

# **New Mexico Geological Society**

## **Spring Meeting**

**Friday, April 15, 2011**  
**Macey Center, 801 Leroy Place**  
**NM Tech Campus**  
**Socorro, New Mexico 87801**

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President:	Barry Kues
Vice President:	Nelia Dunbar
Treasurer:	Greg Mack
Secretary:	Virginia McLemore
Past President:	Kate Zeigler

### **2011 Spring Meeting Committee**

Technical Program Chairs:	Karl Karlstrom and Laura Crossey
Logistical Chair:	Shari Kelley
Registration Chair:	Connie Apache

## **Schedule of Events – 2011 NMGS Annual Spring Meeting**

**REGISTRATION 7:30 – 8:20, ENTRY/FOYER, MACEY CENTER**

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#### **MANIFESTATIONS OF MANTLE-TO-SURFACE CONNECTIONS IN THE SOUTHWEST**

##### **8:20 – 8:30 THEME SESSION-WELCOME:**

Karl Karlstrom

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## EVIDENCE OF STRIKE SLIP MOVEMENT AND ATTENUATION OF OFFSET, PECOS SLOPE, SOUTHEASTERN NEW MEXICO

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The Pecos Slope of southeastern New Mexico has been explored for years for oil and natural gas fields, such that there is a large amount of subsurface data for the region. Experience in the subsurface of the Permian basin indicates that the magnitude of structural features increases with depth. This is especially true when mapping vertical uplifts such as those found on the Central Basin Platform and structures in the Tatum basin. Differential compaction, erosion, continuous uplift, additional sedimentation, and facies changes both off and on structural highs are primarily responsible for this relationship. Isopach maps of purely vertical uplift, constructed of these structures, demonstrate that sediments thin over the top and thicken on the flanks. The Pecos Slope has been involved in significant lateral, strike slip movement. The dramatic northeast trending "Buckles" are the surface expression of basement sourced, right lateral strike slip faults. Lateral displacement has been intermittent, but continuous from Precambrian time to the present. Current expression of this lateral deformation is both vertical and horizontal. Strike slip movement is generated in the basement and transmitted vertically. When basement is overlain by rigid, brittle rock, movement is transmitted directly to surface outcrops and is relatively easy to identify. When basement is overlain by plastic sediments (e.g., shale, evaporates, or other incompetent sedimentary rocks), coupling with overlying rigid beds is compromised and both horizontal and vertical displacement at the surface is attenuated. Recent mapping efforts by the New Mexico STATEMAP program have produced a series of 1:24,000 surface geologic maps for part of the Pecos Slope. In comparing subsurface data with surface bedrock expression, substantial discordance in vertical offset is observed on faults between the top of Precambrian basement and the Permian Yeso and San Andres Formations at the surface. In some places, the difference in vertical displacement is up to an order of magnitude (e.g., ~4000' Precambrian offset versus ~300' San Andres offset). Attenuation of vertical displacement on faults in the eastern Sacramento Mountains occurs in the much less competent Yeso Formation, which is primarily comprised of mudstone, siltstone, gypsum and lesser sandstone and dolomite.



## AN ASSESSMENT OF PROVENANCE AND MAXIMUM DEPOSITIONAL AGES USING DETRITAL ZIRCONS FROM PROTEROZOIC, CAMBRIAN, PENNSYLVANIAN, AND CRETACEOUS SANDSTONES, SOUTHWESTERN NEW MEXICO

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Detrital zircons from sandstones from southern New Mexico were analyzed for U-Pb ages using LA-ICP-MS. These include: (1) Proterozoic quartzite from the San Andres Mts.; (2) Cambrian-Ordovician Bliss Sandstone from the San Andres Mts., San Diego Mt., Mud Springs, Florida Mts., San Lorenzo, and the Burro Mts.; (3) A quartzite within the Pennsylvanian La Tuna formation at Bishop Cap southeast of Las Cruces; and (4) Cretaceous Beartooth Quartzite from the Burro Mts. An average of 75 grains/sample were analyzed. "Peaks" refers to peaks on a relative probability distribution diagram. The results have implications for provenance and maximum depositional age of the units.

Two samples of foliated micaceous quartzite from the San Andres Mts. were collected from below the unconformity with overlying Bliss Sandstone. They both yielded a single population at 1680 Ma. These ages have been reported from basement rocks locally and throughout the Mazatzal province.

The Bliss Sandstone has some variation in ages among the 12 samples analyzed, but most have the following main peaks: 1250 Ma, 1470 Ma, 1715 Ma, and 1850 Ma. The sample of Bliss Sandstone from the Florida Mts. lies unconformably over the Cambrian Florida granite. The dates from the granite range from  $501 \pm 6$  Ma to  $512 \pm 8$  Ma. Samples had only one population of zircons at ~500 Ma. The 500 Ma zircons were found in Bliss from the Burro Mts., and a single 500 Ma grain was found at San Lorenzo. The Bliss differs from all of the other units with Proterozoic grains in that the main peak is at 1250 Ma instead of ~1650 Ma suggesting a larger proportion of 1.2 Ga igneous rocks exposed at the time.

The sandstone at Bishop Cap is a thin member within the Pennsylvanian La Tuna formation. The main peaks are at 1650 Ma, 1440 Ma, and 1100 Ma. Two grains have ages of ~320 Ma, or Mississippian, but the youngest cluster of 3 or more ages is 493 Ma; this is much older than the depositional age as determined by fossil ages. The Cretaceous Beartooth Quartzite in the Burro Mountains has several Proterozoic peaks including 1050 Ma, 1450 Ma, and 1680 Ma, a strong peak at 214 Ma, and a young peak of  $102 \pm 4$  Ma that includes seven grains and provides a maximum depositional age near the Early/Late Cretaceous boundary. This is the first known absolute age constraint on this non-fossiliferous unit.

## DEPOSITIONAL ENVIRONMENTS, SEDIMENT DISPERSAL, AND PROVENANCE OF THE LOWER PERMIAN GLORIETA SANDSTONE, CENTRAL AND NORTHERN NEW MEXICO

BAUER, EDWARD M., and MACK, GREG H., Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003

During early Permian time, the region that now encompasses the Colorado Plateau was periodically covered by large eolian dune fields. Lower Permian formations in New Mexico, some of which may be eolian in origin, generally have not been included in regional paleogeographic reconstructions. Among these formations is the Glorieta Sandstone. The Glorieta Sandstone is a light gray, cliff forming, fine-to medium-grained, well-sorted quartzarenite or subarkose with calcite cement. There are seven distinct lithofacies within the Glorieta: (1) large-scale crossbeds, (2) small-scale crossbeds, (3) wind ripples, (4) massive sandstone, (5) thin gray shale, (6) dolomite, and (7) limestone. The Glorieta was deposited as eolian dunes and sand sheets. Paleocurrent measurements (n=157) indicate the dunes were transported by northeasterly winds.

Future work will answer the following question: What source area(s) provided detrital sediment to the Glorieta Sandstone and how does it compare to the provenance of coeval deposits on the Colorado Plateau? This question will be addressed by U-Pb ages of detrital zircons. The results will test whether sand of the Glorieta had a similar provenance as that of the Coconino Sandstone.

## GROUNDWATER GEOCHEMISTRY OF THE SOUTH TAOS VALLEY

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Data has been compiled by TSWCD staff from a well sampling program analyzed by the New Mexico Bureau of Geology and Mineral Resources, and including information from the NM Environment Department and tests run by private companies for Subdivision reviews for Taos County. Contoured maps were prepared for 19 selected constituents. Anomalous concentrations are noted in a number of areas, including most of the known "hot springs" in Taos County. These anomalous concentrations, above background levels, are probably due to hot waters rising along deep seated faults and mixing with shallow groundwater. Analyses of perennial streams in the Taos Valley shows surprisingly high TDS, that is tapped by the acequia system in the south Taos valley. A specific example of these results is best exemplified by the fluoride map. The highest concentrations, exceeding EPA drinking standards, are at the Ponce de Leon Hot Springs, located along the eastern fault bordering the Miranda Canyon graben. Wells drilled for domestic water supply in the same area also produce warm waters, with elevated levels of fluoride. Other high concentrations of fluoride (and arsenic, chloride, etc.) are mapped along other faults in the valley. High concentrations of several ions have been tested in groundwater wells near the Pecos-Picuris system of faults south of the Rio Pueblo and north of the Picuris mountains. This developing area around the Taos Country Club golf course and UNM-Taos Klauer campus is where faults buried by Quaternary fan and valley alluvium connect from the surface-mapped four plus Pecos-Picuris system of the Picuris Mountains to the four plus Los Cordovas faults north of the Rio Pueblo.

Additional studies of water geochemistry and water level monitoring are being planned by the New Mexico Bureau of Geology and Mineral Resources and the Taos Soil and Water Conservation District.

## MICROBIAL ECOSYSTEMS AT DEPTH: CONTRASTS IN NUTRIENT AND OTHER ENVIRONMENTAL GRADIENTS BETWEEN NATURAL CAVES AND ULTRA-DEEP MINES

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In the subsurface of Earth, myriad microorganisms make their living conducting their affairs in a world of darkness, of often extreme nutrient limitation (either organic or mineral), and frequently extreme temperatures, pressures, and highly reactive gases. Are these organisms just evolution's "losers" who have had to retreat to the subsurface because they have been outcompeted for all the desirable real estate on the surface? Or in contrast, are they part of an emerging story of a subsurface rock-inhabiting microbial biosphere that has persisted over much of the course of Earth's history? Evidence is slowly mounting that the latter situation may be the case.

Some clues that will help us unravel this story are emerging from studies of natural caves at depths ranging from very shallow (a few meters) to over 1-2 km in depth, and from human-delved mines some of which now reach depths in excess of 4 km. Although all of these environments are often described as "subsurface", they represent very different environmental conditions and ecological opportunities for microbial inhabitants. Suggestions of systematic differences in microbial biodiversity, nutritional strategy, and other properties with depth are potentially distinguishable between shallow and mid-range crustal levels. Trends observed include a decreasing tendency to heterotrophy and an increasing tendency to chemoautotrophy with depth. This may be accompanied by decreasing biodiversity with depth. Sheer availability of living space may also be a major gradient between mesoporosity and macroporosity (caves) at shallower depths and very small rock fracture spaces available to microorganisms at greater depths.

