 % difference in mineral volume fraction at 1.25×10^7 seconds, depending upon the mineral assemblage. However, we found that variability among rock type was extreme; suggesting that CO_2 injection in some geologic media may induce significant dissolution and dramatically increase CO_2 mobility. As an introduction to larger-scale simulations, we simulated CO_2 injection at the reservoir scale. Contrary to the bench-scale results, the TR-T simulator predicted negligible changes to the matrix. We hypothesize the displacement of brine by the expanding supercritical CO_2 plume may limit brine reactivity with the geologic media. However, we employed a smaller ratio of injected CO_2 to calcite volume in our reservoir-scale simulation, which may account for the discrepancy between the simulated matrix change at the bench and reservoir scales. These introductory simulations were used to quantify fluid-mineral interactions, compare simulations to experimental data, and to demonstrate the ability of the TR-T simulator. The ultimate goal will be to employ the TR-T simulator to identify ideal CO_2 repositories and to assess the effectiveness and environmental implications of sequestering CO_2 in deep basin environments.

New Mexico State University

SEDIMENTATION PATTERNS IN A SALT-DIAPIR INFLUENCED FORELAND BASIN—UPPER CRETACEOUS TO LOWER TERTIARY DELGADO SANDSTONE TONGUE, POTRERILLOS FORMATION, LA POPA BASIN, NUEVO LEON, MEXICO, by *Jennifer L. Aschoff*, 2003, M.S. thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 259 pp.

Synorogenic Cretaceous strata exposed in La Popa Basin, northeastern Mexico, record the development of local salt structures, Sierra Madre Oriental fold and thrust belt, and the resultant sedimentation patterns. Detailed sedimentologic and stratigraphic analysis of the synorogenic Upper Cretaceous to lower Tertiary Delgado Sandstone Tongue reveals complex sedimentation patterns that delineate the impact of regional tectonics, local salt stock growth, and eustasy on stratigraphic development.

Fourteen lithofacies observed in the Delgado Sandstone Tongue are interpreted as outer shelf and inner shelf depositional environments that form a geometrically complex shoreline assemblage. Three parasequence types are observed and stack as two parasequence sets, a lower, progradational parasequence set and an upper, retrogradational parasequence set. A sequence boundary is interpreted between the two sets, thus defining a highstand and transgressive systems tract as part of two partial sequences in the Delgado Sandstone Tongue.

Regional thickness trends show thinning both toward and away from the paleocoastline. Thinning away from the coastline reflects the nondeposition of sandstone. In contrast, thinning toward the paleocoastline reflects erosional removal of strata resulting from transgressive revinement. Localized thinning trends are observed adjacent to all salt stocks as well as La Popa weld. Stratal thinning begins at a greater distance from El Gordo diapir than La Popa weld and El Papalote diapir. This suggests that El Gordo diapir had a higher bathymetry than El Papalote and La Popa weld.

Lithofacies, thickness, and percent sandstone data show that Delgado Sandstone sands were deposited as part of a wave- and storm-dominated delta system or sinuous coastline. Sandstone provenance analysis suggests that the Sierra Madre Oriental fold and thrust belt, Alisitos magmatic arc, and intrabasinal limestone lentils contributed detritus to the Delgado Sandstone Tongue; this suggests that detritus was derived from the west/northwest. Additionally, lithofacies data, percent sandstone data, and thickness trends suggest that the orientation of the paleoshoreline was roughly northeast/southwest; this is consistent with sandstone source regions in the west/northwest and sparse paleocurrent data. Sandstone bodies were generally controlled by the overall depositional system and were influenced by salt diapirism within 2 km of the salt.

DEVELOPMENT OF A VERTICAL SALT WELD, LA POPA BASIN, NUEVO LEON, MEXICO, by *Kyle S. Graff*, 2003, M.S. thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 127 pp.

The La Popa Basin in northeast Mexico contains thick sections of Cretaceous through Tertiary strata disrupted by several salt diapirs and one salt weld. The salt weld is a fault-like structure trending east-southeast 12 km from its western end to a bend, and another 12 km southeast to its tip in the study area.

