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

ADSORPTION AND DESORPTION STUDIES OF SOME MODEL SURFACTANTS FROM OIL-BASED DRILLING FLUIDS, by *Elizabeth Bryant*, 2004, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 109 pp.

Characterization of reservoir wettability is an important part of assessment of potential oil recovery. Oil-based drilling fluids include surfactants, which can alter the wettability of mineral surfaces. Cores exposed to these fluids may not reflect the true wettability of the reservoir materials.

The focus of this study was to observe wettability changes induced by adsorption and removal of surfactants of known structure on mica surfaces using tools that are applicable to studies of wetting alteration by crude oil components. The surfactants used were polyethoxylated coconut and tallow amines with chain lengths of 12 and 18 carbons and head groups consisting of two to five ethoxy groups. Mica was exposed to decane solutions of the surfactants. The treated mica was characterized macroscopically using contact angle measurements and microscopically using atomic force microscopy (AFM).

Upon exposure to the surfactant solutions, the mica became oil-wet (~170° for both water-advancing and receding conditions). AFM examination of similarly treated surfaces imaged in air revealed surfactant layers that were easily disrupted or surfaces that showed no surfactant at all. Contact angles were in the intermediate to water-wet range if the mica samples were removed from the surfactant solution, rinsed with non-aqueous solvents, and submerged in decane for measurements of water/decane contact angles. These results suggest only weak surfactant adsorption occurred from non-aqueous solutions. Sorption was less for increased levels of ethoxylation, which was concluded from the difference in the contact angles of TAM-2 and TAM-5; differences due to hydrocarbon chain length were negligible, which was evident when comparing CAM-2 and TAM-2 contact angle results. Stronger adsorption, higher contact angles, and more stable surfactant layers could be demonstrated when mica was exposed to aqueous solutions after surfactant sorption, depending on the pH of the aqueous phase. Low-pH conditions that promote protonation of the surfactants' amine headgroup produced the greatest wetting alteration. Above a pH of 8 or 9, no surfactant remained adsorbed on mica surfaces.

GROUND WATER RECHARGE AND MOVEMENT THROUGH MOUNTAIN-BASIN SYSTEMS OF THE SOUTHWEST—A CASE STUDY IN THE CHIRICAHUA MOUNTAINS–SAN BERNARDINO VALLEY SYSTEM, ARIZONA AND SONORA, by *Samuel Earman*, 2004, Ph.D. dissertation, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 232 pp.

This dissertation discusses several aspects of the hydrogeology of a mountain-basin system (the Chiricahua Mountains, Arizona, USA, and the San Bernardino Valley, Arizona, USA, and Sonora, Mexico). Detailed studies focused on four major phenomena: the hydrogeologic impacts of magmatically active accommodation zones, the conditions necessary for the formation of the evaporite mineral trona ($Na_3CO_3HCO_3 \bullet 2H_2O$) ground water recharge and movement in a high-elevation mountain range, and the proportion of snowmelt in ground water recharge in the Southwest.

Although the San Bernardino Valley and its neighboring basins are bounded by highlands with of similar lithology, are of the same age, and share a common mode of formation, the San Bernardino Valley has distinct hydrogeologic properties, including ground water anion evolution dominated by HCO_3^- (as opposed to SO_4^{2-} and Cl^-), high total dissolved solids content, low ground water ages, and low storativity. The hydrogeologic differences are all related to the presence of the magmatically active accommodation zone. The differences in hydrogeology between the San Bernardino Valley and its neighbors can be used as a basis for interpreting hydrogeological differences between other accommodation-zone basins and their neighbors.

The differences in water chemistry described above include a high ratio of $[HCO_3^-]$ to $[Ca^{2+}]$ in the San Bernardino aquifer due to injection of CO_2 related to the accommodation zone, which means that ground waters from San Bernardino would form significant quantities of the mineral trona upon evaporation, but waters from its neighboring basins would not. Observation of this difference in mineral assemblages that would result from CO_2 injection led to an examination of other trona deposits and trona-forming waters around the world, suggesting that CO_2 injection appears to be a necessary factor for trona formation. This refinement of the generally accepted theory for trona formation helps to explain the limited distribution of trona deposits in the geologic record, and can aid future trona prospecting.

Among other findings, an examination of ground water recharge and movement in the Chiricahuas shows that high-elevation mountain springs are not necessarily hydraulically isolated from lower systems; that the development of snowpack appears to be one of the factors that drives ground water recharge; and that high-elevation zones of the range are the most important contributors of water to the mountain system and the adjacent San Bernardino aquifer.

Stable isotopes in snow are subject to post-fall alteration, which can have significant impacts on mass-balance calculations. Paired precipitation collectors of different designs can be used to determine the magnitude of alteration that occurs at a site. Because the collectors allow different amounts of alteration to take place, comparison of data gathered by different styles of collectors may yield misleading results if snow makes up a significant part of the sample collected. The alteration of snow by precipitation collectors may not be evident, as even samples that have undergone significant alteration can plot on or above the global meteoric water line. Many processes contribute to the alteration of snow, including isotope exchange with atmospheric water vapor. The effects of this process were observed in the field and the laboratory. The isotope signature of fresh snow is typically not representative of the bulk meltwater derived from the snow; because isotope evolution appears to increase with exposure time, samples of snow or melt collected on a given day are also unlikely to be representative of the bulk melt. As a result, isotope mixing models using fresh snow signatures as an end member contributing to ground water recharge appear to underestimate the contribution of snowmelt. Mixing models using snowmelt isotope composition from a precipitation collector designed to provide an improved value for meltwater input (compared to fresh precipitation or a sample of snow or melt from a given day) show that snowmelt accounts for a significant proportion of ground water recharge (typically 40–60%) at four sites in New Mexico and Arizona. The proportion of snowmelt in ground water at these sites is typically higher than the proportion of snow in average annual precipitation, showing that snow has a greater recharge efficiency than rain. Future climate change could significantly affect ground water recharge in the western USA, because it could result in lower proportions of snow.

GEOCHRONOLOGY AND PROVENANCE OF FOUR MESOPROTEROZOIC BASINS ACROSS THE SOUTHWEST UNITED STATES: EVIDENCE FROM ^{40}AR/^{39}AR DATING OF DETRITAL MUSCOVITES, by *Kathryn E. Fletcher*, 2004, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 277 pp.

Detrital muscovite $^{40}Ar/^{39}Ar$ dates provide key constraints on depositional ages and provenances for several Mesoproterozoic sedimentary sequences from New Mexico, Arizona, and California. The data further refine or strengthen existing regional correlations between similar lithostratigraphic units and provide critical information to better understand the tectonic settings and paleogeography for southern Laurentia for the time period between about 1.3 and 1.1 Ga.

Over 1,000 detrital muscovites from the Apache Group and Troy Quartzite, southeast Arizona; Unkar Group, Grand Canyon, Arizona; Crystal Springs Formation, Death Valley, California; and Debaca Sequence, New Mexico, were analyzed. Most of the sedimentary rocks are dominated by muscovites with apparent ages between about 1.4 and 1.7 Ga and record exhumation of Yavapai and Mazatzal crust. There are no muscovites older than about 1.7 Ga, which demonstrates that regions such as the low-grade rocks from the Wyoming Province did not contribute detritus to the southern Laurentian basins. Other than the Unkar Group, most sequences could have received sediment from fairly proximal sources; however, the large region that can contribute 1.4–1.7 Ga muscovites precludes precise location source regions. In contrast, the units such as the Dox Formation that contain muscovites with apparent ages between about 1.25 and 1.1 Ga represent a Grenville source terrain.

The 1,328 ± 5 Ma Pioneer Shale (Apache Group) and Crystal Springs Formation (Pahrump Group) represent the oldest units studied and might be coeval. If correlative, these units suggest a possible shoreline that extended roughly northwest to southeast at about 1.3 Ga. Also at this time, highlands existed in northern Arizona, and it is probable that the Grand Canyon basement was the sediment source for the Apache Basin.

At about 1.25 Ga, regional carbonate deposition began across southern Laurentia. The detrital muscovite data support, but do not require, contemporaneous deposition of the Bass Limestone, the Mescal Limestone, the Caster Marble, and the carbonate member of the Crystal Springs Formation. This regional correlation from west Texas to California supports the hypothesis that a shallow interior seaway flooded southern Laurentia before Grenville collision.

In Arizona, mature marine sandstones like the Troy Quartzite and Shinumo Sandstone cap the limestone members and record regression of the seaway, followed by significant fluvial sandstone deposition. This transition period is marked by a striking change in detrital muscovite ages. Most notably, the Dox Formation of the Unkar Group contains a nearly uniform distribution of ~1.15 Ga detrital muscovites and requires development of a Grenville highlands that shed a large apron of sediment into a foreland basin across southern Laurentia. Evidently, large river systems carried detritus from the actively exhuming Grenville highlands to at least northern Arizona (~800 km) within a relatively short (10–50 Ma) time span.

PETROPHYSICAL PROPERTIES OF MARINE SEDIMENTS AND SEDIMENTARY ROCKS IN PLATE BOUNDARIES—INVESTIGATION AT MULTIPLE SCALES, by *Glen L. Gettemy*, 2005, Ph.D. dissertation, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 184 pp.