Energetics of the systems can differ markedly. In general, near-surface systems (including caves) are dependent on the products of photosynthesis (organic C and/or O<sub>2</sub>) whereas at great depth, the ecosystems are anaerobic and fueled by the products of water-rock interactions that produce H<sub>2</sub> and indirectly, abiotic short chain hydrocarbons. This forms a gradient of increasing importance of abiotic energy sources with depth. Exceptions occur including geochemically enriched shallower systems that push those to supporting mineral-oxidizing chemolithotrophy.

Such comparative analyses of newly characterized subsurface geomicrobial habitats may provide insights into the early origin and evolution of life, and potentially act as biomarker proxies for long timescale geological connections, plate motions, and fluid flowpaths.

## STRENGTH CHARACTERIZATION OF THE BANDELIER TUFF

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Consisting of two members erupted as a series of ash rich ignimbrites during enormous, caldera-forming events at about 1.61 Ma and 1.22 Ma, the Bandelier Tuff's exposure throughout the Jemez Mountains of northern New Mexico is extensive. The Bandelier Tuff controls much of the flow of groundwater beneath Los Alamos, and feeds aquifers for the surrounding communities. The material properties of the Bandelier Tuff are relevant to a number of regional environmental issues such as groundwater contamination and earthquake hazards.

Cooling units in the Bandelier Tuff, which may or may not coincide with contacts between flow units, have been characterized based on primary and secondary features, including welding, devitrification, vapor-phase alteration, oxidation and relative content of crystals, pumice, and lithic fragments. This investigation further characterizes the Bandelier Tuff on the basis of strength, as determined via Schmidt hammer rebound numbers, point load experiments, and triaxial compression tests. Schmidt hammer rebound data collected thus far yield distinct values ranging from 12 to 57 and may correspond to welding, as determined by the morphology of the Bandelier Tuff in thin section and geochemical zonation. Because the degree of welding (among other features such as devitrification and vapor-phase alteration) can vary laterally and can depend on several factors, including temperature at time of deposition, input of meteoric water during cooling, major and trace element data are often used to provide definitive identification of flow units. Our data is consistent with previous studies that show that the Tshirege Member is stratigraphically zoned from more high-silica rhyolite at its base to more low-silica rhyolite at its top.

## CANOPY INTERCEPTION LOSS FOR A MIXED CONIFEROUS FOREST IN SOUTHERN NEW MEXICO PRIOR TO TREE-THINNING TREATMENT

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The Southern Sacramento Mountains, located in southeastern New Mexico serves as a recharge area for adjacent regional aquifers. Out of concern about the region's future groundwater and surface water supplies, water resource managers are interested in potentially increasing groundwater levels and stream discharges by thinning trees in mountain watersheds. The Sacramento Mountain Watershed Study (SMWS) is focused on assessing the effects of tree-thinning on the local hydrologic system in the Sacramento Mountains. A watershed-scale water balance will be evaluated before and after thinning. The SMWS field area is 3 L Canyon, a small watershed located in the southern Sacramento Mountains. The forest in 3 L Canyon is mixed conifer, with Douglas fir being the primary species. An important parameter affecting input to the water balance is the amount of rainfall lost to tree canopy interception, which can be upwards of 40% in a mixed conifer forest. Throughfall was measured in 3 L Canyon from September 2008 to December 2010 as part of the baseline data before thinning, and interception loss was determined using the volume balance method.

Gross rainfall and other meteorological data were collected at the highest elevation in the watershed. Throughfall was measured at two locations near the ridge-top. The two throughfall collectors were located under visibly different densities of tree canopy. Direct leaf area index (LAI) measurements were made at each throughfall measurement point using an optical plant canopy analyzer (LI-COR LAI-2000). Averaged over the period from May until September, interception loss was generally greater at the throughfall collector with higher LAI and denser canopy than at the throughfall collector with smaller LAI and less dense canopy. However, for shorter timescales (monthly and per-event), the observed interception loss was not always greater at the throughfall collector with higher LAI. This could be due to spatial variability, which gets averaged out when looking at longer timescales. The ultimate goal of this research is to correlate throughfall to LAI and other spatial data, including satellite imagery, to create throughfall maps for the 3 L Canyon watershed that will be used to estimate rainfall inputs to the watershed-scale water balance.

**Keywords:** Rainfall interception; Canopy interception loss; Leaf area index; Optical plant canopy analyzer

## A NORTH-FLOWING MIOCENE(?) ANCESTRAL PECOS RIVER IN SOUTHEASTERN NEW MEXICO: A RECORD OF LATE PALEOGENE–EARLY NEOGENE EPIEROGENY

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The Gatuña Formation of southeastern New Mexico consists of fluvial and eolian deposits within the modern valley of the Pecos River and nearby areas to the east and west. The Gatuña is poorly dated; it contains ~13 Ma and 0.6 Ma volcanic ashes (Powers and Holt, 1993 NMGS guidebook) and is capped with calcretes that range in age from several million years to ~0.5 Ma (Hawley et al., 1993 NMGS guidebook; Powers and Holt, 1993 NMGS guidebook). On-going provenance, paleocurrent, and facies analyses of the Gatuña Formation show the presence of a light pink to gray axial fluvial facies near the modern Pecos River and intercalated reddish-brown alluvial and eolian deposits that accumulated in local transverse drainages. Clasts in the axial fluvial facies are typically well rounded and consist of diverse lithotypes including carbonate, sandstone, chert, quartzite, volcanic rocks (andesite, rhyolite), hypabyssal intrusive rocks, and basement lithotypes (granite, gneiss, schist).

Previous workers interpreted the axial fluvial facies of the Gatuña Formation as deposits of south-flowing rivers. This interpretation derives from the close geographic association with the modern south-flowing river and the southward-decreasing elevation of the basal Gatuña (e.g., V.C. Kelley, 1980, NMGS guidebook). This latter attribute, however, is clearly influenced by solution-subsidence effects, as the base of the Gatuña south of Carlsbad commonly lies in sinkholes far below the grade of the modern Pecos.

Several lines of evidence indicate the axial fluvial facies of the Gatuña Formation was deposited by north-flowing rivers: (1) All axial facies outcrops thus far examined in the Loving-Malaga area (upper and lower Pierce Canyon, NM 31 bridge, Herradura Bend) show unambiguous pebble imbrications indicative of northerly paleoflow; (2) About 10–20% of the volcanic clasts are rhyolite, and some of these show eutaxitic textures typical of ignimbrite. Of the potential sources of coarse volcanic detritus near the Pecos drainage (the Ortiz, Sierra Blanca, and trans-Pecos volcanic fields), only the trans-Pecos contains substantial volumes of rhyolite; (3) Although the Proterozoic Ortega Quartzite is the dominant resistant lithotype in the headwaters of the modern Pecos drainage, clasts of this distinctive lithology are not present in the Gatuña Formation.

Northerly paleoflow in the ancestral Pecos axial system of southeastern New Mexico may reflect late Oligocene-early Miocene epirogenic uplift and northward tilting of the southern High Plains. This uplift caused ~1–2 km deep erosion in southeastern New Mexico after intrusion of the 28.8 Ma Capitan pluton and before the beginning of deposition of the Ogallala Group at ~13 Ma. Uplift was contemporaneous with that of the southern Colorado Plateau, and may have resulted from mantle-buoyancy effects related to voluminous ignimbrite volcanism in the Sierra Madre Occidental.

## NEW CONSTRAINTS ON THE KINEMATIC AND PALEOGEOGRAPHIC HISTORY OF THE LITTLE HATCHET MOUNTAINS, SOUTHWESTERN NEW MEXICO

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New geochronological, structural, and sedimentological data provide insight into the complex deformational, erosional, and magmatic history of the Little Hatchet Mountains. Previous studies in the range proposed that an array of north-east verging basement-involved structures and NW-, NE-, and east-west trending normal and strike-slip faults are related to two distinct stages of Laramide deformation, that include: (1) a block uplift stage beginning in the Late Cretaceous followed by (2) left-lateral wrenching between the Paleocene and Eocene. Reinterpretation of mapped relationships with additional data suggests that Laramide orogenesis, as seen in the Little Hatchet Mountains, cannot be clearly segregated into two discrete deformational periods of variable style. Instead, Laramide structures include low- and high-angle thrust faults that generally verge to the northeast, involve basement ( $1080.4 \pm 6.8$  Ma; U-Pb zircon), and represent reactivated Bisbee rift faults. Faults with N60E, N60W, and E-W trends and latitic intrusions all formed as a response to a north-south extension event that occurred in the Oligocene, as suggested by the age of a granitic sliver ( $33.1 \pm 1.4$  Ma; U-Pb zircon) along an east-west normal fault with at least 1000m of throw. Subsequent Neogene Basin and Range normal faults created several offset blocks in the range and juxtaposed variable structural depths from the two earlier deformational events. New interpretations and field relationships should be considered for future geophysical and tectonic studies regarding the subsurface structure and kinematic histories of the surrounding area and ranges.



# THE TOPOGRAPHY OF THE WESTERN U.S. AND ITS RELATIONSHIP TO UPPER MANTLE PROCESSES

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The topography of the Earth's surface provides important information for regional and global geomorphic studies because it reflects the interplay between tectonic-associated processes of uplift and climate-associated processes of erosion. Recent advances in the field of geomorphometrics, defined as the science of quantitative land surface analysis [Pike et al., 2008], provides the opportunity to evaluate signatures in the landscape that have their origin in large-scale tectonic process such as convection of material in the upper mantle. The Western U.S. provides an ideal location for such a study: the topography of the actively deforming western U.S. Cordillera is characterized by high relief and regionally high elevation, typically exceeding 1.5 km. The interpretation of high-resolution seismic tomograms in the Southern Rocky Mountains (recently generated as part of the NSF-funded CREST project) substantiates the notion that much of the high elevation coincides with thin or attenuated continental crust, necessitating topographic support by anomalous buoyancy of the mantle. It is therefore increasingly clear that the geodynamics responsible for the topography in the Western U.S. has a significant component associated with deep sources in the upper mantle. In an attempt to sharpen our understanding of the underlying geodynamics, we evaluate the correlation between the surface topographic character (as delineated by topographic roughness, organization and spectral power) and datasets that provide information about density variations

indicative of buoyancy in the upper mantle (e.g., the lithospheric geoid, upper mantle seismic velocity anomalies, and crustal (Lg) Q). Our general conclusion is that mantle buoyancy is driving differential surface uplift throughout the western U.S. and this driver of topography manifests itself in measurable anomalies in the topographic roughness at short wavelengths (tens of kilometer) and elevated spectral power in the topography at longer (several hundred kilometers) wavelengths.