Shallow marine siliciclastic strata of the Parras Shale (Campanian), Muerto Formation, and lower members of the Potrerillos Formation (lower Maastrichtian) thin toward the salt weld, indicating syndepositional topographic expression of a salt wall. The strata are composed mainly of siltstone, shale, sandstone, and uncommon limestone. These units represent deposition at the distal parts of a deltaic system. Petrography and stratigraphic position of a thin limestone unit suggest that it is a calci-turbidite deposited at the southeast tip of the salt wall.

Muerto Formation sandstones are feldspathic litharenites originating from a recycled orogen or magmatic arc. The composition of the Muerto Formation varies within the basin. Petrographic analysis of samples from throughout the basin shows that the salt wall blocked the dispersal of sediment in the La Popa Basin.

Structural features in the study area include three distinct fault sets and a fold set. Faults within the study area trend north-northwest. Post-depositional folds also trend northwest. Sub-parallel trends of the weld trace, folds, and faults suggest a kinematic link between shortening and salt evacuation.

A four-phase weld history consisting of diapirism, welding, shortening, and fault displacement due to continued salt flow is inferred. Normal faulting and diapir-flank folding accompanied the rise of an elongate diapir during sediment deposition. The welding phase was nearly synchronous with diapirism. The Hidalgoan orogeny initiated southwest-northeast shortening oblique to the trend of the salt weld. Detachment folds formed adjacent to the weld where salt was more abundant. Right-lateral, transpressional slip occurred along the salt weld, causing increased vertical displacement to the northwest. Transpression along the salt weld forced the evacuation of remnant diapiric salt. Continued salt flow toward the remaining diapirs in the basin caused the formation of two southwest-dipping normal faults.

LATERAL VARIABILITY OF AXIAL-FLUVIAL LITHOFACIES AND AUTHIGENIC CARBONATE IN THE PLIO-PLEISTOCENE CAMP RICE FORMATION, HATCH–RINCON GRABEN, SOUTHERN RIO GRANDE RIFT, by *Risa D. Madoff*, 2002, M.S. thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 105 pp.

Lateral variability of the distribution of pebbly sand channels, floodplain fine-grained sand, silt, and mudstone, and of authigenic carbonate is evident in axial-fluvial strata of the late Pliocene to early Pleistocene Camp Rice Formation in the Hatch–Rincon graben, southern Rio Grande rift, New Mexico. Five stratigraphic sections, averaging 35 m thick and spaced approximately 1.5 km apart, were measured along the northern flank of Rincon Arroyo, which bisects the northern half of the graben. The sections were correlated utilizing (1) a lower carbonate bed of probable geothermal origin (white bed) that is traceable between the middle three sections, (2) a 1.6 Ma pumice-clast conglomerate

that is present at all five sections, and (3) the constructional top of the formation, the La Mesa surface, which connects all five sections. Reversal magnetostratigraphy at one of the sections establishes an age range from the Reunion subchron (2.15 Ma) to near the Matuyama–Brunhes chron boundary (0.78 Ma).

The relative abundance of multistory channel sands increases toward the basin center, whereas channel sands are restricted to isolated ribbons near the basin edge. Channel recurrence interval is 152 kyrs in the basin center and 685 kyrs near the edge. The ratio of floodplain mudstone to fine-grained sand and silt increases toward the basin edge, as do the number of calcic paleosols, the abundance of soil welding, and the maturity of the paleosols expressed as a greater number of K horizons. Assuming an average time of development of 10 kyrs for stage II and 100 kyrs for stage III calcic horizons, approximately half of the stratigraphic history near the edge of the basin was taken up in soil formation. The number of ground water carbonates and paleosols with gleyed horizons also increases toward the basin edge.

A see-saw-like motion of the basin related to independent histories of movement of the border faults best explains the channel facies distribution. Southward flow of shallow ground water into the basin from northern recharge areas best explains an increase in ground water carbonates and gleyed horizons near the basin edge.