This dissertation essentially follows from a simple question asked quite frequently in geologic research: *What can geophysical observations made at one scale say about earth system processes at much bigger or much smaller scales?* The work presented here addresses this issue for four separate questions at three different plate boundaries of two different types. After a brief introduction, Chapters 2–4 present three diverse studies of two separate rapidly converging margins (Costa Rica and Peru, respectively) focusing on aspects of the coupled mechanical-hydrothermal system associated with such early-stage subduction. Chapter 5 highlights the importance and complexity of matching geophysical sampling to geologic scale to determine the seismic velocity architecture of even a geologically simple fault using a large dominantly strike-slip fault zone in the San Andreas transform boundary as an example. The concluding chapter opens with a review of result highlights, a synopsis of vital concepts that can be extracted from the scientific work as a whole, and presents a short discussion of two possible future research areas that follow directly from the concepts and results of the four scientific chapters. The scientific chapters are individually discussed below.

Chapter 2 investigates changes in petrophysical characteristics within three distinct tectonic domains (undeformed oceanic plate; underthrust-equivalent oceanic plate; proto-wedge, < 500 m thick) at the toe of the deformation front in the Costa Rica margin off shore the Nicoya Peninsula. Combined laboratory elevated effective stress consolidation and ultrasonic velocity (both compressional and shear phase) data are used to (i) explore the systematic modifications to sediment elastic properties that result from rapid dewatering and (ii) investigate in situ V_P–V_S-porosity values. With respect to the physical and mechanical properties of the subducted oceanic plate sediments, study results reveal that an apparent underconsolidation, produced by the rapid dewatering in the first ~ 0.6 km of underthrusting, can be detected in the distinct change in sediment fabric characteristics as measured by bulk moduli-porosity systematics. Wedge sediment hydromechanical evolution, on the other hand, is dependent on depth-specific development of shear fabric and sediment matrix stiffening due to pore collapse.

Chapter 3 shows that the unique depositional and diagenetic histories of a particular set of shallowly buried Peru margin sediments define the microgeometrical and poroelastic parameters (i.e., reference state) that compose an effective Biot medium description of those sediments. A novel combination of SEM imaging and ultrasonic V_P dispersion techniques, designed to detect poroelastic interactions at an effective representative elementary volume of several mean particle diameters, is used to estimate and constrain these parameters. Key results focus on issues of scale-equivalent measurement differences (e.g., porosity and permeability estimates over the micro- to core-scale length change), detection and estimation of microstructural heterogeneity, and viscoelasticity in the sedimentary framework. In particular, the microscale permeability estimates are shown to be 30–50 times greater than core-based measurements for several sediments. Also, negative velocity dispersion and microstructural resonance phenomena are used to estimate the physical dimensions of key components of the sediment framework not accounted for in the basic parameterization of the effective Biot medium. The elastic parameters of the characteristic particulate framework for all sediment types are shown to be highly viscoelastic and distinct, with the ratio of the imaginary-to-real components of the complex effective grain (K_g) and frame (K_{fr}) bulk moduli between 0.3 and 0.6, and K_g (K_{fr}) ranging between ~ 20 GPa (10 MPa; biogenic oozes) and ~ 35 GPa (200 MPa; siliciclastic sediments).

Chapter 4 examines the hydrate distribution in the rapidly deforming front of the Peru margin near the Peru–Chile trench (ODP Leg 201, Site 1230). The toe and portions of the lower slope of this convergent margin is rapidly dewatered, resulting in significant subvertical advective transport of hydrothermally and geochemically distinct fluids. Full-waveform compressional wave sonic logging data are analyzed through a combination of (i) a regenerated V_P-depth log and (ii) a novel high-frequency hydrate-scatterer image in the near-borehole sediments (< 3 m lateral extent). The objective is to understand the distribution of free gas and gas hydrate over the depth interval 92–185 mbsf. These wave propagation results are further used to constrain vertical and lateral dimensions of the imaged hydrate pockets and ultimately to estimate hydrate volume fraction through the top of the gas hydrate stability zone.

Chapter 5 addresses the prospect of seismically deciphering the lithostructural architecture of fault zone elements by study of a large (in terms of both seismic hazard and geographic scale) active fault in a transform boundary system. The surface exposure of the San Gregorio fault zone, 30 km southwest of San Francisco in the San Andreas fault system, provides a natural laboratory for the multi-scale, multi-frequency investigation that utilizes both field refraction tomography and ultrasonic velocity measurements to determine the nearsurface seismic velocity structure. Laboratory ultrasonic velocities are upscaled to their seismic-frequency equivalents by correcting for fluid- and structure-related dispersion. The critical result—development of a scale-matched seismic velocity model that correlates almost exactly to the geologic construct previously developed, with a low velocity anomaly of ~ 30% characterizing the velocity change from the host rock relative to the fault core—highlights the uncertainties inherent in using seismic data to estimate in situ structural delineation and petrophysical property states.

HYDROLOGIC AND GEOLOGIC CHARACTERISTICS OF THE COALBED METHANE RESOURCE, RATON BASIN, NEW MEXICO, by *Christopher Haley*, 2004, M.S. Thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 261 pp.

Coalbed methane is a newly emerging resource for the Raton Basin in New Mexico. Wells are producing methane from coalbeds in the Upper Cretaceous Vermejo Formation and Upper Cretaceous to Paleocene Raton Formation. In recent years a stronger emphasis has been placed on understanding the hydrogeology related to coalbed methane production because of the inextricable relationship of water and gas in such reservoirs. The purpose of this study was to investigate the extent to which hydrological and geological factors contribute to the coalbed methane potential of the basin.

Hydrologic and geologic data were collected, examined, and interpreted. Data from core, well logs, and cross sections suggest coalbeds are relatively thin (1–6 ft) with about ⅓–½ of the beds lacking lateral continuity on the ½ mile well spacing. The average net coalbed thickness of 42 ft is relatively low in comparison to other coal basins in the western United States. Both of these factors limit coalbed methane potential for the basin. Structural contouring of the top surface of the Trinidad Sandstone revealed a connection between subsurface structural features associated with the Vermejo Park dome and increased water production. Increased water production, which limits coalbed methane potential, was noticed in wells near the western basin margin. Wells that contain igneous sills have 24% higher gas and 7% higher water production than wells lacking sills, a definite advantage when producing coalbed methane. Ion ratios of produced waters indicate ground water flow is generally west to east with younger water usually associated with increased water production in wells. The low (0.02–0.07 darcies) matrix permeabilities measured suggest fracture permeability as the primary contributor to water production in wells. Potentiometric surface calculations show that the aquifer system in the basin becomes under pressured with increasing depth. This limits the maximum gas content in coalbeds while at the same time potentially limiting non-coalbed water production for wells. Gas composition analyses show methane on average comprises 97% of the gas being extracted from wells. The high methane content identifies the gas as thermogenic in origin and is almost ideal for production.

PERMEABILITY UPSCALING—A MODELING INVESTIGATION OF GAS MINIPERMEAMETERS, by *Justin Jayne*, 2004, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 205 pp.

Because of technological limitations, the scale of property heterogeneity that can be represented with a computational model is significantly larger than the scale at which properties are measured by most instruments. Consequently, techniques are needed to upscale and synthesize small-scale measurements to infer larger-scale effective properties. Laboratory upscaling experiments were conducted by Tidwell and Wilson (2000) using an automated gas minipermeameter system. Repeated permeability measurements on geologic samples showed different but related patterns of spatial variability at different sample supports and, depending on the rock, different upscaling behavior.

We numerically simulated a field of log permeability values prescribed to geostatistically replicate a block of Massillon sandstone. Log permeability values were simulated using sequential Gaussian simulation on a block-centered grid using laboratory data to prescribe geostatistical parameters. The operation of a steady-state gas minipermeameter was modeled by means of the finite-difference method. The laboratory multisupport minipermeameter allows for highly resolved gridded measurements to be made using a set of five interchangeable tip-seals, each twice the size of the next, ranging in inner radius from 0.15 cm to 2.54 cm. The numerical scheme that models the multisupport minipermeameter replicates change of sample support by holding constant the boundary conditions representing the tip-seal (thereby maintaining constant flow geometry) while repeatedly doubling the resolution of the grid, effectively mimicking the corresponding halving of tip-seal dimensions. The x-y positioner that moves the tip-seal of the multisupport minipermeameter across the face of the rock sample is numerically modeled by shifting the grid of log permeability values row by row relative to the fixed boundary conditions. The multisupport minipermeameter made measurements on a 50 x 50 grid; due to the time required to perform the computations, the numerical experimental measurement “grid” consists of a transect of 100 points.

Effective log permeability measurements show that the numerically modeled minipermeameter capably replicates the operation of the laboratory instrument. The variance of the numerical effective log permeability decreases as tip-seal size increases, as does the variance of the laboratory data set. This result is consistent with the simple averaging characteristic of both the measurement grid and the change of sample support. In addition, semivariograms calculated from numerical effective log permeabilities show patterns similar to those of the laboratory data, namely that the sill decreases and the range increases as tip-seal size increases. The behavior of the sill is simply a reflection of the upscaling of the variance, and the behavior of the range reflects the fact that as the tip-seal size increases, two measurements must be separated that much farther apart before they become uncorrelated.