## XENOWHIFFS: MANTLE GASES IN HYDROLOGIC SYSTEMS

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Throughout the western U.S., Quaternary travertine and lacustrine carbonate deposits record long-lived interactions of deeply-sourced (“endogenic”) carbonic fluids with the near-surface hydrologic regime. These were deposited by springs analogous to modern CO<sub>2</sub> springs that occur along faults and fracture zones associated with both local and regional extension (e.g., Rio Grande rift; Basin and Range; Colorado Plateau; Arizona transition zone; Hurricane fault, Utah). Upwelling groundwaters containing ‘xenowhiffs’ (deeply-derived gases entrained in hydrologic systems) emerge along basin margins as well as mix with aquifer waters in shallower hydrologic systems. Gas and water chemistry from hot springs, gas vents, CO<sub>2</sub>-rich cool springs, and high-P<sub>CO2</sub> groundwaters of the western U.S. indicate a regionally extensive flux of deeply sourced volatiles. A measurable mantle-derived helium component (<sup>3</sup>He/<sup>4</sup>He > 0.1 RA) occurs in nearly all springs. The highest flux of mantle volatiles (<sup>3</sup>He/<sup>4</sup>He = 1 to 8 RA) occurs above regions of lowest mantle velocity indicating direct fast-pathways from the sublithospheric mantle to the surface hydrologic system. The total CO<sub>2</sub> flux into the western U.S. near-surface system (>10<sup>11</sup> moles per year) rivals that of mid-ocean ridges and subaerial volcanism (each ~10<sup>12</sup> mol/yr). Important components of the CO<sub>2</sub> are derived from the lithosphere and from active asthenospheric upwelling. We use interdisciplinary datasets integrating tectonic setting, mantle velocity models, water and gas chemistry, and microbial community analysis for a suite of CO<sub>2</sub>-rich springs of the western U.S. The spring vent environments exhibit a range of temperature, pH and salinity but share key geochemical similarities to chemolithotrophic microbial ecosystems found in oceanic hydrothermal systems. Degassing in continental extensional settings supports microbial assemblages that are analogous to chemolithotrophic communities at mid-ocean ridges and continental volcanic hydrothermal systems as indicated by the widespread presence of archaea and thermophilic organisms in cool as well as hot springs.

## MAPPING THE McCARTYS LAVA FLOW, EL MALPAIS, ZUNI-BANDERA FIELD: THE ROLE OF INFLATION IN THE EMPLACEMENT OF LARGE LAVA FLOWS

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Based on mapping of the McCarty's lava flow, comparison with flow-fields in Hawaii, and observations of actively inflating flows, we are beginning to untangle the sequence of emplacement mechanisms on large flow-fields, particularly those with characteristics attributed to inflation. These results are providing insights that we believe will enable us to map the sequence of events during the emplacement of the McCarty's lava flow.

Mapping efforts have focused on determining the dimensions, geometry, and timing of lava surface characteristics, and structure of vertical sections along transects of the McCarty's flow field at several places along its length. We have done similar measurements at the distal ends of the 1859 lava flow, Hawai'i, although the 1859 lava flow has proven more complicated. Both lava flows are pahoehoe flows similar in thickness and length, and consist of extensive sheeted surfaces with micro-spiny surface textures and deformed "skins" of variable thickness (from millimeters to meters). Central platy pahoehoe-bearing platforms with V-shaped pits and marginal clefts are commonly elevated from one to over 10 meters above surrounding pahoehoe sheet lobes. These sheet lobe surfaces were subjected to differential surface stresses causing immediate plastic and subsequent brittle shear, compressional, and extensional deformation zones defined now by thin platy rubble zones. Based on timing estimated from thickness of deformed pahoehoe crusts, the lavas of these platforms were emplaced and deformed in less than a few hours. Subsequent deformation of the margins, squeeze ups in deep clefts, and marginal tilting and apparent elevation of the platforms occurred as late as several weeks after the sheet lobe.

As a first order model, the platform-sheet lobe characteristic appears to have been strongly influenced by the balance of lava margin strength and lava hydrostatic head. Stress in excess of the critical yield strength necessary for breakouts and advance may be governed largely by regional slope or, on low angle slopes, the timing of excess pressure from local inflation.

## CORRELATING MAGMATIC TEMPERATURES AND MELT INCLUSION COMPOSITIONS AT THE SINGLE CRYSTAL LEVEL AT VALLES CALDERA, NEW MEXICO

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Isotopic signatures and major and trace element compositions of single quartz crystals with melt inclusions from the Cerro Toledo Rhyolite of Valles caldera (New Mexico) have never been correlated with crystallization temperatures of the same crystals. Combining the compositions of melt inclusions and the localized temperatures of host quartz crystals offers insight into how high silica rhyolite magma systems evolve.

Two major ignimbrite units were erupted from Valles caldera, the Otowi (1.61 Ma) and Tshirege (1.22 Ma) Members of the Bandelier Tuff. Between the Otowi and Tshirege eruptions, much smaller-scale eruptions of Cerro Toledo Rhyolite were sporadically erupted. Secondary Ionization Mass Spectrometry was used to measure titanium concentrations for titanium-in-quartz geothermometry and trace element compositions within melt inclusions. Trace element compositions in melt inclusions are variable within the Cerro Toledo eruption deposits and crystals. Strontium concentrations are ~1 ppm within melt inclusions, with crystals from one Cerro Toledo eruption deposit ranging from ~7-11 ppm. Such low strontium concentrations must result from fractionation of feldspar. Niobium concentrations range from ~60-180 ppm indicating quartz crystals form in highly fractionated melts. Future isotopic studies will be undertaken to help characterize distinct melts with unique isotopic signatures, or whether mixing can be recognized between isotopically distinct melts for the same Cerro Toledo quartz-hosted melt inclusions.

Titanium in quartz geothermometry was originally calibrated at 10 kbar. Thomas et al. (2010) added pressure, or depth dependence that affected the solubility of titanium in quartz. Using this additional pressure constraint at ~3 kbar, Cerro Toledo Rhyolite quartz crystals yield temperatures that range from ~460-560 °C, which are not realistic for quartz formed in a chamber which eventually formed a caldera. Thus, either this titanium in quartz geothermometer does not yield accurate temperatures for quartz associated with caldera forming eruptions, or these quartz crystals were formed at or near 10 kbar depth (~680 °C), which seems highly unlikely.

## TESTING A HYPOTHESIS FOR MULTISTAGE UPLIFT OF THE ROCKIES USING THERMOCHRONOLOGY AND DETRITAL ZIRCON DATA: LARAMIDE REVERSE FAULTING, LONG WAVELENGTH OLIGOCENE UPLIFT, AND SHORTER WAVELENGTH NEOGENE DIFFERENTIAL UPLIFT

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A compilation of thermochronologic age-elevation transects shows temporally and spatially partitioned Cenozoic cooling indicative of multistage uplift of the Rocky Mountain region. These data lead to a testable hypothesis that explains the present data: 1) Laramide contraction and cooling of the basement, recorded by hanging wall blocks near the eastern and western Front Range uplifts and some Colorado Plateau monoclines, with typical cooling rates of 60m/Ma from 75-45 Ma; 2) Relative tectonic quiescence from 45-35 Ma during which the Rocky Mountain Erosion Surface developed; 3) Initial stages of long wavelength uplift driven by the Oligocene ignimbrite flare-up resulted in the deposition of the "Eocene" conglomerates in latest Eocene/earliest Oligocene and creating the Great Plains topographic ramp. Typical exhumation rates from 38-25 Ma were 100 m/Ma; 4) Relative tectonic quiescence from 25-10 Ma, inferred to reflect changing far field stress regimes culminating in, 5) Neogene acceleration of cooling and exhumation to rates >120, driven by small scale mantle convection.

This study focuses on the transition from post-Laramide quiescence into the Oligocene by examining five geologic units that span the southern Rocky Mountains. We hypothesize these units are related in that they record the initial pulse of uplift associated with Oligocene volcanism. Recent studies indicate that deposition of the Telluride Conglomerate initiated just prior to and ended just after the onset of Oligocene San Juan volcanism, supported by the presence of volcanic clasts in the upper portions of the unit. The Blanco Basin may be the eastward expression of similar early unroofing of the Needles Mountains. The coeval El Rito and Galisteo Formations may also record uplift in the southern Rockies. We have begun detrital zircon analysis and plan apatite fission track analysis on these units to test if they can be temporally and spatially linked to create a surface datum recording the Rocky Mountain landscape just prior to and in early stages of the ignimbrite flare-up. Beginning with the model of the Rocky Mountain Erosion Surface, and combining geochronologic and thermochronologic histories, our goal is to reconstruct the pre-Oligocene Rocky Mountain topography to constrain post-Oligocene and Neogene Rocky Mountain uplift histories.

## GEOLOGY, ALTERATION, AND MINERALIZATION OF THE COPPER FLAT PORPHYRY COPPER DEPOSIT, SOUTHWESTERN NEW MEXICO

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The Copper Flat deposit, located in southwestern New Mexico, is a Laramide porphyry copper deposit with associated molybdenum, gold, and minor silver. The hydrothermal evolution of this deposit is associated with an andesite that has been intruded by the mineralized Copper Flat quartz monzonite (CFQM) and a series of dikes that radiate out from the CFQM. The CFQM contains a breccia pipe that hosts high-grade mineralization.

Preliminary petrographic analyses indicate the evolution of the porphyry system is characterized by three alteration assemblages: A biotite-potassic, a potassic, and a quartz-sericite assemblage. The biotite-potassic assemblage is characterized by potassium feldspar and biotite flooding in which plagioclase is replaced by orthoclase and igneous biotite is replaced by hydrothermal biotite. The potassic is characterized by the presence of potassium feldspar rimming plagioclase and a minor to moderate amount of chloritization of the biotite. The quartz-sericite suite is distinguished by the replacement of plagioclase and biotite by white phyllosilicates. Minor argillic alteration exists locally and is fracture-, vein-, and fault-controlled. This suite is recognized by the replacement of feldspars by and the filling of veins with clays. The biotite-potassic and potassic assemblages are associated with the majority of copper mineralization.