University of New Mexico

GEOLOGY AND GROUND WATER FLOW, TESUQUE QUADRANGLE, SANTA FE COUNTY, NEW MEXICO, by *Claudia Isabel Borchert*, 2002, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 129 pp.

This study includes geologic mapping of the 7.5-min Tesuque quadrangle at 1:24,000 scale and a ground water study covering 40 km^2 within the quadrangle to determine what geologic features control ground water flow in the Tesuque aquifer. Geologic mapping substantiates early workers' choice of including the volcaniclastic strata of the Bishop's Lodge Member within the Tesuque Formation, because the volcaniclastic layers are interbedded with and conformably overlie characteristic arkosic strata of the Nambé Member of the Tesuque Formation. Major-element glass geochemistry of the tephra within the Nambé and the Skull Ridge Members aided in stratigraphic correlation across faults and between discontinuous outcrop exposures. Deposition of the Nambé Member began before Bishop's Lodge Member, which confirms that subsidence of the Española Basin was underway before 31 Ma. Previous restriction of the age of the Nambé Member to the middle Miocene overlooked the presence of diagnostic fossils only in the upper part of the member. Many late Pliocene to early Pleistocene-age deposits (QTg and QTg$_{a\text{-}c}$) form broad upland surfaces, which are likely remnants of fluvial systems emerging from the foothills. Multiple terrace deposits, commonly inset into existing stream valleys, show an overall 80-m lowering of base level during the Quaternary. Mapped units are tentatively correlated to units from other studies within the Española Basin based on stratigraphic correlation of volcanic sediment, soil studies, or elevation above base level. Only two Pliocene and Quaternary terrace deposits close to the mountain front have been offset by faults, precluding significant Quaternary fault movement. The contact between the Tesuque Formation and the mostly Proterozoic rocks of the Sangre de Cristo Mountains is both structural and depositional.

The ground water elevation data measured in 1998 for this study provide a degree of accuracy for interpolation of the ground water flow geometry not provided by the existing NMOSE WATERS data. The ground water elevation map interpolated from the 1998 data delineates a gaining reach along the Rio Tesuque and establishes that the regional aquifer is hydrologically indistinguishable from the Rio Tesuque alluvial aquifer. Anomalous ground water elevations, which do not conform to the interpolated water-table surface, are likely the result of local gradients and variability in permeability. The map does not reveal barriers to ground water flow such as faults. The density of the 1998 well data alone cannot resolve geologic controls that act on a hundreds-of-meters scale, such as the heterogeneity of permeability in the Tesuque aquifer. Additional insight into the geologic controls on ground water flow was gained by combining the measured 1998 data with adjusted data from the NMOSE WATERS database to achieve greater data density. This prevented interpolation methods from smoothing over variability and reveals that arroyos and valleys are recharge zones.

LATE QUATERNARY CLIMATE HISTORY OF THE PLUVIAL LAKE PALOMAS SYSTEM, NORTHERN CHIHUAHUA, MEXICO, by *Peter J. Castiglia*, 2002, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 161 pp.

Beach ridge and lacustrine deposits from Laguna El Fresnal and Laguna Santa María in the Chihuahuan Desert, Mexico, reveal episodic Holocene lake highstands and long-term climate changes in currently dry basins. Situated approximately 70 km south of the U.S.–Mexico border, lakes occupying these internally drained basins combined during episodes of wetter than modern climatic conditions to form pluvial Lake Palomas.