The numerical experiment allows for comparison between the numerical effective log permeability and the underlying synthetic log permeability field. In an effort to determine how well the instrument characterizes the spatial structure of the field it samples, we determined that it is neither possible for an instrument to resolve features of the target field smaller than twice the characteristic length (in this case the inner tip-seal radius), nor can a set of measurements made on a regular grid fully resolve features at scales less than twice the measurement grid interval. This result is consistent with the sampling theorem of Fourier analysis. In addition, comparison between the numerical effective log permeability and the mean of the log synthetic permeability field confirms that the two variables are strongly correlated and that minipermeameter measurements of heterogeneous permeability fields are most strongly correlated with the regions of the field that lie nearest the inner and outer edges of the tip-seal. This result confirms the spatial weighting function theories proposed by Aronson (2001) and Molz et al. (2003) for homogeneous fields.

Though the numerical experiment replicates many operational characteristics of a physical minipermeameter, it failed to capture the most important feature of the laboratory experiment: the upscaling of the mean effective log permeability. Whereas the laboratory values show a strong upward trend as the tip-seal size increases, the numerical results are essentially flat. The fundamental physical reason for this is that the laboratory sample allows the development of fast flow paths as tip-seal size increases. We identified three primary causes for the failure of the numerical experiment to reproduce the mean upscaling seen in the laboratory. First, small-scale structures of the laboratory sample are not measured by the laboratory instrument, primarily because of the limitations of bandwidth noted above. As a result, these high spatial frequency features are not simulated in the synthetic log permeability field, based as it is on the laboratory data set. Second, the simulated field is assumed to be lognormally distributed, which is an incorrect parameterization of the laboratory measurements. As a result, the semivariogram of the synthetic log permeability field is only approximately representative of the laboratory version. Third, qualitative features of the laboratory measurements are not replicated by the simulation. The sequential Gaussian simulation routine fails to replicate the zones of depositionally related cross strata unconformably separated by low permeability bounding surfaces. These three shortcomings, at a minimum, should be addressed in order to create a faithful replica of the laboratory sample that will demonstrate effective mean log permeability upscaling.

GEOLOGIC CONTROLS ON SHALLOW GROUND WATER QUALITY IN THE SOCORRO BASIN, NEW MEXICO, by *Brad T. Newton*, 2004, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 163 pp.

Proper water resource management along the middle Rio Grande entails satisfying many different needs with a limited water supply and requires an understanding of the regional hydrologic system. This study focuses on a reach of the Rio Grande that flows through the Socorro Basin, located in central New Mexico. The water quality of the Rio Grande deteriorates as it flows downstream due to many factors such as evapotranspiration, irrigation return flow, wastewater disposal, and the introduction of deep sedimentary brines. High-chloride waters were observed in the shallow ground water system in the Socorro Basin. These high-chloride waters are geochemically similar to typical sedimentary brines. Previous hypotheses for the upwelling of the high-chloride waters include structural controls such as cross-basin faults and the leakage of geothermal waters along Rio Grande rift faults. This thesis develops a hypothesis that relates the flow paths of the high-chloride waters to a synrift structure, the Socorro accommodation zone (SAZ). The SAZ is a 2-km-wide, topographically high zone that separates tilted half grabens of opposite polarity.

Stable-isotope and ground water-chemistry data were used to identify different water types in the shallow aquifer system. The observed spatial relationship among the different water types suggested that some regional flow paths might be controlled by cross-basin structures related to the Rio Grande rift. Some known faults strike across the basin, but have no surficial expression in the Rio Grande valley. The geometry of SAZ can give clues about whether or not one would expect cross-basin structures in the area where these high-chloride waters are observed. Cross-basin structures associated with the SAZ might act as conduits for certain water types including the high-chloride waters. The mechanism by which these high-chloride waters are forced up to the shallow system may be related to differences in permeabilities in a highly fractured fault zone and the leakage of geothermal waters along these structures. The actual source of these high-chloride waters cannot be conclusively identified.

ECOHYDROLOGICAL CONTROLS ON SOIL-MOISTURE FLUXES IN ARID VADOSE ZONES, by *Renee Sandvig*, 2005, M.S. thesis, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 295 pp.

In water-limited environments, the relationships between vegetation and soil moisture are important and pronounced. The understanding of the interactions and relations of terrestrial ecosystems and hydrology is termed ecohydrology. Whereas soil moisture often determines the distribution of vegetation communities, recent research suggests that the communities also affect the soil-moisture, resulting in a complex feedback loop. Therefore, knowledge of the ecohydrology of desert regions is critical to understanding the vadose-zone moisture fluxes. An additional motivation for this study is the accurate determination of the water budget for the Rio Grande basin, which is crucial given that the area is arid and has an increasing population. This study has concentrated on the infiltration component of the water budget, which can, in part, be quantified by determining the partitioning of the subsurface water between evapotranspiration and deep percolation or recharge. Determination of these vadose-zone fluxes for an entire basin through point data is expensive and time consuming. If a surface characteristic could be identified that would indicate the underlying vadose-zone moisture fluxes, this would substantially reduce the cost and effort of identifying potential recharge areas. This surface indicator must have a strong linkage with deep vadose zone moisture fluxes and be readily observable on the surface. Previous research has demonstrated that in arid regions, vegetation type may be a possible surface indicator of deep vadose-zone moisture fluxes and that arid vegetation communities play a significant role in controlling the soil-moisture fluxes in the underlying vadose zone.

To test for any relationship between arid vegetation communities and the water dynamics of the underlying vadose zone, eleven, 5–10-m-deep boreholes were drilled under ponderosa pine, juniper, grassland, and creosote communities along a transect in Socorro County, New Mexico. The hydrometeorological conditions of this transect were quantified by means of the aridity index, equal to the average annual potential evaporation divided by the average annual precipitation. The aridity index decreases gradually along the transect, from east to west from 7 to 3.5.

Whereas the results exhibited some variation within each ecosystem tested, there were systematic differences between the ecological communities. These systematic differences demonstrate that the ecology of an area influences vadose-zone moisture fluxes in addition to the influences on the fluxes from climate alone. The observed vadose-zone moisture regimes are the result of the complex interactions between soil moisture, vegetation, and climate. This system is best described as a multiple feedback loop with each part affecting the other. This study has demonstrated that there have been no downward liquid movement under the creosote sites past the root zone since the last climate change, which was approximately 15 k.y. ago. There have been periodic downward fluxes past the root zone under the grass and juniper sites (less than 0.44 mm/yr), as well as preferential flow. Whereas preferential flow appears to be the dominant flow process over complete flushing of the profile under these ecosystems, the extent to which either process has influenced the observed water-potential and chloride-concentration distribution cannot be determined conclusively. The downward liquid fluxes under the ponderosa pine ecosystem are appreciable (~ 2.3 mm/yr).

Since vegetation ecology has been shown to have an influence on vadose-zone moisture fluxes, in addition to the influence from climate, the use of surface vegetation as an indicator of vadose-zone moisture fluxes may prove to be an efficient method for estimating basin-wide vadose-zone moisture fluxes. More ecosystems would have to be studied in order to accomplish this, as not all the ecosystems that exist in the Rio Grande basin have been studied.

CHARACTERITICS OF FAULTS IN NONWELDED IGNIMBRITES FROM THE PAJARITO PLATEAU AND IMPLICATIONS FOR FLUID FLOW, by *Jennifer E. Wilson*, 2004, Ph.D. dissertation, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, 194 pp.

Faults can impact ground water flow as well as vadose-zone processes of recharge and transport. The impact of a given fault on fluid flow and transport depends in part on geologic products of fault-zone processes. For example, the presence of fractures versus deformation bands (narrow cataclastic shear zones) and degree and nature of diagenetic alteration directly influence the hydrologic properties of a given fault. Both fractures and deformation bands occur in ignimbrite sequences at Los Alamos, New Mexico, and Busted Butte, Nevada. The primary controls on mode of failure in these ash-dominated ignimbrites are grain-contact area and strength, which are directly related to degree of welding and crystallization and inversely proportional to porosity. Low-porosity welded units deform by transgranular fracture; high-porosity, glassy, nonwelded units deform by cataclasis within deformation bands. Moderately high-porosity, nonwelded units that have undergone devitrification and/or vapor-phase crystallization form either deformation bands or fractures, depending on local variations in the degree and nature of crystallization (qualitatively indexed by relative amounts of glass, cristobalite, and tridymite).

Grain- and pore-size reduction in deformation bands commonly produces indurated, tabular zones of clay-sized fault material. Unlike fractures, which increase saturated permeability through welded ignimbrites by at least two orders of magnitude, preliminary data suggest that deformation-band permeability can be up to an order of magnitude less than adjacent protolith. This decrease in permeability within deformation bands may introduce permeability heterogeneity into nonwelded ignimbrites, which were previously considered to accommodate fluid flow by slow, matrix diffusion. If sufficiently continuous and numerous, deformation bands may cause permeability anisotropy at the scale of perched aquifers. This could affect water recovery rates in shallow wells, where short production time scales are coupled with subvertical zones of small reductions in permeability.