The breccia pipe consists of quartz monzonite fragments surrounded by a matrix of mainly quartz, biotite, pyrite, chalcopyrite, and molybdenum. Two types of breccias within the pipe are distinguished, a biotite breccia and a quartz breccia, both classified depending on the relative amounts of biotite and quartz present. Alteration of the breccia occurred both pre- and syn-brecciation. This is evidenced by breccia clasts of mineralized and altered quartz monzonite exhibited in core.  $\delta^{34}\text{S}$  values of chalcopyrite and pyrite extracted from the breccia matrix range from 0.9 to 1.8 per mil and from -0.1 to 2.2 per mil, respectively, which is consistent with a magmatic origin for the breccia.

Ongoing investigations focus on the sources of hydrothermal alteration, determining temperatures and pressures at the time of brecciation, and documenting the distribution of gold throughout the deposit.

## NITRATE FLUXES IN THE RIO GRANDE

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The Rio Grande is the most important source of water for the irrigation of agricultural fields in the Rio Grande Valley of West Texas. Return flows from this irrigation likely add to the salinity of the Rio Grande and may include the addition of excess nutrient chemicals like nitrate ( $\text{NO}_3$ ). To date, however, the seasonal concentrations of  $\text{NO}_3$  within the Rio Grande and the sources that contribute this nutrient chemical have not been well-defined. To address this problem, we measured  $\text{NO}_3$  concentrations of the Rio Grande surface water in five locations of the Mesilla Valley, stretching approximately 100 kilometers between Radium Springs, New Mexico and El Paso, Texas. Samples were collected monthly from these five sites in 2010. In general,  $\text{NO}_3$  concentrations were significantly lower in the upper part of the Mesilla Valley, ranging from 0.1 to 1.3 mg/L, as compared to higher values of 3.9 to 5.0 mg/L in downstream locations near El Paso. However, the highest  $\text{NO}_3$  fluxes (as large as 27 mg/L) were found in the central part of the Mesilla Valley, adjacent to the town of Vado, New Mexico. This  $\text{NO}_3$  flux is most likely associated with a surface water and/or groundwater discharge from dairy farms common in this area. The flux is diluted as the river moves downstream. The seasonal variation of  $\text{NO}_3$  shows that during non-irrigation season we see slightly higher concentrations compared to lower concentrations during irrigation season. The significance of these findings leads us to believe that there are various contamination issues related to return irrigation flows and/or discharges of municipal/dairy effluents. This initial work demonstrates that  $\text{NO}_3$  concentrations in the Rio Grande increase in downstream locations. The contamination of nitrate in the Rio Grande is additional factor causing the decrease of water quality in the region.

## MAGMATIC CONSTRAINTS ON THE ENIMATIC COLORADO MINERAL BELT

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The Colorado Mineral Belt (CMB) is a Laramide (75 to 40 Ma) magmatic lineament that trends NE from the Four Corners region to the Colorado Front Range. Spatially restricted magmatic activity ~1000 km inboard from the trench of the subducting Farallon Plate is a puzzling enigma of the Laramide orogeny and many models for the origin of the CMB have been presented. End-member hypotheses place geographic control of the CMB within the crustal lithosphere versus the slab. Approximate alignment of the mineral belt with the strong NE trending Precambrian structural grain has supported focusing of magmas along pre-existing crustal weaknesses and/or enhanced melt fertility associated with the shear zone regions. Alternatively, a Farallon slab tear or subduction of oceanic boundaries (e.g. transform fault) provide linear features that can allow melt production in a restricted region.

Any hypothesis that accurately explains the CMB needs to account for the spatial and temporal magmatic activity. The Twin Lakes Batholith (TLB) ~20 miles south of Leadville, CO places important constraints on the origin of the CMB. Detailed  $^{40}\text{Ar}/^{39}\text{Ar}$  and U-Pb geochronology reveal a protracted magmatic history between 65 and 30 Ma. In this single region we have identified at least 7 temporally distinct intrusions (~65-57 Ma and ~43-30 Ma) with an apparent magmatic gap between 55 and 43 Ma. The TLB is representative of the entire CMB in that geochronology data compilation demonstrates that magmatism initiated at ~70 Ma throughout the length of the CMB with no apparent sweep of magmatism and that other regions also record multiple and protracted magmatic activity with an associated gap. The Front Range intrusions are multiple and range from 75 to 58 Ma in a fairly restricted area.

Simultaneous initiation of magmatism along the length of the CMB, plus the protracted magmatism in individual areas, are difficult to reconcile with plate motion considerations if the primary control of the CMB is within the Farallon slab. Over the 30 Ma magmatic period the North American plate would have moved nearly 900 km relative to the asthenosphere (hot spot reference frame) which would seem to predict geographically widespread magmatism rather than recurring magmatism at specific sites along the CMB. Alternatively, structural and compositional controls within the continental lithosphere could account for observed magmatic patterns in the CMB.



## NEOGENE AGE OF DECOLLEMENT-STYLE FAULTING IN PERMIAN YESO FORMATION, SIERRA LARGA, SOCORRO COUNTY, NEW MEXICO

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East of Socorro, NM, several east-dipping, normal-separation faults root into a sub-regionally developed low-angle fault system in evaporites of the Permian Yeso Formation (Cather, 2010, NMGS Guidebook). In nearly all known outcrops, the faults of this system cut down-section eastward and excise stratigraphy. This fault system was postulated to be either Laramide or mid-Tertiary but timing constraints are sparse.

Detailed and reconnaissance mapping along the western side of the Sierra Larga shows that the Neogene Bustos fault can be traced north to deeper structural levels where it soles into the Yeso decollement zone. The Bustos fault is an east-dipping, listric normal fault with 1–1.5 km of stratigraphic separation that cuts strata as young as upper Eocene-Oligocene, proving its Neogene age. In at least one place, a fault within the decollement zone cuts an andesitic(?) dike, also suggesting Neogene slip. Several levels of Quaternary terraces overlap the fault so it is probably not Quaternary in age.

Thus, at least the Blackington Hills–Sierra Larga portion of the Yeso decollement system has had significant slip in post-Laramide time, and our current preferred hypothesis is that the Yeso decollement here is mainly a rift-age structure. It is possible that this and other parts of the decollement were active earlier, however, and that the system in the Sierra Larga was reactivated by “capturing” the Bustos fault. It remains unknown whether the Yeso decollement is (1) a rooted fault system that accommodated regional crustal extension east of the Sierra Larga or (2) a superficial, gravity-driven feature that dies out eastward at shallow crustal levels in folds within the Yeso section.

## CENOZOIC INTRUSIVE AND EXHUMATION HISTORY OF THE ELK AND WEST ELK MOUNTAIN PLUTONS, SOUTHWEST COLORADO

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The Elk and West Elk Mountains of southwest Colorado are dotted with Mid-Cenozoic plutons that can provide important geochronological and thermochronological data about the transitional interval between the end of Colorado Mineral Belt (COMB) magmatism and the onset of San Juan volcanic field activity. <sup>40</sup>Ar/<sup>39</sup>Ar biotite and U/Pb zircon geochronology are used to determine intrusion age whereas low temperature apatite fission-track (AFT) and apatite (U-Th)/He (AHe) thermochronology constrain southwest Colorado exhumation. Exhumation patterns provide possible links to present-day low velocity zones in the upper mantle. Intrusion ages (relative to Fish Canyon sanidine at 28.02 Ma with 2 sigma errors) decrease from north to south: Mt. Sopris 34.59 ± 0.12; Capitol 33.96 ± 0.06; Snowmass 33.82 ± 0.04; Marcellina 30.76 ± 0.11; E. Beckwith 29.62 ± 0.11; and Mt. Gunnison 29.78 ± 0.17 Ma and can be broadly grouped into ca. 34 Ma and 30 Ma suites. The AFT ages (Sopris 31.3 – 21.4; Capitol 23.8 – 21.7; Snowmass 28.8 – 17.6; Ragged 31.3 – 15.4; Marcellina 25.7 – 22.4; Beckwith 30.5 – 27.6; and Gunnison 33.8 – 29.0 Ma) and AHe ages (Sopris 12.4 – 9.9; Capitol 11.2 – 8.2; Snowmass 15.0 – 5.8; Ragged 11.6 – 5.6; Beckwith 29.4 – 15.1; and Gunnison 34.6 – 32.0 Ma) for all the transects are either concordant with or younger than their coexisting intrusion ages. An exception is Mt Gunnison, which has AHe ages that are older than the coexisting biotite age. In general, the majority of the plutons experienced slow exhumation that started immediately to 10 Ma after emplacement. However, the two southernmost plutons, Beckwith and Gunnison, underwent exhumation earlier than the northern plutons and at a much more rapid rate. Additionally, the low temperature data for these two plutons is equal within error to their Ar/Ar biotite ages and demonstrate emplacement structurally above the ambient 110°C isotherm. This data and compilation of regional thermochronological results demonstrate highly variable AFT and AHe ages that appear to indicate a pulsed Cenozoic exhumation history. Short wavelength upper mantle velocity variations may correlate to thermal history differences of exposed rock at the 100's of meter scale with the overall low velocity mantle driving dynamic rock uplift and high surface elevation that is not correlated to crustal thickness variation.

## GEOCHEMICAL PARAMETERS THAT INFLUENCE THE DISTRIBUTION OF BACTERIAL COMMUNITIES IN LAVA TUBES IN NEW MEXICO AND HAWAII: A COMPARISON

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Bacterial mats cover walls and ceilings of lava tubes around the world, yet little is known about what controls their species diversity. To address this issue, I and others in my lab group, are asking the following questions: 1) Does diversity vary with respect to the different ages and elemental composition of lava flows in which the lava tubes occur? 2) What is the amount of organic carbon and nitrogen present in the drip water entering the cave system that can fuel heterotrophic microbial growth? To address these questions, rock and water samples were collected from three lava tubes in El Malpais National Monument (ELMA) in New Mexico and from six lava tubes on the Big Island of Hawai'i. Dissolved organic carbon, total nitrogen, and ammonia were measured in infiltrating water. Carbon, nitrogen, phosphorus, manganese, sulfur, iron and other minor elements were analyzed from volcanic rock samples from each lava tube. These data are shedding light on how geological/geochemical parameters influence the diversity of the bacterial communities, which is poorly understood. Examining the different geologic constraints found at each site in New Mexico and Hawai'i will provide a better understanding of the effects these parameters have on bacterial communities found within lava tubes. In a general trend, the composition of the Hawaiian lava cave basalt shows significantly more of the following elements: calcium, magnesium, lead, phosphorus and zinc. Other elements such as cobalt, copper, iron, manganese and sulfur have similar values between Hawaiian and New Mexican lava caves. These results will help to elucidate the role of geology in shaping diversity within caves and the interplay between biology and geology.