Constructional beach ridges dated at 221 ± 33 and 435 ± 39 ^{14}C years before present (^{14}C yr B.P.) (Little Ice Age), 3,815 ± 52 to 4,251 ± 59 ^{14}C yr B.P. (early Neoglacial), 6,110 ± 80 to 6,721 ± 68 ^{14}C yr B.P. (middle Holocene), and 8,269 ± 64 and 8,456 ± 97 ^{14}C yr B.P. (early Holocene) provide the first detailed Holocene lake-level chronology for northern Mexico. Distinct pluvial episodes during the early Holocene and probably during the late Pleistocene are marked by two shorelines above an intrabasin sill. At these times, conditions were wet enough to form one large lake that encompassed all of the subbasins. We estimate that the largest spatial extent of this combined lake covered approximately 7,030 km^2 during maximum pluvial conditions, probably during the late Pleistocene. In addition, this lake-level record shows unambiguous evidence for wetter than present conditions during the middle Holocene, a time that is widely considered to have been relatively dry in this region. These lake highstands correlate with other records of millennially spaced wet or cold events in the northern hemisphere, and are inferred to be driven by a greater frequency of winter storms, and reduced temperatures and evaporation rates over the southwestern U.S. and northern Mexico.

An ~17-m-long sediment core from the center of Laguna El Fresnal reveals climate-driven changes in sedimentology, magnetic susceptibility (MS), total organic carbon, and total inorganic carbon that delineate episodes of wet and dry conditions for the last ca 70,000 calendar years (cal yr). Colder than modern climate conditions coupled with low-energy lacustrine deposition before 30,000 cal yr B.P. are marked by low total organic carbon and a gradual increase in clay-dominated sediments. Maximum pluvial conditions ca 21,000 cal yr B.P. are characterized by peaks in sand-size sediment, high MS, and low organic productivity within El Fresnal Basin. The transition to relatively drier, warmer climate ca 10,500 cal yr B.P. is shown by a marked decrease in MS, increased organic and inorganic carbon concentrations, and pulses of fine sand. These results are consistent with other regional paleolimnological evidence of late Quaternary climate change, and represent the first detailed chronology of glacial to interglacial changes in climate from the pluvial Lake Palomas system.

OUTCROP INVESTIGATION OF THE PERMEABILITY AND SPATIAL DISTRIBUTIONS OF ALLUVIAL-SLOPE LITHOFACIES NEAR ESPAÑOLA, NEW MEXICO, by *Michael N. Gaud*, 2002, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 127 pp.

Aquifer heterogeneity at small scales (meters to tens of meters) can be characterized by investigating outcrops that are geologically analogous to aquifers. To evaluate and contribute to techniques used in outcrop-analogue studies, I defined and mapped lithofacies, and measured permeability in situ, at an outcrop of the Tesuque Formation (Miocene) near Española, New Mexico. The depositional environment of the Tesuque Formation was an alluvial slope, which is an streamflow-dominated piedmont setting that is similar to many Basin-and-Range basins. The depositional processes were channelized ephemeral streams, overbank floods, and wind. Lithofacies shapes are both ribbon-form and tabular, and the sediment is poorly lithified mostly silt and sand, but also clay and gravel. The outcrop is a 30-m-think stratigraphic panel ca 370 m long.

I tested the hypothesis that the permeability frequency distributions of the different lithofacies are distinct by using nonparametric statistical tests to compare permeability measurements from the different lithofacies. The full sets of permeability measurements could not be used in these tests, which assume statistical independence, because the permeability data are spatially correlated and therefore not statistically independent. Therefore, I selected from each set of measurements subsamples that were spatially uncorrelated. Each subsample included only data spaced farther apart than the correlation length; correlation lengths were defined by variograms ranges. The statistical tests generally support the claim that the permeability frequency distributions of different lithofacies are distinct from one another.

For lithofacies to be useful in ground water

studies, furthermore, the spatial distribution of lithofacies must also be quantifiable. Toward this end, I calculated relative proportions of the lithofacies, measured thicknesses and widths of channel lithofacies, attempted Markov chain analysis on a vertical transition matrix, and calculated horizontal and vertical indicator variograms for the different lithofacies. The indicator variograms are perhaps the most sophisticated of these methods to quantify spatial distributions of lithofacies. Indicator variograms permit quantification of traditionally descriptive geologic data, and can incorporate the spatial, temporal, and process-based knowledge of the geologist.

SOURCES OF AND CONTROLS ON ARSENIC IN THE GROUND WATER OF FERNLEY AREA, NEVADA, by *Senait Tecle Ghebremicael*, 2002, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 113 pp.