Although this reduction may have minimal impact on saturated flow, preferential water retention and geochemical modification within these deformation bands in unsaturated, near-surface ignimbrite deposits suggest that they do affect fluid flow and solute transport in the vadose zone. More than two-thirds of the deformation bands identified in this study are locally rich in smectite and/or cemented by calcite. Stable isotope analyses indicate that these diagenetic minerals result from low-temperature meteoric fluid-fault interaction. The microstructural character, REE signatures, and chemical compositions of smectite in the deformation bands suggest that it is added to fault zones by a combination of localized in situ alteration of fault gouge and translocation from the surface. In situ alteration of ignimbrite to form smectite indicates preferential water retention in the presence of unstable mafic minerals and volcanic glass. Colloidal transport of smectite into the deformation bands requires preferential fluid flow in these zones. Rod-shaped microcrystallites of calcite and increased spatial density of plant roots in deformation bands suggest pedogenic precipitation associated with repeated desiccation events and microbial activity. Since roots in this semiarid climate seek moisture, it is inferred that preferential root growth and associated calcite are indicators of episodic preferential wetting of deformation bands, which facilitates fluid flow in semiarid vadose zones. Presence of smectite and calcite increases the surface area of fault material available for contact with fluids. This is interpreted to facilitate the addition and subtraction of some trace elements and oxides in these fault zones (e.g., TiO_2, Cr, Cu, and V).

Collectively, these observations indicate that these faults have served as, and may still be, zones of preferential vadose-zone fluid flow. Therefore, numerous, vertically continuous deformation-band faults in nonwelded ignimbrites in the vadose zone may serve as relatively fast pathways for fluids to reach the water table from the surface. Preferential fluid flow and transport lead to alteration and mineralization, further modifying fault-zone permeability (by closing pore throats) and the mechanical properties of the fault zone (through the development of relatively weak, clay-rich gouge or relatively strong calcite-cemented zones).

New Mexico State University

SEQUENCE STRATIGRAPHY, SEDIMENTOLOGY, AND PROVENANCE OF THE DRIP TANK MEMBER, STRAIGHT CLIFFS FORMATION, KAIPAROWITS PLATEAU, SOUTHWESTERN UTAH, by *Amy E. Christensen*, 2005, M.S. thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 100 pp.

The Drip Tank Member of the Straight Cliffs Formation located in the Kaiparowits Plateau of southwestern Utah is an amalgamated stacked braided-fluvial system. The Drip Tank Member was initially described as a mappable lithostratigraphic unit; however, the Drip Tank Member does not represent a single genetic package of strata. At its uppermost extent, the Drip Tank Member is capped by a laterally discontinuous dark-orange quartzolithic valley fill sandstone. Dividing this dark-orange sandstone from the underlying sandstone is an erosional surface, that truncates a minimum of 8 m of the underlying sandstone and represents a by-pass surface and sequence boundary. A combination of composition and paleocurrent indicators records mixing of detritus in a foreland basin by a fluvial system that flowed primarily from the south and west and evolved to an eastward flowing system in the upper part of the Drip Tank Member. Accompanying this shift was a decrease in feldspar content. Limited fossil and palynomorph data, combined with the presence of an unconformity represented by a sequence boundary near the top of the Drip Tank Member, suggest a probable latest Santonian age. Although previous models place the amalgamated facies tract entirely above the sequence boundary, in the Kaiparowits Plateau the Drip Tank Member includes the highstand systems tract, a sequence boundary, and the overlying lowstand or transgressive systems tract. Paleocurrent indicators record an initially underfilled basin that evolved to an overfilled basin in the Henrieville and Kaiparowits Basins. The Drip Tank Member most closely fits the tectonic thrust-propagation model for the filling of the basin.

STYLE, TIMING AND UPLIFT HISTORY OF THE FRONTAL SIERRA MADRE ORIENTAL FOLD BELT DETERMINED THROUGH ANALYSIS OF GROWTH

STRATA AND VITRINITE REFLECTANCE, by *Rachel D. Couch*, 2005, M.S., thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 234 pp.

Growth strata deposited in lower and upper shoreface environments in the Las Encinas and Rancho Nuevo Formations indicate a Maastrichtian age for fold development in the northern part of the Parras Basin. The El Tulillo folds developed through detachment folding and limb rotation during northward propagation of the Sierra Madre Oriental fold belt into the foreland basin, suggesting a pre-Maastrichtian deformation age for the fold belt itself. The growth of the El Tulillo folds impacted facies relationships, causing shallow water facies to be deposited near topographic highs created by anticlinal crests and deeper water facies to be deposited in synclinal troughs. Petrographic data indicate the source of the Cerro Grande, Las Encinas, and Rancho Nuevo Formations was the Sierra Madre Oriental fold belt with minor volcanic input derived from the Guerrero composite terrane of western Mexico, which is consistent with comparisons of previous provenance studies of the Difunta Group. Two detachment levels cause east-west-trending fold development in the Parras Basin, one at depths ~ 2 km below the surface in the Cañon del Tule Formation and one at ~ 3 km in the Parras Shale. These two detachment levels were themselves folded by uplift of the northwest-trending La Gavia anticline, with a lowermost detachment level in Jurassic evaporites during inversion of the La Popa Basin. These relationships suggest that the east-west-trending folds developed before the mid-Maastrichtian, the onset of active northwest-trending La Popa shortening. Vitrinite reflectance analyses used to compare burial depths in the study area and locations to the south in the Sierra Madre Oriental fold belt indicate that the entire area has experienced burial depths of 3.6–5.3 km below sea level, after which the strata were uplifted to elevations between 0.8 and 1.5 km above sea level. Comparison of burial and uplift amounts in the study area and closer to the fold belt indicates that the geometry of the fold belt during the Maastrichtian was similar to its present day geometry and that the entire area has been uplifted as a plateau.

SEDIMENTOLOGY AND STRATIGRAPHY OF THE SAN JOSE LENTIL, LA POPA BASIN, MEXICO, AND ITS IMPLICATIONS FOR CARBONATE DEVELOPMENT IN A TECTONICALLY INFLUENCED SALT BASIN, by *Dominic C. Druke*, 2005, M.S. thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 132 pp.

The San Jose lentil, located in northeast Mexico in the La Popa Basin, nucleated on a seafloor topographic high created by the La Popa salt wall. San Jose lentil consists of 8 carbonate lentil horizons initiating in the lower mudstone member of the Potrerillos Formation and terminating in the middle siltstone member. Nine lithofacies arranged by lentil facies versus inter-lentil facies make up the San Jose lentil. The lentil facies are: (1) Sponge-red algal boundstone, (2) rhodolith framestone and rudstone, (3) fossiliferous packstone and grainstone, (4) meta-igneous clast fossiliferous packstone and grainstone, (5) quartz silt-meta-igneous clast fossiliferous packstone and grainstone, (6) meta-igneous clast-quartz silt fossiliferous packstone and grainstone, and (7) quartz silt extraclastic packstone. The inter-lentil facies consist of: (1) quartz silt brachiopod-bivalve packstone and (2) calcareous shale and siltstone. Siliciclastic detritus becomes increasingly integrated into the carbonate facies from the lower mudstone member-hosted lentils (San Jose lentils 1 and 2) to the middle siltstone member-hosted lentils (San Jose lentils 3–8). The beds of the San Jose lentil are interpreted to be leeward deposits of a former isolated carbonate buildup. Windward San Jose deposits are interpreted to be similar to the lower Gordo lentil and buried in the down-dropped block, on the south side of the La Popa salt weld. The lentils also define the basal portion of 8 halokinetic sequences that make up the San Jose. The ideal halokinetic sequence at the San Jose lentils consists of a basal storm-reworked carbonate unit followed by a succession of fossiliferous grainstone units that are then capped by siliciclastic inter-lentil facies. All halokinetic sequences found at San Jose are Type-A, characterized by high angles of unconformable truncation geometries. Halokinetic sequences at San Jose are typically stacked with the exception of the amalgamated halokinetic sequences 1–3, which coalesce and are deformed together at the La Popa salt weld. San Jose lentil 3 is interpreted to exhibit thickening into the La Popa syncline, putting the initiation of the Hidalgoan orogeny in the late Maastrichtian. The extrinsic controls on the Maastrichtian lentils in La Popa Basin are eustasy, regional and local tectonism, and siliciclastic influx. Maastrichtian sea level was high, and there was also high subsidence in La Popa Basin caused by early deformation by the Hidalgoan orogeny. Siliciclastic sedimentation was restricted to landward positions except at the end of the Cretaceous. The combination of low sea level and increased siliciclastic influx at the end of the Maastrichtian buried the lentils in the basin. The lower Gordo and San Jose lentils are similar with respect to thickness (80–120 m), facies present, and areal extent (4–5 km from the diapir), whereas the time-equivalent El Papalote lentil 1 is thin (12 m), has less diversified facies, and only extends 1–1.5 km from the El Papalote diapir. El Gordo diapir and La Popa salt wall were in the hinges of anticlines and shortened, whereas El Papalote diapir was on the limb of the El Gordo anticline and experienced less shortening. Carbonate accumulations at San Jose and El Gordo lentils were higher and had a larger bathymetric halo because of higher salt rise rates due to Hidalgoan shortening. El Papalote lentil 1 accumulated less carbonate and a narrow halo of bathymetric relief because it nucleated on a non-shortened diapir. Carbonate accumulations in La Popa Basin differ greatly compared to conventional carbonate deposits. Carbonate development in La Popa Basin is non-existent in the lowstand systems tract, greatest in the transgressive systems tract, and greatly reduced to non-existent in the highstand systems tract. In contrast, other isolated platforms typically have carbonate development in all the systems tracts, with greatest development in the transgressive and highstand systems tracts.