## STRUCTURAL, ANISOTROPY OF MAGNETIC SUSCEPTIBILITY (AMS), AND PALEOMAGNETIC INVESTIGATIONS OF A STEEPLY DIPPING, WELDED TUFF (AMALIA TUFF) SOUTH OF PETACA, NEW MEXICO

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An intriguing outcrop of welded tuff is found 40 km WNW of Taos, in north-central New Mexico near the town of Petaca in the Cañada del Abrevadero canyon. The welded tuff outcrop is peculiar for several reasons. Previous geochemical analyses indicate it is correlative to the Amalia Tuff; a distinctive ignimbrite erupted from the Latir volcanic field at 25.1 Ma, the southern margin of which is located about 30 km north of Taos. East of the San Luis Basin, the Amalia Tuff is commonly welded, but in exposures on the west flanks of the basin it is weakly to moderately welded. At the study area, the Amalia Tuff is a light maroon color and strongly welded, with distinctive, flattened pumices (fiame). The second feature is its outcrop geometry, structure, and its stratigraphic relations to surrounding volcanic units. The outcrop extends 75m N-S across the floor of the canyon, is 15-28m in width, and rises up 22-23m on its south wall. The long axes of fiame are orientated NW and the short axis dip steeply (60°-87°) to the W. The outcrop is bounded by rhyolite flows assigned to the 22.5-23.0 Ma Peña Tank rhyolite. We propose three hypotheses to explain its geometry: 1) the welded tuff was steeply tilted due to faulting or folding. This is discounted because no faults or folds have deformed the overlying rhyolites. 2) The welded tuff was carried down in a mega-landslide block, which was less resistant than the Amalia Tuff and later eroded away prior to emplacement of the purplish gray rhyolite flow. 3) The welded tuff formed in-situ within a N-S trending paleovalley, similar to ignimbrites in central Colorado and western Nevada. In order to test the second and third hypothesis we collected fiame orientations and AMS/paleomagnetic samples from 5 sites. Forty-five fiame measurements yield 305-338°, 60-87° SW for most of the outcrop, however, at the north end the orientations are 070-099°, 64-88° N. AMS results yield oblate shaped ellipsoids that mimic the structural data, and are consistent with flattening against the margin of a channel during emplacement. Paleomagnetic analysis is underway and should help further constrain the emplacement. We tentatively interpret these data to indicate that this part of the Amalia Tuff was channelized into a constricted paleovalley allowing it to travel more than 50 km from the eruptive caldera in the Latir volcanic field.

THE EUPELYCOSAUR *DIMETRODON* FROM THE LOWER PERMIAN ABO FORMATION, FRA CRISTOBAL MOUNTAINS, SIERRA COUNTY, NEW MEXICO

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A neural spine from the lowermost Abo Formation (Wolfcampian) is the first recorded occurrence of the eupelycosaur *Dimetrodon* from the Fra Cristobal Mountains of Sierra County, southern New Mexico. The *Dimetrodon* fossil (New Mexico Museum of Natural History [NMMNH] P-40458) was collected from NMMNH locality 5382 at Red Gap, in a conglomerate bed approximately 6 m above the Abo Formation base. The paleoenvironment of Abo strata in the Fra Cristobal Mountains has been interpreted as an inland floodplain. The slender, elongate neural spine is preserved together with its neural arch atop two matrix blocks, where it is visible in right lateral aspect. The distalmost portion of the spine was not recovered. However, its preserved height, measured from the top of the prezygapophyses is 180 mm. At its base, the spine has an anteroposterior length of 14 mm, which narrows abruptly to 9 mm at a shoulder-like constriction, above which it decreases gradually to an anteroposterior length of 4 mm along the remainder of its height. The broken distal edge of the spine is transversely expanded (width = 8 mm), and displays the figure-eight cross sectional outline that is diagnostic of most species of the genus *Dimetrodon*. With a single exception, the oldest records of *Dimetrodon* are known from the Lower Permian Abo Formation, and pertain to small specimens of the genus from inland habitats. Thus, the Fra Cristobal *Dimetrodon* fossil reported here adds to the growing number of *Dimetrodon* records from the Abo Formation of New Mexico, and lends support to the phylogenetic hypothesis that the genus *Dimetrodon* evolved in an upland environment as a predator of small size.

## A RE-EVALUATION OF THE COPROCOENOSIS FROM THE UPPER PENNSYLVANIAN KINNEY BRICK QUARRY, CENTRAL NEW MEXICO

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The Kinney Brick quarry, NMMNH locality 345, in the Manzanita Mountains of central New Mexico is a Lagerstätte that yields a diverse fossil invertebrate, vertebrate and plant biota. The New Mexico Museum of Natural History and Science (NMMNH) has conducted systematic collecting over a 25 year period at the site and has comprehensively sampled all fossils, including coprolites. There are about 30 cataloged Kinney coprolite lots in the NMMNH collection that were first described in 1992. In general, the coprolites are laterally compressed and occur in finely laminated shale.

There are six principal morphologies of coprolites in the Kinney sample. Two specimens are ovoid and consist primarily of conchostracan valves with very little groundmass. About seven specimens are large, thin ovoids (up to 60 mm long) that occur on bedding planes and have little groundmass and much fish debris – similar specimens have elsewhere been described as regurgitalites. Modern sharks occasionally regurgitate material, but there is no clear evidence that such behavior can be demonstrated for fossil fish. Most putative regurgitalites are most parsimoniously interpreted as: (1) disarticulated fish; (2) decomposed coprolites; or (3) coprolites with little groundmass.

About 10 Kinney specimens represent ovoid coprolites of medium size (up to 40 mm long), which are very compact. One morphology of large (70 mm long), elongate coprolite has more three-dimensionality than other forms and is 20 mm thick. Six specimens represent a small, compact, circular-to-ovoid coprolite with a longest dimension of 10-20 mm. Three specimens represent small, linear, ribbon-like coprolites less than 11 mm long. The Kinney coprofauna differs from other Pennsylvanian localities in New Mexico in lacking distinct, spiraled morphologies. The Kinney Quarry yields a large fish fauna. The absence or paucity of spiral coprolites is reflective of the relative scarcity of chondrichthyans and sarcopterygians at Kinney. The conchostracan-rich coprolites may have been produced by acanthodians. The majority of ovoid coprolites at Kinney probably represent palaeonisciforms.

## NEW MEXICO MUSEUM OF NATURAL HISTORY AND SCIENCE AND THE VERTEBRATE COPROLITE RECORD FROM NEW MEXICO

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The New Mexico Museum of Natural History and Science (NMMNH) is unique in that for a quarter of a century it has considered vertebrate coprolites (and other trace fossils) worthy of collection during any field collecting program. Thus, coprolites ranging in age from Pennsylvanian to Pleistocene were collected in association with osteological paleofaunas and also from discrete localities rich in this type of trace fossil. As a result of this work, NMMNH has more than 600 cataloged specimens/lots of coprolites. NMMNH 's collection includes specimens from outside the state, but the majority are from NM. As a result, NMMNH has arguably the best sample of coprolites from any discrete area (state of NM). Other museum collections that include coprolites from NM include the American Museum of Natural History (New York), University of Michigan Museum of Paleontology (Ann Arbor) and Yale Peabody Museum of Natural History (New Haven), but their NM coprolite holdings are few in number.

The Pennsylvanian of NM includes three significant coprofaunas; (1) Kinney Brick Quarry yields non-spiralled, compressed coprolites from laminated shale; (2) Tinajas locality produces dominantly compressed, spiral coprolites from a laminated shale; and (3) Beeman coprolites from the Sacramento Mountains are not compressed and are principally spiral in morphology. Permo-Pennsylvanian and Early Permian coprolites occur in redbeds in north-central New Mexico, many of which are spiral (e.g., *Hyronocopros*). Upper Triassic strata (Chinle Group) across the northern half of NM yield locally abundant coprolites, particularly in Quay County, with notably large samples from Ciniza, Revuelto Creek and Apache Canyon. The Permo-Triassic ichnofaunas from NM have been significant in constructing a biostratigraphy of coprolites for this time interval. The San Juan Basin has yielded Jurassic coprolites from the Todilto Formation and a series of Late Cretaceous and Paleogene coprolites, which is currently the only stratigraphic sample that straddles the K/T boundary. Quaternary cave deposits in New Mexico yield discrete vertebrate coprolites and specimens from pack rat middens. The most significant specimens were found in association with the partially mummified carcass of the Shasta Ground Sloth (*Nothrotheriops shastensis*) in Doña Ana County.

## MIXING BETWEEN AN ALPINE RIVER AND HYDROTHERMAL SPRING : CONTROLS ON WATER QUALITY AND SOLUTE LOADING IN THE JEMEZ RIVER, NM

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Alpine watersheds are increasingly relied upon in the western U.S., requiring a thorough understanding of annual hydrologic patterns and geologic controls on water quality. The hydrogeology of the Jemez River of central New Mexico is characterized by geothermal inputs from the Baca hydrothermal system associated with the 1.2 Ma Valles caldera, as well as groundwater and surface water mixing, fresh surface water input, and dissolution of local carbonates. Fifteen sites along a 35 km reach of the Jemez River were sampled between 2006 and 2010. Discharge ranged from 10-876 cfs over this period. Geochemical data collected include temperature, conductivity, pH, dissolved oxygen, major ions, trace elements, and stable isotopes. Modeling and time series analyses performed using PHREEQC, Geochemist's Workbench, and MATLAB produced a model describing the hydrology and geochemistry of the Jemez system. Results show that geothermal springs are the primary contributors to dissolved load. Solute concentrations spike where the river crosses the Jemez fault system that localizes discharge of hot spring brines from the hydrothermal system. Solute loading from these geothermal inputs is intensified by low flows in the river observed on the annual hydrograph during late winter, and diluted during periods of high flow such as spring runoff and late summer monsoonal rains. Importantly, solute concentrations were found to increase downstream regardless of season. Stable isotope analyses support water chemistry control by geothermal systems, with enriched values of  $\delta^{18}\text{O}$  for thermal waters and near-meteoric values for river waters. Analyses completed during the spring of 2010 indicate that TDS and arsenic exceed EPA drinking water standards at low flows (<30 cfs). This suggests that the Jemez River may be susceptible to unacceptable degradation of water quality under scenarios of decreasing snowpack connected to climate change. Continuous records of temperature, conductivity, pH, and D.O. data collected from a water quality sonde installed in March 2010 also illustrate the effects of discharge fluctuations. Water chemistry of this system directly affects recreational use of the Jemez River and shallow aquifer recharge, and must be considered by communities along the river in planning for domestic and municipal use in the future.