Fernley is located in west-central Nevada, at the point where the Truckee River is diverted by the Truckee Canal. The ground water shows isotopic signatures of the Truckee Canal water, indicating that the aquifer gets its recharge mainly from Truckee Canal leakage and irrigation return flow. The ground water chemistry in this area is highly mineralized compared to the dilute Truckee Canal water. It is high in arsenic; 97% of the wells sampled have concentrations above the current United State Environmental Protection Agency–maximum contaminant level (US EPA–MCL) in drinking water of 10 µg/L.

This study used mass balance calculations to describe how the Truckee Canal water evolves to the ground water chemistry observed in wells. It evaluated the correlation of different chemical constitutes with arsenic and the temporal variability of arsenic to predict the sources and processes causing high arsenic in the ground water. The dissolution and precipitation of the minerals plagioclase, muscovite, halite, mirabilite, magnesite, kaolinite, illite, and chlorite control the major ion chemistry in the area. The source of arsenic in the area is natural, mainly associated with iron oxide coatings in the lake sediments. The main process that controls arsenic concentration in the area is adsorption/desorption from oxide surfaces, and changes in pH play a major role in this process. This is shown by the increase in arsenic concentration with pH. The negative correlation between arsenic and sulfate and calcium show that pyrite and calcium arsenates are not important sources of arsenic in the ground water of Fernley area. The role of evaporation in concentrating dissolved ions in the ground water of Fernley is much less than the addition and removal of these ions by dissolution/precipitation and adsorption/desorption.

A TECTONIC HISTORY OF THE PROTEROZOIC ROCKS EXPOSED IN THE BLACK CANYON OF THE GUNNISON, COLORADO, by *Micah J. Jessup*, 2003, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 143 pp.

The dominant orogenic fabric in Proterozoic rocks of the southwestern U.S. includes a series of northeast-striking shear zones that are commonly interpreted as suture zones across which blocks of juvenile crust were assembled to the southern margin of Laurentia. New structural and geochronological data from southwestern Colorado suggest that fabrics related to assembly of tectonostratigraphic terranes in this area strike northwest. The northwest-striking foliations represent deformation at ca 10–20 km paleodepths (ca 1.77–1.71 Ga), and are parallel to magnetic anomalies and to gradients in mantle velocity structure. The agreement between these data sets suggests that the northwest-striking structures are important at lithospheric scale, extend to >100 km depth, and may record assembly of southwestern Colorado across northwest-striking tectonic boundaries. Geochronologic data indicate that northwest (central Colorado)- and northeast (Cheyenne belt)-striking boundaries developed simultaneously during accretion of southwestern Laurentia between ca 1.78–1.73 Ga. To account for this evidence we propose that, at ca 1.75 Ga, the Yavapai province may have involved a complex arcuate subduction system, with multiple arcs, analogous to that of the modern Banda Sea in the Indonesia region.

A detailed structural analysis combined with new U/Pb zircon/titanite geochronology, in situ monazite geochronology, Ar/Ar thermochronology, and geothermobarometry constrain a six-stage tectonic history of the Proterozoic rocks in the Black Canyon of the Gunnison and region. 1) The island-arc stage (ca 1.79–1.73 Ga) involved deposition of submarine bimodal volcanogenic rocks of the Dubois and Cochetopa successions in arc-related settings and the emplacement of coeval calc-alkaline granites. 2) The outboard assembly of island arcs (ca 1.73–1.70 Ga) and the creation of isoclinal F1 folds and northwest-trending F2 folds occurred during progressive northeast-southwest convergence and marks the beginning of the Yavapai orogeny. 3) The Yavapai orogeny progressed into the assembly of the composite arc terrane to Laurentia (ca 1.70–1.68 Ga) and the formation of various northeast-trending F3 folds and S3 foliations, such as the Black Canyon shear zone, mark a change from northeast-southwest to northwest-southeast shortening. 4) Quartzite deposition in syn-tectonic basins (ca 1.70–1.68 Ga) that separate orogenic pulses. 5) The Mazatzal orogeny (~1.65 Ga) involved continued northwest-southeast shortening. 6) Intracontinental magmatism and tectonism (ca 1.43–1.39 Ga) reactivated the Black Canyon shear zone, further enhancing the northeast-southwest grain of the Proterozoic orogen. The results of this investigation are presented as two looping pressure/temperature/time/deformation (P/T/t/D) paths that add to models for the evolution of Proterozoic rocks exposed in the southwestern United States.