PETROLOGY AND EMPLACEMENT OF THE UPPER CRETACEOUS SYLVANITE INTRUSIVE COMPLEX, LITTLE HATCHET MOUNTAINS, HIDALGO COUNTY, NEW MEXICO, by *Leyla D. Kirkpatrick*, 2004, M.S. thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 81 pp.

The Sylvanite intrusive complex in the Little Hatchet Mountains of southwestern New Mexico is a mafic to intermediate intrusion of Laramide age. Zeller (1970) mapped monzonite and diorite phases of the intrusion. Diorite ranges from 45 to 62% SiO_2, 16.7 to 18.2% Al_2O_3, 2.9 to 12.8% FeO, and 1.2 to 6.4% MgO. Monzonite averages 57–66% SiO_2, 15.1–18% Al_2O_3, 1.6–6.9% FeO, and 1.1–2.7% MgO. The overlapping values for the rock types suggest that the rocks are genetically linked by sharing a common parent magma and by the processes through which they evolved. Assimilation fractional crystallization models for Nb and Zr suggest that two crustal sources produced the Sylvanite intrusive complex. The first source has typical crustal Nb and Zr concentrations, similar to those of the intrusion (25 ppm Nb, 275 ppm Zr). The second source differs by having high Zr concentrations (1,500 ppm Zr, 25 ppm Nb).

Channell et al. (2000) suggested, based on geochemistry and proximity, that the Sylvanite intrusive complex is the plutonic equivalent of the Hidalgo Formation, a volcanic sequence exposed in the northern half of the mountain range. Spider diagrams comparing the Sylvanite intrusive complex to the Hidalgo Formation show similarities in the incompatible trace elements. The Hidalgo Formation has been dated at 70.5–71.4 Ma (Young et al. 2000), indicating that the Sylvanite intrusive complex would have similar ages.

The depth of crystallization of the Sylvanite intrusive complex is estimated at slightly greater than 4 km, based on the stratigraphy of overlying units and a lack of degassing textures in the intrusive rocks. However, because the magmas are evolved and need multiple contaminants, the magmas did not differentiate at the depth where they stalled out. Given the shallow depth and geochemistry, the Sylvanite intrusive complex does not represent a single magma body, but rather the shallow conduits between the magma chamber and the volcano.

EXPERIMENTAL DETERMINATION OF THE BIOGENICITY OF MOONMILK, AND THE CHARACTERIZATION OF MOONMILK AND ITS DEPOSITIONAL ENVIRONMENT IN SPIDER CAVE, CARLSBAD CAVERNS NATIONAL PARK, NEW MEXICO, by *Morgan Perrone-Volt*, 2005, M.S. thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 175 pp.

Microorganisms affect many of earth's processes, including cave formation. The absence of light and limited availability of organic materials make caves the perfect analogue for other extreme environments as well as providing a unique look at microbe/rock interactions through the study of speleothems, such as moonmilk (a two-phase system of calcite and water). Moonmilk is interpreted as forming by either primary deposition (subaqueous, subaerial, or both) or secondary deposition (i.e. degradation product of cave popcorn) and has been implicated as forming biotically as well as abiotically.

This proposed research project was designed to test two hypotheses: 1) microorganisms found and cultured from moonmilk in Spider Cave play a direct role in the precipitation of moonmilk, and 2) the microorganisms that are cultured in the lab leave behind biosignatures of major elements, stable isotope ratios, and trace elements that are similar to biosignatures found in moonmilk deposits in caves.

Moonmilk from Spider Cave of Carlsbad Caverns National Park, NM (known as "Crisco") was analyzed to determine the geochemistry, fabric, depositional setting, and extent of biogenicity. Crisco moonmilk is composed of filamentous, calcitic carbonate that is associated with microbes and has a greasy texture. Microbes derived from Crisco were cultured using four types of media to study their precipitates. Solid and liquid cultures were made with different nutrients and were incubated for 2–7 months at 18ºC (ambient temperature of Spider Cave) and at 24ºC for faster growth. A survey of the cave was performed to determine patterns and location of the moonmilk. Moonmilk samples were analyzed using scanning electron microscopy (SEM) and energy dispersive X-ray spectrometry (EDS), transmission electron microscopy (TEM), thin sections stained with alizarin red S, microprobe analysis with X-ray maps, trace element analysis, stable isotopic analysis, and X-ray diffraction (XRD).

All media types showed bacterial and fungal growth, but none produced visible precipitates. The cultures were destroyed after one year. SEM examination at low magnification showed a smooth, curd-like, biofilm-like texture and at high magnification showed both an organic filamentous fabric with calcite coatings and calcite rhombohedrons. TEM shows that the filaments are organized in a mat-like structure, with filaments oriented in all directions.

A survey of the cave shows that moonmilk only forms below a certain depth (67 ft below the entrance), and that the flood line (a detrital silt coating) follows this moonmilk line. The entrance of Spider Cave is in an arroyo and has been subjected to flooding throughout its history. The areas that contain moonmilk are at the lowest depths, where standing water could form.

Thin sections show three types of fabrics: Type 1 Crystalline) continuous, regular laminations that do not take the stain; Type 2 Diffuse) discontinuous, irregular laminations that stain red; and Type 3 Recrystallized) no laminations or any distinguishing features and irregular staining. Within Spider Cave, Type 1 and Type 2 form in protected, higher elevation areas, whereas Type 3 forms at the lowest elevations where they would have remained under water the longest. Most of the samples show a combination of the three types, with remnants of laminations and irregular staining; these samples are found along the main pathway, neither on the ceiling nor on the floor. EDS, trace element analysis, and microprobe analysis show that Type 1 and Type 2 samples are the most elementally diverse. These samples contain the highest amounts of calcium, magnesium, aluminum, sulfur, and sodium; Type 3 and the combination samples contain smaller quantities of those elements, but have a higher abundance of carbon and oxygen. Type 2 diffuse shows the most aluminum and sulfur, as well as having more irregular layers, indicating that this type may be biotic. Type 1 has more regular, continuous layering, indicating that this type may be abiotic. Type 3 is the recrystallized version of Types 1 and 2, due to the longer amount of time the Type 3 samples would have remained under water.

Crystallization factors affecting the precipitation of a crystal were also considered. The temperature at which moonmilk formed is unknown, as it is not possible to date the formation of moonmilk. However, it is known when Spider Cave formed (approximately 6 m.y. ago) and from that time to the present, there have been alternating glacial and interglacial cycles. Atmospheric pressure has always influenced the cave, whereas hydrostatic pressure played a role while the cave was forming and during flooding. The water amount in Spider Cave has always been saturated, either due to flooding or saturated water vapor. Water chemistry played an important role, as the formation of moonmilk required standing water. Changes in water chemistry affected the formation of moonmilk. Standing water would have allowed for microbial precipitation, but the influx of new water through flooding would have changed the concentration of elements available, as well as allowing CO_2 to escape, which could have led to abiotic precipitation. After the flooding stopped and the water became stagnant, biotic precipitation could have continued.

Parent rock, though important for influencing the types of precipitates that could form due to the elements available, is not the main factor in Spider Cave moonmilk formation. Spider Cave was compared to an area in Carlsbad Cavern known as Chocolate High, which is found in the same formation (the Yates Formation), contains the same parent rock (limestone and dolomite), and is at the same elevation (approximately 1260 ft). Chocolate High has very small patches of moonmilk, whereas Spider Cave has roomfuls of moonmilk. The main difference between the two is the Spider Cave entrance is in an arroyo, which leads to flooding, and the areas that contain moonmilk are at the lowest elevation, so standing water can form. Chocolate High does not have a source for flooding, and it is at one of the highest elevations, so standing water cannot form.

SEM and TEM show the presence of organic filaments, and isotopic analysis shows a light isotopic carbon and oxygen signature, both indicative of biotic processes. Although precipitates did not grow in the lab, other sources of evidence indicate that microorganisms played a role in moonmilk formation.

The term moonmilk does not indicate how moonmilk was formed. Studies must be done on numerous moonmilk caves characterizing the formation of moonmilk in that particular cave. Then it will be possible to form a new genetic classification system that includes new names that indicate how that particular type of moonmilk formed.

EJECTA-BEARING DEPOSITS AT THE CRETACEOUS–TERTIARY BOUNDARY AND THEIR IMPLICATIONS FOR TIMING OF HIDALGOAN (LARAMIDE) FOLDING, LA POPA BASIN, NUEVO LEON, MEXICO, by *Kyle W. Shipley*, 2004, M.S. thesis, Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, 146 pp.