## U-PB ZIRCON AGES AND SR ISOTOPIC COMPOSITION OF PALEOGENE INTRUSIONS AND FLOWS FROM THE SOUTHERN MOGOLLON-DATIL VOLCANIC FIELD, BURRO MOUNTAINS, SOUTHWEST NEW MEXICO

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The northern Burro Mountains exposes Paleogene intrusive and extrusive rocks that are part of the extensive Mogollon-Datil volcanic field (MDVF). Zircons from a granitic pluton, felsic and intermediate dikes, and an intermediate flow from the Burro Mountains, southwest New Mexico, were analyzed for U-Pb ages by Laser Ablation MC-ICP-MS. One of the dated dikes, an andesite porphyry, had plagioclase phenocrysts that were analyzed for Sr isotope compositions using TIMS.

Analyses of 9 plagioclase crystals from the plagioclase-phyric andesitic dike have  $(^{87}\text{Sr}/^{86}\text{Sr})_o$  values from 0.712 to 0.715 when age-corrected to 34.5 Ma. Previously published whole-rock Sr data from other MDVF andesites have lower  $(^{87}\text{Sr}/^{86}\text{Sr})_o$ : 0.706-0.709 (Davis et al., 1993). Assimilation of Proterozoic basement can explain high initial  $^{87}\text{Sr}/^{86}\text{Sr}$  signatures observed in the northern Burro Mountains.

The Hummingbird granite pluton southwest of the Red Rock area was mapped by Hedlund (1978) as Precambrian, but zircon dating yielded a much younger age at  $32 \pm 2$  Ma. A granophyric dike also from the western area was  $\sim 74$  Ma. A plagioclase-phyric andesite dike has a weighted mean  $^{206}\text{Pb}/^{238}\text{U}$  age of  $34.5 \pm 2.6$  Ma and an andesite flow has an age of  $32.8 \pm 4.1$  Ma. The dike cuts the Cretaceous Beartooth Quartzite, and the flow is stratigraphically below rhyolitic ash-flow tuffs. More precise dating of Paleogene dikes and flows will help constrain the timing of the transition from andesite to rhyolite magmatism in the MDVF. The presence of coeval intrusive rocks and tuffs indicates that the deeper levels of the magmatic system were exposed during NW tilting of crustal blocks along Neogene normal faults.

## NEOGENE AND ONGOING DYNAMIC UPLIFT OF THE ROCKY MOUNTAINS DUE TO MANTLE CONVECTION, AND ITS SURFACE MANIFESTATIONS.

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Evidence from the Colorado and Green River systems of the Colorado Plateau suggests that neotectonic mantle flow has driven 500-1000 m of epeirogenic surface uplift and long wavelength surface deformation (tilting and warping) over the last 10 Ma. This amounts to 25-50% of the current elevation of the region. Evidence includes: 1) the correspondence of low seismic velocity mantle with: atypically high (and rough) topography, steep normalized river segments, and areas of greatest river incision in the Grand Canyon and Colorado Rocky Mountains; 2) higher incision rates and magnitudes in the upper Colorado River system relative to the Green River, 3) thermochronologic and geologic data showing a significant increase in regional exhumation rate starting 6-10 Ma; 4) basalt Nd compositions in the western Colorado Plateau that change from lithospheric to asthenospheric during the last 10 Ma; and 5) mantle <sup>3</sup>He degassing concentrated in CO<sub>2</sub>-rich springs overlying low velocity domains. These lines of evidence support convective flow in the last 10 Ma at both whole- and upper-mantle scales, and at >1000 km from the plate margin. The provocative correspondence between mantle anomalies and differential incision of continental-scale rivers offers a promising method for interpreting mantle-to-surface interactions in orogenic plateaus within continental interiors.

## THERMOCHRONOLOGIC CONSTRAINTS ON THE EXHUMATION HISTORY OF THE COLORADO PLATEAU- ROCKY MOUNTAIN-RIO GRANDE RIFT REGION

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A regional compilation of apatite fission-track (AFT) and (U-Th)/He (AHe) data from surface and subsurface samples from the Colorado Plateau/ Rocky Mountain/ Rio Grande rift region reveals a multi-stage, episodic, exhumational history with Laramide (80-40 Ma), middle Cenozoic (35-25 Ma), middle to late Cenozoic (25-10 Ma), and late Cenozoic (<10 Ma) components. Areas with Laramide cooling histories include the Colorado-Wyoming Front Range, the White River and Gunnison uplifts, the Santa Fe Range, the Sierra Nacimiento, the Los Pinos Mountains, monoclines of the Colorado Plateau, and the western margin of the Colorado Plateau (including the western Grand Canyon). Middle Cenozoic cooling is recorded on the High Plains of SE Colorado and NE New Mexico, in the San Juan and West Elk volcanic fields, and in the western Grand Canyon. Areas that cooled in the 25-10 Ma time frame include the Virgin Mountains on the western margin of the Plateau, mountain ranges of the Rio Grande rift, and Laramide basins on the Colorado Plateau. The youngest cooling events are preserved in the upper part of the Colorado River drainage system, on the Monument Uplift, and in the mountain ranges of the central and southern Rio Grande rift.

Cooling ages of 80-40 Ma are preserved in Laramide highlands that were not reheated to  $T > 110^{\circ}\text{C}$  during subsequent tectonic events. Waning of extensive volcanism, elevated heat flow, and modification of crustal density structure following the ignimbrite flare-up (35-25 Ma) is recorded in cooling ages from S Colorado and New Mexico. Buoyancy caused by crustal modification lingered into the 25-10 Ma time frame, enhancing exhumation on the Colorado Plateau and High Plains. Extensional ranges along the margins of the Plateau also exhumed during this time interval. The 5-10 Ma cooling ages in SW Colorado lie above profound low wave-speed anomalies in the uppermost mantle and are interpreted to place an upper bound on the timing of formation of these anomalies.

## STRATIGRAPHY AND SEDIMENTATION OF THE MIDDLE PENNSYLVANIAN RED HOUSE FORMATION, CABALLO MOUNTAINS, SIERRA COUNTY, NEW MEXICO

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In the Caballo Mountains, we studied several sections of the Atokan Red House Formation, which is the basal unit of the Pennsylvanian section locally. At these sections, the Red House Formation thickness ranges from 29 to 49 m, much thinner than reported in the literature. The Red House overlies Mississippian, Silurian, and Devonian strata. Its upper contact is at the base of the first thick, very cherty limestone unit of the overlying Gray Mesa (= "Nakaye") Formation. The Red House Formation is composed of alternating sandstone, shale and covered shale units, and various types of limestone. A distinct facies change is recognized from the northernmost section at Apache Canyon to the southernmost section at Red House Mountain. Sandstone is most abundant in the northernmost section, decreasing towards the south, comprising only 1.7% at Nakaye Mountain and absent at Red House Mountain. Grain size also decreases from north to south, with conglomerates and pebbly sandstones present at Apache Canyon, where two sandstone horizons are present: one at the base and one in the middle of the formation overlying a thin shale-limestone unit. The basal sandstone unit is absent in all sections farther south. The upper sandstone unit is a very distinct horizon that can be traced south to Nakaye Mountain. The thickness and grain size of this sandstone decrease towards the south, and the sandstone pinches out somewhere between Nakaye Mountain and Red House Mountain. As sandstone units are decreasing in thickness, limestone units increase in thickness and abundance towards the south. In the northern part (Apache Canyon-Garfield Crest), individual limestone units are up to 2.6 m thick and limestone comprises 17-36%, whereas in the southern part (Nakaye Mountain and Red House Mountain) individual limestone units are thicker and more abundant, comprising 41-50% of the total thickness. The sandstone horizon in the middle of the Red House Formation displays trough crossbedding, contains plant remains and is interpreted as fluvial, thus marking a distinctive regressive event, probably caused by a tectonic pulse. The facies change within the Red House Formation is a continuation of the interfingering of the Red House Formation with the Sandia Formation farther north--the coarse siliciclastic "Sandia facies" thins southward within the Red House Formation.

## GEOPHYSICAL RECORDS OF ANTHROPOGENIC SINKHOLE FORMATION IN THE LOWER PECOS REGION, EDDY CO., NEW MEXICO

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A significant minority of sinkholes formed in gypsum bedrock in the lower Pecos region are of human origin. These anthropogenic sinkholes are often associated with improperly cased abandoned oil wells, or with solution mining of salt beds in the shallow subsurface. In July, 2008 a sinkhole formed abruptly at the site of a brine well in northern Eddy Co., New Mexico. The well operator had been injecting fresh water into underlying salt beds and pumping out the resulting brine for use as oil field drilling fluid. Borehole problems had prevented the operator from conducting required downhole sonar surveys to assess the dimensions of subsurface void space. The resulting sinkhole formed in just a few hours by catastrophic collapse of overlying mudstone and gypsum, and in less than one month had reached a diameter of 111 m and a depth of ~45 m. Fortunately, a seismograph had been deployed ~13 km southeast of the brine well a few months earlier, and precursor events were captured on the seismograph record a few hours before the subsurface cavity breached the surface. Four months later another sinkhole collapse occurred in northern Eddy Co., again associated with a brine well operation. A third brine well within the city limits of Carlsbad, NM has been shut down to forestall possible sinkhole development in this more densely populated area. Electrical resistivity surveys conducted adjacent to the Eddy County sinkholes indicate the presence of large, brine-filled cavities a few tens of meters deep in the subsurface beneath both sinks.