TECTONIC DEVELOPMENT OF PROTEROZOIC STRUCTURES AND THEIR INFLUENCE ON LARAMIDE AND MIOCENE DEFORMATION, NORTH VIRGIN MOUNTAINS, SOUTHEAST NEVADA AND NORTHWEST ARIZONA, by *Mark Cameron Quigley*, 2002, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 194 pp.

The northeast-trending Virgin Mountain anticline (VMA) of the North Virgin Mountains straddles the boundary between the unextended Colorado Plateau and the highly extended crust of the central Basin and Range province. The anticline is 50 km long and 8 km wide, is doubly plunging, and has overturned Paleozoic beds on both limbs. The crystalline core of the VMA is composed of Paleoproterozoic supracrustal and intrusive rocks that record four tectonic events from ca 1,740 Ma to 1,550 Ma (D_1–D_4) characterized by distinct structural fabrics and associated metamorphic assemblages and microstructures. The most prominent Proterozoic structure is the Virgin Mountains shear zone (VMSZ), which was initially defined as a crustal weak zone during D_1 northeast-southwest contraction and may represent an important crustal suture, as it contains "exotic lithologies" commonly associated with ophiolites. A clockwise-rotating strain field during progressive east-west (D_2) and northwest-southeast (D_3) contractional events resulted in the prominent northeast strike of this zone. Late Paleoproterozoic, east-west contraction across this zone (D_4) resulted in a complex array of linked, dextral transpressive shear zones that partitioned strain into strike-slip, pure-shear, reverse, and normal sense deformation zones. Deformation within the VMSZ continued to 1,600 and 1,550 Ma based on syn-tectonic monazite rim ages that are associated with sub 500°C (greenschist facies) metamorphic assemblages and textures, and sub 500°C deformational microstructures. Development of these highly fissile shear zones later controlled the geometry of Laramide and Miocene brittle deformation.

The Proterozoic basement in the core of the VMA now resides at elevations of more than 2 km above sea level, roughly 2.5 km higher than the elevation of basement in the adjacent Colorado Plateau. The northeast trend and vertical uplift of the anticline is a result of Miocene east-west extensional deformation superimposed on the pre-existing northeast- and north-trending structural grains created during Paleoproterozoic (D_2, D_3, D_4) and Laramide contractional tectonic events. Outward-verging monoclinal reverse faults similar in style to Laramide-age faults in the Colorado Plateau are present on the east and west limbs of the VMA, and we propose that much of the vertical uplift of the anticline occurred during this time. The geometry of Miocene deformation was both strongly partitioned and directed by these pre-existing structures, and also manifest as steeply dipping conjugate normal faults in the Mesozoic and Paleozoic section that soled into basal detachments in the Cambrian Bright Angel shale and at the Great Unconformity. Apatite-fission track (AFT) dates range from 21.7 ± 2.3 Ma directly below the Cambrian–Precambrian unconformity to 14.0 ± 2.5 Ma in the core of the VMA, and indicate that the anticline was unroofed in Miocene time. Short AFT lengths (<13µm) with large standard deviations (>2.5) from the 22–20 Ma AFT ages suggest that Proterozoic rocks of the VMA cooled slowly through the AFT partial annealing zone at 22–20 Ma before extension, whereas longer AFTs suggest rapid cooling and syn-extensional exhumation from 16–14 Ma. We interpret the former ages to represent pre-extensional erosional cooling of a regionally elevated terrain, contrary to most models that assume a peneplain pre-extensional surface. Our model is consistent with geophysical, sedimentological, and tectonic studies of the region.