Ejecta-rich strata located at or near the K/T boundary in La Popa Basin, northeast Mexico, were deposited by tsunami-induced subaqueous debris flows and offshore-directed supercritical flow. An ejecta-bearing event deposit occupies a stratigraphic position within the upper 5–15 m of the Delgado Sandstone Member of the Potrerillos Formation (late Maastrichtian), on a sharp contact above the delta-front and lower shoreface deposits. The depositional system of the Delgado Sandstone Member consists of wave-dominated deltaic facies that prograded into the basin from the northwest to the southeast. The most abundant facies recognized in the depositional system include hummocky cross stratified sandstone, sandstone with abundant soft-sediment deformation, and finer grained siltstones and shales. The Delgado Sandstone Member thickens in the hinge of a northwest-trending detachment fold (the La Popa syncline) indicating that foreland deformation took place during deposition. The event deposit is continuous throughout the basin, but varies laterally and stratigraphically in lithology and thickness (0.25–6.1 m). The deposit contains interbedded crudely laminated sandstone, matrix-supported polymictic boulder to cobble conglomerate, and graded coarse-grained sandstone. Conglomeratic units locally occupy three paleovalleys that are approximately 300 m, 400 m, and 500 m wide with axial azimuths between ~180° and 200°. The valley-fill succession is as much as 6.1 m thick and contains basal, subangular, very fine sandstone blocks (1.5 m length) overlain by multiple graded pebbly sandstone beds. Conglomerate and sandstone onlap valley walls, whereas a younger hummocky-stratified sandstone succession overlaps the entire event deposit. Conglomerate matrix and sandstones contain a distinctive grain assemblage that includes: (1) bubbly calcite spherules; (2) silicate spherules; (3) silicate fragments; (4) micrite-coated silicate and sparry carbonate grains interpreted as ooids; and (5) abundant bioclasts derived from shallow marine and onshore lagoonal settings, commonly filled with micrite, but generally lacking micrite coats. Bubbly spherules and silicate spherules and fragments are interpreted as impact ejecta. Spherules are present at the very base of the deposit, indicating that the ejecta were deposited at or near the site before reworking by traction-flow processes. Ejecta are concentrated near the bases of individual sandstone beds and comprise approximately 10–36% (locally) of framework grains. Matrix-supported boulder conglomerate was deposited by one or more subaqueous debris flows within the southward-trending paleovalleys. Overlying ejecta-bearing sandstones were likely deposited by offshore-directed, upper flow regime processes that included antidune collapse and upper plane bed deposition. The abundant ejecta link both depositional processes with the impact at Chicxulub 800 km to the southeast, on a bearing of 115°. Early arrival of ejecta may have taken place as base surge(s) created by the gravitational collapse of the ejecta cloud or by ballistic trajectories from the impact site.

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PALEOMAGNETIC AND FAULT KINEMATIC ASSESSMENT OF LARAMIDE-AGE DEFORMATION IN THE CENTRAL AND EASTERN UINTA MOUNTAINS, COLORADO AND UTAH, by *James M. Ashby*, 2005, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 132 pp.

The over 7 km thick Neoproterozoic-age (~1,000–700 Ma) hematite-cemented sandstone and siltstone dominated Uinta Mountain Group (UMG) defines the core of the Uinta Mountains in northeast Utah and northwest Colorado. The UMG provides high-quality paleomagnetic data that permit testing hypothesized Laramide-age (from latest Cretaceous, ~70 Ma, to early Tertiary, ~35 Ma) clockwise vertical-axis rotation of the easternmost Uinta Mountains due to east-directed shortening from Sevier-related structures. Throughout the core and along the flanks of the western and central Uinta Mountains, UMG bedding strikes east-west to northwest-southeast, whereas in the easternmost Uinta Mountains structures and strikes of UMG strata are deflected southward in an apparent bend. Comparison of interpreted-as-primary Neoproterozoic UMG characteristic remanent magnetizations (ChRMs) between the central and eastern region reveal the same west declination and shallow, negative to positive inclination, as well as an opposite polarity magnetization, interpreted as a primary Neoproterozoic magnetization acquired when Laurentia was at low, equatorial latitudes, as part of or during the early stages of Rodinian supercontinent breakup. Statistically, no significant degree of vertical axis rotation is observed either; relative to north-central ChRMs, eastern UMG localities indicate clockwise rotations ranging from 10.8° ± 13.6° to 3.2° ± 13.2° and flattening from 1.9° ± 5.6° to –15.7° ± 6.0°. At the extreme southeast end of the Uinta Mountains other UMG outcrops isolated from the main contiguous exposure of the sedimentary sequence reveal only north to northeast-directed, steep positive inclination magnetizations, which are interpreted as secondary and superimposed. Analysis of Laramide-age or younger conjugate fault pairs in the eastern Uinta Mountains indicate no rotation and a horizontal maximum shortening direction oriented 316° (N42°W). This is perpendicular to regional NNE-directed Laramide-age shortening and taken to represent a localized event preserved along the major extensional axis of regional Laramide deformation. Absence of rotation in paleomagnetic and fault data indicates that Laramide-age deformation of the eastern Uinta Mountains did not result in appreciable vertical axis rotation. The observed southward deflection of UMG rocks and major range-bounding structures is likely due to reactivation of a pre-existing structural grain already deflected southward. A recently reported large-scale north-south orientated crustal arch newly formed during the latest Cretaceous that intersects the eastern end of the range is possibly responsible for the north-south oriented Cross and Lone Mountains.

ASPECT AND MICROCLIMATIC INFLUENCES ON HILLSLOPE GEOMORPHOLOGY, NORTHEASTERN ARIZONA, by *Benjamin N. Burnett*, 2004, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 85 pp.

The effects of aspect-related microclimate on slope characteristics and processes were studied in three small (~0.5 km^2) east-draining canyons dominated by the weakly cemented sandstones and shales of the Salt Wash Member of the Morrison Formation near Blue Gap, northeastern Arizona. A strong across-canyon asymmetry exists where south-facing slopes are steeper and have more cliffs than north-facing slopes. This asymmetry is explained through differences in weathering and erosion driven by temperature and moisture contrasts.

Temperature and soil moisture data were collected for one year starting in September 2002 in order to quantify the microclimates of north- and south-facing canyon slopes. Air, surface, and subsurface (10 cm depth) temperatures were 1.4–2.1°C, 3.2–3.9°C, and 5.6°C warmer respectively on south-facing slopes than on north-facing slopes. Soil moisture was also drastically lower on south-facing slopes primarily from higher evapotranspiration.

Slope characteristics were measured in the field and calculated with a 3-m resolution digital elevation model. The south-facing slopes are 1–3° steeper with significantly less weathered bedrock, colluvium, and vegetation cover than north-facing slopes. Large cliffs exist on south-facing canyon slopes that account for 29% of the vertical relief, but north-facing cliffs only account for 2.5% of the relief.

Slope forms and characteristics are controlled by bedrock weathering and erosion. The Salt Wash Member weathers rapidly by clay hydration, resulting in a progressive reduction in bulk density and grain contacts and an increase in porosity. South-facing slopes were too dry for most of the instrumented year for significant clay expansion to occur, whereas the north-facing bedrock slope was moist all year. Enhanced weathering and debris production has inhibited the formation of cliffs on north-facing slope. Cliff initiation and growth appear to be occurring on north-facing slopes at the present, but given the small height (typically <3 m) of modern north-facing cliffs, it is likely that these are primarily a Holocene phenomenon. Late Pleistocene climates would have prevented cliff formation and may have erased cliffs on north-facing slopes, but the height of south-facing cliffs (up to 70 m) indicates that they were maintained throughout the late Pleistocene.

VOLATILE LIGHT HYDROCARBONS IN GEOTHERMAL GAS EMISSIONS FROM YELLOWSTONE NATIONAL PARK, USA, AND COMPARISONS TO EL SALVADOR AND HONDURAS, by *Bethany J. Burnett*, 2004, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 95 pp.

Twenty-six samples from hot springs and fumaroles in Yellowstone National Park (YNP) and 11 in Central America were analyzed for inorganic gases (CO_2, SO_2, H_2S, HCl, Ar, N_2, CO, H_2, He, O_2), methane, and trace volatile light hydrocarbons. Stable isotope analyses of carbon and nitrogen were used in conjunction with the gas geochemistry to determine potential sources of hydrocarbons.

$\delta^{13}C$-CH_4 values ranged between –37.6 and –18.2‰ for YNP, from –31.9 to –30.2‰ for El Salvador, and from –38.8 to 23.9‰ for Honduras. $\delta^{13}C$-CO_2 values ranged from –4.0 to –1.0‰ and $\delta^{15}N$-N_2 values ranged between –3.0 and +5.2‰ for YNP. These values support thermogenic breakdown of organic sedimentary material as the major source of volatile light hydrocarbons in YNP and Central America. Abiogenic synthesis may be a minor contributor to observed hydrocarbon concentrations.

Overall hydrocarbon compositions in YNP and Central America are similar, with samples containing light alkanes, alkenes, and aromatics. Hydrocarbon concentrations generally decrease with increasing carbon number and are lower in Central America than in YNP. Larger differences in hydrocarbon composition were observed between sites within YNP than between geologic settings (hot spot, arc, back arc).