WALPIA FROM THE EARLY PERMIAN ABO FORMATION OF SOCORRO COUNTY,  
CENTRAL NEW MEXICO,

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We document a new occurrence of *Walpia* White, 1929, an invertebrate ichnogenus that has not previously been reported from New Mexico. The specimen (New Mexico Museum of Natural History, NMMNH P-63036) is from NMMNH locality 8278, which is in the upper part of the Early Permian (Wolfcampian) Abo Formation (Cañon de Espinoso Member) of the Cerros de Amado area in Socorro County. NMMNH P-63036 consists of several horizontal burrows preserved in positive epirelief on a slab of reddish-brown, very fine grained sandstone. The burrows display raised nodular margins and an open medial depression. The medial depression is irregularly filled by nodules in some few places along the burrow courses. The nodules are smooth, rounded, 1-3 mm across, and identical in composition to the surrounding matrix. The burrows are 1-2 mm below the bedding surface, and burrow widths are typically about 10 mm. The burrow courses are mostly straight with gentle curves, and maximum burrow length is 19 cm. Branching and intersecting of burrows are seen. The upper surface of the specimen slab shows, in addition to the burrows, incipient desiccation cracks and small, subhorizontal root traces.

The Abo Formation material differs from the *Walpia* type material of the Early Permian Hermit Shale of the Grand Canyon, Arizona, by displaying a medial depression. We therefore provisionally assign the burrows to *Walpia* cf. *W. hermitensis* pending further study. *Walpia* is a monospecific, poorly known, and rarely reported ichnotaxon that is probably the shallow foraging burrow of an early beetle. There is a range of morphological variation within *Walpia*, such as the medial depression seen in the Abo Formation burrows, which was not recognized in the original diagnosis. It is therefore important to document any new records of *Walpia*.

## **MINERALOGIC STUDY OF MORTAR FROM FORT UNION RUINS, MORA COUNTY, NEW MEXICO**

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Fort Union National Monument, located in the Mora Valley in northeastern New Mexico, features the ruins of the Fort Union military post and ruts of the Santa Fe Trail. At the request of the National Park Service, we studied mortar samples from the ruins in order to characterize their mineralogy and assess if the materials came from a local geologic source. The samples are pale colored, brittle, and porous (averaging 18%). They contain 1.0-3.0 mm lithic fragments embedded in a very fine-grained calcite-clay matrix. Each mortar sample contained approximately 40% quartz grains. The quartz is 0.25-0.50 mm in size, rounded to subangular in shape, and coated with iron oxide. Half of the quartz population showed straight extinction and half the population showed undulatory extinction. Other major phases included 15% lithic fragments (polycrystalline quartz, quartz arenite, and micrite) and 2% opaque grains. Accessory (<1%) minerals included fine-grained microcline, hornblende, biotite, and muscovite. Low-field susceptibility versus temperature experiments yielded a very narrow spectrum of response, indicating the presence of a low-Ti ferrimagnetic (s.l.) mineral phase, likely low-Ti titanomagnetite, within the mortar samples.

The major mineral phases identified in the mortar samples are non-unique. They are the most common rock-forming minerals in the region's sedimentary rock formations. In particular, the quartz-rich Cretaceous Dakota sandstone is a likely source for the abundant quartz grains and quartz-rich lithic fragments. The Graneros shale and the Greenhorn Limestone are probable sources for the calcite-clay matrix and calcareous lithic fragments. While the mortar mineralogy does not point to a specific geologic outcrop for resource procurement, the similarity in terms of percentages of phases present among the mortar samples suggests that the raw materials were obtained from the same location(s). A larger sample set is needed to confirm this hypothesis and to make conclusions about resource procurement for the construction of the Fort Union compound.

## PETROLOGIC STUDY OF THE CIENEGUILLA BASANITES, SANTA FE COUNTY, NEW MEXICO

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We initiated a petrogenetic study of the 25-26 Ma Cieneguilla basanites at Cerro Seguro and another unnamed vent in the southern Española Basin, Santa Fe County, to improve our understanding of early Rio Grande Rift magmatism. These small-volume poorly bedded monogenetic centers erupted through Eocene sedimentary rocks, Oligocene intrusive stocks, and Oligocene volcanic rocks, some of which are related to a north trending chain of volcanic centers of monzonitic-latic activity that includes the Cerrillos Hills and Ortiz Mountains. The Cieneguilla basanites are olivine porphyritic, magnetic, slightly vesicular, and relatively unweathered. These samples contain mildly to moderately altered olivine phenocrysts in a fine-grained intergranular olivine-orthopyroxene-magnetite-plagioclase matrix. Rock magnetic experiments conclude that two distinct Fe-Ti oxide phases are responsible for the rocks' magnetic character. The Cieneguilla basanites are mildly alkaline and fall within the sodic series of the alkali olivine basalt scheme. They have low silica values (42.4-44.1 weight percent) and high MgO values (11.5-13.5 weight percent) and are some of the most primitive eruptive products in the central Rio Grande Rift. They are sufficiently mafic that their incompatible trace element compositions are controlled mainly by their mantle source region(s). The basanites are enriched in the light rare earth elements relative to the heavy rare earth elements (La/Yb)<sub>N</sub>=18-26. Chondrite-normalized trace element patterns show a strong enrichment in most incompatible elements, but marked depletions in K and Rb relative to light rare earth elements, Nb, Ta, and Th. These are characteristics of strongly silica-undersaturated ocean island basalts (OIB). The basanites have (La/Nb)<sub>N</sub> values 1.2-1.5, which are also characteristic of OIB. The Cieneguilla basanites have high Ta/Ba and Nb/Ba ratios which are interpreted as originating from either an OIB-like asthenospheric mantle or an OIB-modified lithospheric mantle.



## PETROLOGY AND AGE OF THE SALINAS PEAK SILL, NORTHERN SAN ANDRES MOUNTAINS, SOUTH-CENTRAL NEW MEXICO

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Salinas Peak is the highest (2,733 m) and most prominent (1,105 m relief) peak in the San Andres Mountains. Bachman and Harbour (1970) show that the peak is the thickest part of a sill (490 m thick) made up of microgranite or alaskite. The sill extends at least 7.4 km to the north and 10.8 km to the southwest of the peak. The underlying Paleozoic rocks and contact with the Proterozoic rocks are dipping to the west-northwest about 12 degrees whereas the overlying Paleozoic rocks above the sill dip to the west as much as 24 degrees.

Two specimens of the sill were taken from exposures along the road to the top of Salinas Peak—one from a road cut excavated in jointed rocks about 5 m below the weathered ground surface and a second exposure at the top of the peak. Despite sampling what appeared to be the least weathered rocks in the road cut, the microgranite looked somewhat altered and many of the borders of the joints exhibited liesegang oxidized iron staining. The specimen from the top of the peak had megascopic (2-3 mm in diameter) muscovite that provided a good candidate for  $^{40}\text{Ar}/^{39}\text{Ar}$  age determination.

Backscattered electron (BSE) images acquired during electron microprobe analysis of the road-cut sample show a typical igneous texture of uniformly fine-grained size of 100 microns or less. The sample is composed of an equigranular mix of quartz, feldspar and mica. The feldspar is dominantly potassic feldspar (orthoclase) with minor Na-rich plagioclase (albite). A fine-grained micaceous phase is ubiquitous throughout the sample. Much of this phase appears altered, although some fresh-appearing mica is also present. That the sample has undergone some alteration is reinforced by the presence of calcite, which appears to be replacing orthoclase in some areas of the sample. Quantitative chemical analyses performed on both fresh-appearing and altered areas of the micaceous phase yield a muscovite composition that is chemically essentially identical. The difference appears to be that the altered mica is slightly more hydrous, suggesting that although alteration has added some water to the mica structure, the major cation chemistry of the mica is essentially unchanged.

Large, fresh muscovite yielded a well defined  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau age of  $34.45 \pm 0.04$  Ma that is interpreted to record the age of intrusion. Whole-rock  $^{40}\text{Ar}/^{39}\text{Ar}$  analysis yields a disturbed age spectrum with a younger bulk age of  $31.49 \pm 0.12$  Ma that likely records argon loss related to deuteric alteration within the cooling sill or later subsurface weathering adjacent to joints from infiltrating meteoric water.

Bachman, G.O., and Harbour, R.L., 1970, Geologic map of the northern part of the San Andres Mountains, central New Mexico: U.S. Geological Survey, Miscellaneous Investigations Map I-600.

## QUATERNARY STRATIGRAPHY AND PALEONTOLOGY EXPOSED ALONG SALT CREEK, NORTHERN TULAROSA BASIN, SOUTH-CENTRAL NEW MEXICO

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Salt Creek drains the southern Oscura Mountains, Mockingbird Gap Hills, and northern San Andres Mountains southward to Big Salt Lake (playa), and rarely to Lumley Lake (playa). Salt Creek is perennial in an upper reach due to base flow, and is home to one of two endemic populations of White Sands pupfish (*Cyprinodon tularosa*) in the northern basin. Although incision of the valley of Salt Creek into older basin fill and through intermediate terraces is subtle, local exposures of cross-cutting relationships, stratigraphy, and paleontological remains allow interpretations of the valley's Quaternary geologic history.

Tularosa Basin fill consists of many layers of reddish brown fine-grained alluvium, channels of pebble gravel and pebbly sand, and gypsiferous layers of pedogenic, eolian, and spring-evaporite origins. This Quaternary fill locally contains megafauna trackways and one known fragmentary proboscidean tusk. Some coarse-grained channels are exposed as meandering ridges in deflated blowouts south of 33°13'.

Inset below the top of the basin fill are several discontinuous terraces capped with pedogenic gypsum crust containing reworked pebbles from the basin fill. Inset below these terraces is a longitudinally wide-spread dark brown, gray, and reddish-brown fine-grained unit of thinly bedded and crossbedded alluvium. Where this unit is exposed due to lateral stripping of overlying alluvium, megafauna trackways are evident. A partial articulated skeleton of the late Pleistocene and early Holocene bison *Bison antiquus occidentalis* was recovered from this alluvium. Very tiny hydrobiid snail shells and fish scales are found in this unit downstream from the bison locality.