MODIS/ASTER Airborne Simulator (MAS-

TER) remote sensing data were acquired over the VMA in order to evaluate the utility of the data for geological mapping in a structurally complex area. These data proved invaluable in producing more than 60 km^2 of new geologic mapping by the first author, and recognizing many of the key structures that led to our Proterozoic, Laramide, and Miocene tectonic interpretations.

PALEOMAGNETIC AND GEOCHRONOLOGIC DATA BEARING ON THE TIMING, EVOLUTION, AND STRUCTURE OF THE CRIPPLE CREEK DIATREME COMPLEX AND RELATED ROCKS, FRONT RANGE, COLORADO, by *Jason S. Rampe*, 2003, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 82 pp.

Paleomagnetic data, combined with high-precision $^{40}Ar/^{39}Ar$ age determinations, show that Cripple Creek diatreme complex, Front Range of Colorado, experienced modest amounts of deformation since mid-Tertiary time. Overall, the demagnetization response, based on both alternating field and thermal methods, and directional data and field tests, are interpreted to indicate that most rocks in the Cripple Creek district carry geologically stable magnetizations. Site mean directions are of both normal (D = 358.3°, I = 63.0°, α_{95} = 4.4, k = 27.5, N = 39 sites) and reverse (D = 172.1°, I = -62.2°, α_{95} = 4.1, k = 32.7, N = 49) polarity. Notably, the site mean directions of both polarities are steeper than expected mid-Tertiary field directions. An analysis of the overall distribution of the site mean data with respect to different parts of the district suggests that slight north-side-down tilting affected the entire district. Detailed analyses distinguish declination as well as inclination discrepancies within the south and east subbasins. Such deformation could have been accommodated by motion along faults active in part of a northwest-directed transtensional setting during mid-Tertiary and younger extension. Twelve $^{40}Ar/^{39}Ar$ determinations were obtained from hornblende, K-feldspar, phlogopite, and groundmass concentrates. These new data demonstrate that initial igneous events are represented by relatively intermediate rocks (tephriphonolite and phonolite) forming at about 31.9 Ma (31.88 ± 0.15 Ma) and 31.6 Ma (31.59 ± 0.32 Ma), followed by mafic to ultramafic intrusions at about 31.1 Ma (31.12 ± 0.04 Ma, tephriphonolite; 31.15 ± 0.11 Ma, phonotephrite; and 30.41 ± 0.21 Ma, lamprophyre dikes). A second episode of phonolite volcanism is represented by Beacon Hill phonolite (29.56 ± 0.5 Ma). Igneous activity ceased for about 1 m.y., and a final episode of ultramafic activity is represented by the ca 28.4 Ma (28.38 ± 0.21 Ma) lamprophyre Cresson pipe. The high-precision geochronology, in concert with paleomagnetic data, indicates that magmatism took place between chrons 12R and 10R of the Oligocene geomagnetic polarity time scale. Moreover, the combination of these two data sets suggests that the tilting of the Cripple Creek diatreme and differential block movements within the diatreme occurred after all major igneous events. The inferred deformation affecting the Cripple Creek area is clearly not representative of all of the Front Range of Colorado, as upper Eocene volcaniclastic strata, approximately 23 km northwest of Cripple Creek near Florissant, are flat lying.

PROTEROZOIC FARWELL MOUNTAIN–LESTER MOUNTAIN SUTURE ZONE, NORTHERN COLORADO: SUBDUCTION FLIP AND PROGRESSIVE ASSEMBLY OF ARCS, by *Amanda R. Tyson*, 2002, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 144 pp.

The mechanisms by which juvenile Paleoproterozoic continental crust was derived from the mantle, accreted to southwestern Laurentia ca 1.78–1.68 Ga, and stabilized as new continental lithosphere have been much debated. This study addresses the problem by assessing the proposed Paleoproterozoic "Farwell Mountain–Lester Mountain suture zone," a broad, complex zone of deformation that may contain the oldest accretionary structures within Paleoproterozoic crust south of the Cheyenne belt.