Three different hydrocarbon distributions are evident in the Yellowstone samples and were used to group the samples. Differential exposure of sedimentary organic material to high temperatures over time can result in the observed differences in hydrocarbon compositions. Some of the samples contain no hydrocarbons higher than methane in the gas phase and are likely derived from organic sedimentary material that is either mature or overmature (Group 1). Decomposition of organic material at low temperatures and over long periods of time leads to alkane-dominated gases (Group 2). Immature fluids that have been rapidly heated to high temperatures can lead to the formation of alkenes (Group 3). Group 3 samples have much lower concentrations and diversity of alkanes, but they contain the alkenes propene and i-butene, the aromatics benzene and toluene, and dimethyl sulfide.

MAGNETIC PROPERTIES OF MANTLE XENOLITHS FROM THE RIO PUERCO VOLCANIC NECKS, NEW MEXICO, by *Caitlin N. Callahan*, 2005, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 136 pp.

Mantle xenoliths from the Rio Puerco volcanic necks, west-central New Mexico preserve evidence of several types of chemical modification. This study investigates the effects of multiple alteration events on the magnetic properties of spinel lherzolites and pyroxenites from these necks. In chapter one the magnetic properties and chemical composition of pristine spinel lherzolites are compared with metasomatized pyroxenites. Spinel lherzolites generally contain less single-domain magnetite and a lower concentration of magnetite than pyroxenites. The rocks appear to preserve the effect of early melt infiltration beneath the Rio Puerco volcanic necks that produced the pyroxenites. These data provide insight into the effect of melt infiltration at depth in the mantle on the magnetization of mantle xenoliths.

Chapter two compares rock magnetic properties and bulk chemical composition data for a suite of oxidized xenoliths with the data presented in chapter one. The oxidized xenoliths are characterized by the presence of hematite and low coercivity, multi-domain magnetite. Field observations, mineral textures, rock magnetic and chemical composition data, and TEM analyses all suggest oxidation as the alteration mechanism for the red xenoliths. Data indicate that the timing of the oxidation event is close to the time of entrainment in the host basalt and transport to the surface. The results of this study imply that the oxidation state may locally have reached the HM oxygen buffer, if magnetite and hematite were in equilibrium with each other, but the coexistence of amorphous silica, magnetite, and fayalite makes it more likely to have been at the QFM oxygen buffer. In either case, the oxidizing agent was likely a CO_2-rich phase.

ANALYSIS OF NON-FICKIAN DISPERSION FOR LABORATORY-SCALE TRACER EXPERIMENTS IN CROSSBEDDED SANDSTONE, by *Katherine A. Klise*, 2005, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 98 pp.

Geologic heterogeneity occurs over a range of spatial scales, each with potential to influence subsurface flow and solute transport. Understanding such controls is fundamental to developing accurate models for the purpose of design and prediction. In contrast to Gaussian dispersion that assumes a constant dispersivity in time and space, solute transport often results in scale-dependent dispersivity attributed to small-scale heterogeneity. Despite recognition of this anomalous, or non-Fickian, behavior, Gaussian dispersion regimes used in the Advection Dispersion Equation (ADE) persist as the most common method for solute transport prediction. Recent studies suggest that non-Fickian dispersion may be better described by heavy-tailed Levy distributions. By allowing for fractional derivatives, the Fractional Advection Dispersion Equation (FADE) uses Levy motion to predict heavy-tailed behavior associated with non-Fickian dispersion.

To analyze the nature of dispersion, this study investigates the use of Gaussian-based ADE and Levy-based FADE to approximate solute transport through crossbedded sandstone. Through integration of highly resolved permeability and porosity measurements, visual rock attributes, visualization of laboratory-scale tracer experiments, and numerical modeling, this project explores the effects of small-scale heterogeneity on solute transport. A 30.5 cm by 30.5 cm by 2.2 cm slab of Massillon Sandstone was selected for the research due to distinct crossbedding and nested scales of heterogeneity. Permeability and porosity measured to sub-centimeter scale resolution are used to numerically simulate experimental tracer tests. Both spatial distribution of solute and breakthrough curve characteristics are examined.

Results suggest that under the assumptions of Gaussian dispersion, heterogeneity averaged to the sub-centimeter scale is not adequate for predicting solute transport exhibited by the laboratory experiment. A thorough investigation of potential experimental errors related to measured heterogeneity suggests that failure to fit experimental results may lie in the inability to capture connectivity within the crossbedded sandstone below the sub-centimeter scale. The use of Levy dispersion shows marked improvement to the prediction of early-time arrival and late-time recovery seen in experimental breakthrough curves. Estimation procedures used to approximate the heavy-tailed solute transport based on measured heterogeneity suggest a lesser tailing effect than defined by Levy distributions.

LITHOSTRATIGRAPHY AND MAMMALIAN BIOSTRATIGRAPHY OF THE TORREJONIAN–TIFFANIAN TRANSITION IN THE NACIMIENTO FORMATION, NORTHWESTERN SAN JUAN BASIN, NEW MEXICO, by *Shirley A. Libed*, 2005, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 475 pp.

A new lithostratigraphy and mammalian biostratigraphy of the northwestern San Juan Basin (NWSJB) provides first evidence of the Torrejonian–Tiffanian transition in New Mexico. Previously, the stratigraphically highest and youngest fossils from the Paleocene Nacimiento Formation (T_N) were early Paleocene/late Torrejonian (~61.5 Ma) in age and occurred 60 m below the Eocene San Jose Formation (T_{SJ}), whereas the type Tiffanian fauna from the San Juan Basin of southwestern Colorado is estimated late Paleocene/middle Tiffanian (~57.3 Ma) in age. An intervening Torrejonian–Tiffanian fauna was unknown. Thus, a minimum 90 m stratigraphic, ~4.2 m.y. temporal, and morphological gap persisted in the San Juan Basin.

Recent data from the NWSJB reveal less of a hiatus than to the south. A minimum of seven successive fossiliferous intervals is recognized, with the highest horizon now less than 20 m below the San Jose Formation. More than 165 new fossil localities, including 70 mammal-bearing localities, have yielded over 670 vertebrate specimens. Among the over 360 new mammalian specimens, 160 represent a minimum of 27 genera and 41 species—including two new genera and nine new species. In addition, the informal "unnamed member" and superposed NWSJB mudstone-sandstone unit are here respectively named the Kutz Canyon Member and the Bohanan Canyon Member of the Nacimiento Formation. Further, the stratigraphic relationships of these NWSJB units support the long-speculated late Paleocene inception of the San Jose Formation.

Although dominated by Torrejonian taxa, the new Aztec local fauna is assigned a late Paleocene and new earliest Tiffanian age based on the convergence of five lines of evidence: (1) stratigraphic superposition above the formerly youngest, type Torrejonian biostratigraphic zone; (2) stratigraphic lateral equivalence to the paleomagnetically dated Tiffanian Escavada Member of the Nacimiento Formation; (3) derived condition of several Torrejonian forms; (4) new taxa morphologically transitional or antecedent to previously known earliest Tiffanian species; and (5) occurrence of the definitive Tiffanian genus, *Plesiadapis*. Superposed above the youngest known Torrejonian interval, the unique assemblages indicate that the NWSJB deposits preserve a heretofore-unrecognized temporal interval bridging the formerly known latest Torrejonian and Tiffanian in the San Juan Basin.

A RIVER IN TRANSITION—GEOMORPHIC AND BED SEDIMENT RESPONSE TO COCHITI DAM ON THE MIDDLE RIO GRANDE, BERNALILLO TO ALBUQUERQUE, NEW MEXICO, by *Richard M. Ortiz*, 2004, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 64 pp.

Seventy-five years of channel and floodplain modification has greatly altered the middle Rio Grande fluvial system. Dams, levees, and various generations of bank stabilization projects have confined the river to a narrow valley and greatly altered discharge and sediment supply regimes as population centers have grown along its path. The Rio Grande drains more than 273,530 km^2 of the southwestern United States and northern Mexico, with 37,555 km^2 of the basin directly contributing to the flow of the river through the study reach, near Albuquerque, New Mexico. This study specifically investigates the effects Cochiti Dam has had on the Rio Grande over the past 30 years.

Before Cochiti Dam, bed sediment was composed of sand and/or gravel depending on discharge. It's estimated that ~80% of sediment inflow to the middle Rio Grande is trapped by three major dams, with Cochiti alone receiving ~2.2 x 10^6 m^3 of sediment a year. A 31-yr pre-dam record and a 23-yr post-dam record of discharge data show that peak discharges below Cochiti have remained similar, the primary difference being the lack of large flood flows greater than 283 m^3/s. Directly after closure of Cochiti Dam in 1973, the study reach experienced a coarsening of bed sediments from fine sand to medium sand. This coarsening occurred before the development of a transition zone, between coarse and fine-grained sediments, which has migrated downstream into the study area. Through the use of geomorphic and geologic techniques this study characterizes the effects Cochiti Dam has had on a 25.5 km study reach of the middle Rio Grande. It specifically addresses Cochiti Dam induced downstream changes in channel morphology and the development of a bed-load sediment grain size transition zone.