The proposed "suture zone" is mapped in the Park Range of northern Colorado as a northeast-trending belt of imbricated tectonic slivers between ca 1.79 and 1.77 Ga Green Mountain rocks to the north and ca 1.76–1.72 Ga rocks to the south. Marble, chert, mafic to ultramafic bodies, deformed pillow basalts, and sulfide deposits all crop out along the zone and may represent dismembered ophiolites.

One of the major contributions of this study is the correlation of metamorphic and deformational fabrics among four field subareas (Farwell Mountain, Lester Mountain, Mica Basin, and the Soda Creek–Fish Creek shear zone), in an attempt to investigate the history and character of the proposed "suture zone." Steepening and overprinting by an east-west-striking, subvertical fabric is attributed to post-accretionary shortening ca 1.68 Ga. Also documented is an earlier Paleoproterozoic ductile fabric ("S_2/F_2"), which may preserve evidence of a north-vergent fold and thrust system. This is consistent with the hypothesis that the region has a collisional accretionary history.

Seismic data from the CD-ROM experiment reveal north-dipping reflections that are tentatively associated with a 3–5-km offset of the Moho and a north-dipping, high-velosity body and are together referred to as the Farwell Mountain backthrust. Another set of reflections dip southward and project to the surface near Lester Mountain; these are tentatively correlated with the "S_2" fabric. Together, these features may record the juxtaposition of two tectonic blocks along south-dipping structures in the proposed suture zone ca 1.74 Ga.

A tectonic model is proposed to explain the geometries outlined by combined surface geologic and seismic data from the Cheyenne belt and Farwell Mountain–Lester Mountain "suture zone," allowing some investigation of the early tectonic history of the region despite overprinting by subsequent tectonism.

SEASONAL BIOGEOCHEMISTRY AND MINERAL CYCLING OF THE MIDDLE RIO GRANDE ALLUVIAL AQUIFER, NEW MEXICO, by *David Stewart Vinson*, 2002, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 135 pp.

The Rio Grande in central New Mexico flows through a semi-arid, historically aggrading Quaternary rift basin. Flow regulation measures include dams, irrigation diversions, levees, and bank stabilization. These have caused severe impairment including incision, lowered water tables, and less overbank flooding; disrupted ground water-surface water interactions; altered seasonal organic carbon dynamics; and declining native biota. Previously dynamic flowpaths in the shallow alluvial aquifer (hyporheic corridor) have become less reversible due to parallel drain ditches with beds lower than the river. These ditches impose relatively static hydraulic gradients on the alluvial aquifer, which force water to flow from the river to the drains.

A water sampling campaign from May 2001 through April 2002 established seasonal major element and redox chemistry using dialysis multi-level samplers, wells, and surface water sampling. Sediment extractions quantified and characterized authigenic Fe/Mn oxyhydroxides, as well as solid phase P, all of which were more widespread in intermittently wetted sediments near the water table. Filter papers were incubated in the aquifer to grow seasonal precipitates and examined by scanning electron microscopy with chemical characterization by energy-dispersive X-ray spectroscopy.

Oxygen is rapidly depleted from Rio Grande water shortly after it enters hyporheic corridor sediments. A series of terminal electron-accepting processes, including denitrification, manganese reduction, iron reduction, and sulfate reduction, occurs under anoxic conditions as microorganisms metabolize organic carbon. These reactions occur downflow from the Rio Grande through the alluvial aquifer toward the drainage ditch system. These redox processes depend on changes in hydraulic head driven by diel, seasonal, interannual, and irregular (anthropogenic) variations in river stage. Oxic-anoxic cycling produces Fe/Mn oxyhydroxide and Fe sulfide minerals near the water table. Stalky, helical, and spherical oxide morphologies and cubic sulfide morphologies were observed. These phases grow on the scale of weeks, probably as microbial respiration products. Seasonal mineralogy and organic carbon dynamics may affect water quality and the success of potential restoration efforts. Restoration should include geochemical and hydrologic monitoring of ground water-surface water interactions.