OXYGEN ISOTOPE EVIDENCE FOR SUBDUCTION AND RIFT-RELATED MANTLE METASOMATISM BENEATH THE COLORADO PLATEAU–RIO GRANDE RIFT TRANSITION, by *George B. Perkins*, 2005, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 63 pp.

Spinel lherzolite and pyroxenite xenoliths from the Rio Puerco volcanic field, New Mexico, were analyzed for oxygen isotopes by laser fluorination. In the lherzolites, olivine $\delta^{18}O$ values are uncharacteristically high (+5.5‰), whereas $\delta^{18}O$ values for pyroxenes are low (cpx = +5.1‰; opx = +5.4‰) compared to average mantle oxygen isotopic compositions. Pyroxenite $\delta^{18}O$ values (cpx = +5.0‰; opx = +5.3‰) are also less than typical mantle oxygen isotopic compositions and are similar to those of the lherzolites. Calcite in pyroxenite xenoliths has $\delta^{18}O$ values of +21‰, clearly in isotopic disequilibrium with surrounding mantle minerals. The isotopic characteristics of the pyroxenite xenoliths are consistent with a petrogenetic origin from mixing of lherzolitic mantle with slab-derived silicate and carbonatite melts. The anomalously low $\delta^{18}O$ in the pyroxenes reflects metasomatism by a partial melt from subducted altered oceanic crust, and high $\delta^{18}O$ calcite is interpreted to have crystallized from a high $\delta^{18}O$ carbonatitic melt derived from subducted ophicarbonate. These melts may have originated from the subducted Farallon slab, and been released at the onset of Rio Grande rifting, as similar isotopic signatures of metasomatism are seen throughout the Rio Puerco xenolith suite and at Kilbourne Hole in the southern Rio Grande rift. Oxygen diffusion modeling constrains the timing of metasomatism and isotopic disequilibrium between olivine and pyroxene in the lherzolites and between calcite and pyroxene in the pyroxenites to less than 1 m.y. before entrainment. Melt infiltration before eruption is likely a result of ongoing heating and extension related to Rio Grande rifting and may have promoted rift-related volcanism.

HOLOCENE FIRE REGIMES AND GEOMORPHIC RESPONSE IN CONIFER FORESTS OF THE NORTHWESTERN UNITED STATES—EVIDENCE OF MILLENNIAL-SCALE CLIMATE CHANGE, by

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Jennifer L. Pierce, 2004, Ph.D. dissertation, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 241 pp.

Relations exist between fire, vegetation, and climate over different spatial and temporal scales. Severe fires change processes and rates of erosion, fuel loads and conditions (vegetation) influence fire severity, and variations in climate change vegetation, fire regimes, and geomorphic response. Interpretation and dating of fire-related alluvial-fan deposits in the South Fork Payette River (SFP) drainage, Idaho, reveal a ~8,000-yr record of sedimentation events following fire in ponderosa forests in central Idaho mountains.

Alluvial-fan records show maxima in the probability of frequent, small fire-related events in Idaho ~350–500, 1,200–1,300, and 2,800–3,000 cal yr BP. The most recent episode (~350–500 cal yr BP) coincides with the LIA, a time of hemispheric-to-global cooling; prior episodes correspond with paleoclimatic indicators of colder climates in the Northern Hemisphere. I infer that during cooler and effectively moister intervals, Idaho ponderosa pine forests maintained high canopy moisture content that inhibited stand-replacing fires, and increased understory grass growth provided fuel for frequent low- to moderate-severity burns. These fires correspond with limited geomorphic response recorded in alluvial-fan deposits.

In contrast, severe stand-replacing fires occur infrequently during times of widespread and severe drought, such as during the Medieval Climatic Anomaly (MCA, ~1,050–650 cal yr BP). The MCA is characterized by fires in a range of ecosystems, and MCA fires promoted infrequent but large sedimentation events that contributed significantly to long-term sediment yields and landscape evolution. Results indicate climate is a key control over fire regimes on centennial to millennial timescales, and suggest that continued large, severe burns are likely with anticipated future warming.

Dating and characterization of Holocene terraces of the SFP River indicate a general trend of downcutting during the Holocene. Episodes of stability and floodplain widening ~8,000–6,600, ~4,000–1,300, and ~1,155–540 cal yr BP are punctuated with intervals of downcutting ~6,600–5,800, 1,293–1,155, and after 542 cal yr BP. Incision 1,293–1,155 cal yr BP corresponds with a peak in fire-related sedimentation events ~1,300–1,150 cal yr BP. The average incision rate of the upper South Fork Payette River was ~0.82–0.73 m/ky from 7 ka to present, likely several times faster than incision averaged over the last glacial-interglacial cycle.

ORIGIN AND MODIFICATION OF GARNET PYROXENITE IN XENOLITHS FROM CERRITO NEGRO, RIO PUERCO VOLCANIC FIELD, NEW MEXICO—A RECORD OF INCIPIENT LITHOSPHERIC EXTENSION, by *Courtney A. Porreca*, 2005, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 139 pp.

Garnet pyroxenite xenoliths entrained in basalt from Cerrito Negro in the Rio Puerco volcanic field, west-central New Mexico, preserve symplectites from multiple decomposition reactions and show evidence for multiple metasomatic events. The origins of the pyroxenites and the preserved symplectites are important in evaluating the effects of incipient extension on the flanks of the Rio Grande rift. Spinel lherzolites and spinel pyroxenites are abundant in many of the necks in the area, whereas garnet pyroxenites are rare. The few garnet pyroxenites occur in Cerrito Negro and contain small relict garnet grains surrounded by optically dark rims and/or symplectites and secondary black spinel grains. Electron probe microanalyses indicate that the dark rims around garnet grains are symplectites composed of sp+opx+cpx+glass. The large dark spinel grains also have symplectite rims composed of opx+an+glass±cpx. Matrix pyroxene grains in the garnet pyroxenites show coarse intergrowths and inclusion relationships with one another in addition to local exsolution features. Olivine is almost never observed in the pyroxenites. Many pyroxenite samples contain grains of sharply zoned carbonate and/or interstitial veins or inclusions within pyroxenes. In contrast, spinel lherzolites have granoblastic to porphyroclastic textures with rare inclusions and less common exsolution features. Spinel grains are small and brown and appear to be primary. Black spinels contain less Mg and Cr and more total Fe relative to brown spinels. Two-pyroxene thermometry yields temperatures of 900–1,000°C for spinel lherzolites and 950–1,145°C for the pyroxenites. Garnet-orthopyroxene barometry yields pressures ranging from 16 to 18 kbar for the garnet pyroxenites, corresponding to depths of ~55–65 km. These data place geotherms for the Rio Puerco xenoliths at intermediate temperatures relative to the cooler geotherm inferred for the Colorado Plateau and the warmer Rio Grande rift from other xenolith studies. The reaction textures preserved in garnet pyroxenite and the spinel lherzolite are thus consistent with heating±decompression under the Rio Puerco volcanic field in response to Rio Grande rifting.

CYCLOSTRATIGRAPHY AND METEORIC DIAGENESIS OF THE MIDDLE PENNSYLVANIAN GRAY MESA FORMATION, LUCERO BASIN, CENTRAL NEW MEXICO, by *Lea A. Scott*, 2004, M.S. thesis, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 157 pp.

The Middle Pennsylvanian (Desmoinesian) Gray Mesa Formation of central New Mexico is composed of twelve deeper subtidal through shallower-water carbonate and siliciclastic facies. Subtle facies variations stack to form ~75-m-scale upward-shallowing subtidal cycles, which were deposited during short-term (~6 to ~253 k.y.) changes in accommodation space, likely induced by glacio-eustatic sea-level fluctuations and associated climate changes. The meter-scale upward-shallowing cycles stack into 4½ sequences (40–80 m thick) composed of slope-forming, siliciclastic-rich intervals overlain by cliff-forming, carbonate-rich intervals. Sequences represent long-term (~100 k.y. to ~4.2 m.y.) changes in accommodation space produced by long-term eustasy and/or long-term tectonic induced subsidence.

Approximately 40% of cycles are capped by subtle, but laterally persistent (up to 2 km), early diagenetic features. Features can be associated with dilation cracks and rhizoliths and have $\delta^{13}C$ values (-5.58 to +0.25‰) that are smaller than their immediately adjacent host limestone (-4.32 to +2.19‰) and Pennsylvanian marine values (~+2.3 to +6‰). Features formed during early marine-meteoric mixing or meteoric phreatic diagenesis during high-frequency sea-level falls. During sea-level lowstands, laminated black calcites subsequently formed on some cycle tops as pedogenic calcretes within the vadose zone.

$\delta^{13}C$ values from fine-grained pelleted lime mudstone matrix sampled every ~10 cm throughout individual upward-shallowing cycles record up to 5‰ negative shifts from bottom to top. Depleted $\delta^{13}C$ values persist up to 0.5 m beneath cycle tops, suggesting alteration by isotopically light soil gas incorporated into downward-percolating, meteoric waters during sea-level lowstands. Results from this study indicate that field studies, petrographic observations, and stable isotope analyses are necessary to understand the subtle history of deposition and diagenesis controlled by Middle Pennsylvanian glacio-eustasy in the Lucero Basin.