Overlying this unit south of 33° 17' is thicker-bedded reddish brown fine-grained alluvium and local cross-cutting pebbly channels containing two extinct members of Pleistocene megafauna, the horse *Equus conversidens* and the camel *Camelops hesternus*. An extensive marsh covering an area more than 50 km<sup>2</sup> deposited up to 3 m of gypsum above the alluvium. This marsh contains the aquatic snails *Planorbella* and *Stagnicola*, scales and bones of small fish and aquatic microorganisms. Three radiocarbon ages from vegetal remains and ostracode valves date this marsh from 10,900 to 10,160 radiocarbon years before present.

Salt Creek entrenched through this marsh and the underlying alluvium as much as 12 m. Entrenchment followed deflation of extensive blowouts and playas at the down-stream end of Salt Creek (e.g. Big Salt Lake) during Holocene time. At least two intermediate levels of alluvial terraces mark still-stands in erosion in both the blowouts and Salt Creek.

## A NEW LOCALITY FOR VERTEBRATE COPROLITES FROM THE BEEMAN FORMATION (UPPER PENNSYLVANIAN), SACRAMENTO MOUNTAINS, NEW MEXICO

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New Mexico has an important record of Late Pennsylvanian coprolites from the central portion of the state (Kinney Brick quarry, NMMNH locality 345; Tinajas locality, NMMNH locality 8042). A third, new, significant locality for vertebrate coprolites, NMMNH locality 3276, occurs in a road cut of NM Highway 82 that exposes strata of the Missourian Beeman Formation in the Sacramento Mountains in the southeastern portion of the state. The majority of coprolites from this locality are large in size (up to 5 cm long) and spiral in form. The coprolites are three-dimensional, relatively undeformed and readily separable from the matrix. In contrast, the Kinney coprolites are compressed and occur in finely-laminated shale, whereas the Tinajas specimens represent an intermediate condition, with more three-dimensionality, although they also occur in laminated shale.

Approximately five morphotypes are represented in the Beeman coprofauna. Type one coprolites are macrospiral heteropolar in form and resemble *Liassocopros*, but they differ from the Mesozoic genus in being narrower and proportionally more elongate. Type two coprolites are heteropolar in morphology. They resemble the Permian ichnotaxon *Hyronocopros*, but some examples are more spindle-shaped with more acute tips than is typical of *Hyronocopros*. Type three coprolites are macrospiral heteropolar and appear to represent *Heteropolacopros*. Type four coprolites are conical in shape with spiral structure visible in cross section. Type five coprolites are poorly preserved but represent another spiral form. There are a few poorly-preserved coprolites that could be non-spiral.

The Beeman coprofauna is important in providing an important transition between the coprofaunas of the earlier Upper Paleozoic, which mainly consist of compressed specimens from laminated shales, and the abundant three-dimensional coprofaunas of the Early Permian. The ichnofauna is distinctive in that virtually all the coprolites are spiral in form. Although no fish fauna is known from the Beeman Formation, the majority of the Beeman coprolites are spiral, so they likely represent chondrichthyans with helical anal valves.

## PENNSYLVANIAN SECTION IN THE ROBLEDO MOUNTAINS, DOÑA ANA COUNTY, NEW MEXICO AND ITS PALEOGEOGRAPHIC SIGNIFICANCE

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The Pennsylvanian section exposed on the northern end of the Robledo Mountains (secs. 34-35, T21S, R1W) has not been assigned to a lithostratigraphic unit(s), but instead has been identified by the chronostratigraphic terms Atokan, Desmoinesian, Missourian, Virgilian and "Bursumian." This section rests on a Cenozoic rhyolite sill, is ~ 420 m thick and is interbedded limestone and shale with a few thin beds of conglomerate. The lowermost Pennsylvanian beds have been termed Atokan without age evidence. The lower 82 m is mostly thick-bedded, cherty limestones that yield the Desmoinesian fusulinid *Wedekindellina*. A change to red shale with nodular limestone and thin conglomerate marks the Missourian base. Overlying Upper Pennsylvanian strata form upward shallowing cycles in which the cycle boundaries are marked by conglomerate beds or by thin, pedogenically-modified, rhizolithic horizons at the tops of limestone beds. Thick-bedded, cherty limestones at the base of the Hueco Group (Shalem Colony Formation) overlie the cyclic Upper Pennsylvanian section. Significantly, the Robledo Pennsylvanian section is very different (especially the post-Desmoinesian part) from that exposed in the Caballo Mountains only 60 km to the north. Instead, except for being relatively thin, the Robledo Pennsylvanian section closely resembles the Horquilla Formation in southwestern New Mexico, especially that at New Well Peak (Big Hatchet Mountains). We thus assign the Robledo Pennsylvanian section to the Horquilla Formation and interpret it as shelfal strata in which glacio-eustatic cycles, not local tectonism, significantly drove sedimentation. This casts doubt on the idea that the Robledo Pennsylvanian section, deposited on the western (Robledo) shelf of the Orogrande basin, was significantly separated from the Pedregosa basin to the southwest by an intervening Florida uplift (highland). Instead, the original idea of the Florida "islands" (shelf) - an archipelago and shallow shelf separating the Orogrande and Pedregosa basins - is more compatible with the stratigraphic data. Subsidence in the Pedregosa basin and along the Florida shelf was relatively even, so that glacio-eustatic cycles are better recorded in these sections than in the more tectonically-influenced sections of the Orogrande basin to the east.

DIMETRODON (EUELYCOSAURIA: SPENACODONTIDAE) FROM THE LOWER PERMIAN ABO FORMATION, SOCORRO AND TORRENC COUNTIES, NEW MEXICO

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Abstract-Here we add to the sparse record of Dimetrodon from New Mexico documenting three specimens collected from two known Lower Permian Abo Formation vertebrate fossil localities which had not previously yielded the taxon. These are diagnostic (figure-eight cross-section) neural spine fragments from the Gallina Well locality in the Joyita Hills, Socorro County and the Abo Mine locality (Scholle Copper Mine) near Abo Pass, Torrence County. The Gallina Well locality was 140 km north of the nearest Early Permian shoreline (near Las Cruces), and the Abo Mine locality was approximately 170 km north of the shoreline. These records are all of relatively small Dimetrodon, which may be better suited to fully inland and "upland" environments. Low stratigraphic positions (Virgillian-Wolfcanpian) of Dimetrodon from New Mexico indicate that diminutive size and a fully terrestrial habitat are primitive characteristics of the genus, with larger size arising as a secondary adaptation to deltaic environments.

## CORRELATION OF OLIGOCENE ASH FLOW TUFFS OF THE BELL TOP FORMATION USING LASER-INDUCED BREAKDOWN SPECTROSCOPY

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Ash flow tuffs represent important marker beds for many types of research, including volcanology, tectonics, archeology, and soil science. Traditional methods for tuff correlation include mapping, mineralogy,  $^{40}\text{Ar}/^{39}\text{Ar}$  age determinations of phenocrysts, and paleomagnetism. Laser-Induced Breakdown Spectroscopy (LIBS) is a relatively new laser ablation technique that can be used to correlate ash flow tuffs by comparing the chemical composition of phenocryst phases. In LIBS, a high-power pulse of laser light ablates and excites ions in a short-lived, high-temperature plasma. As electrons decay to lower-energy orbitals during cooling, they emit light which is collected by a lens or telescope, transmitted to a spectrometer by optic fiber, and diffracted to form a spectrum. Each LIBS spectrum contains information on elemental concentrations for essentially the entire periodic table, forming a detailed chemical fingerprint. Backpack LIBS systems are being designed; in the next few years, geologists will be able to correlate tuffs in the field using this new technology.

In the current study, ash flow tuffs of the Bell Top Formation in southern New Mexico were analyzed by LIBS. Samples of each tuff were collected from at least two different areas. For each sample, 200 LIBS spectra were collected from sanidine and biotite phenocrysts as well as from the whole rock. Using the multivariate technique Projection to Latent Structures (PLS), the spectra from one area were used to train a model to uniquely identify each tuff. The identities of the same tuff units from a different area were then predicted by comparing their spectra to the PLS model. Predictions based on whole-rock and biotite spectra were not successful. However, predictions based on sanidine spectra correctly identified the ash flow tuff units in all cases. Sanidine is the mineral of choice, similar to  $^{40}\text{Ar}/^{39}\text{Ar}$  analysis, because it is more resistant to alteration than biotite and volcanic ash.

## INFLUENCE OF PEDOGENIC CARBONATE ON THE PHYSICAL AND HYDROLOGIC PROPERTIES OF A SEMI-ARID SOIL

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Calcic horizons are ubiquitous features of semi-arid-to-arid soils. The accumulation of calcium carbonate over time produces systematic morphological and textural changes in the soils described as stages of calcic horizon development. These changes in soil properties influence the partitioning of precipitation into infiltration and runoff in semi-arid environments. The calcium carbonate arrives at the soil surface along with dust (primarily silt and clay) so there is also a systematic increase in the silt and clay content of semi-arid soil with time. There has been no systematic study of the impact of increasing amounts of calcium carbonate on the hydrologic properties of semi-arid soils.

This study describes some of the changes in hydrologic properties associated with increasing amounts of calcium carbonate. Three surfaces in Sevilleta National Wildlife Refuge were located to carry out the analysis. Physical and hydrologic properties from three soil profiles of different ages and stages of carbonate development were gathered. Soil textures, total carbonate content, and bulk densities were measured for each horizon. In situ measurements of soil hydraulic conductivity were taken at every soil horizon using a tension disk infiltrometer. The amount and morphology of the calcium carbonate, and thus the hydraulic properties, varied with soil depth for each of the soils. The calcium carbonate cements soil particles changing the apparent texture of the soil horizon and thus other soil properties such as structure, porosity, moisture retention, and unsaturated and saturated hydraulic conductivity also change significantly. The ultimate goal of this study is to provide a basis for developing more accurate pedotransfer functions, which is the main method for obtaining soil hydrologic properties of rangeland soils.

## DYNAMIC TOPOGRAPHY OF THE GREAT PLAINS: EVIDENCE FROM FLUVIAL INCISION AND EXHUMATION IN NEW MEXICO AND COLORADO

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Fluvial incision data from the Great Plains of New Mexico and Colorado show differential incision across broad (50-100 km) convexities, suggesting that the region's bedrock channel systems are in a period of adjustment to a regional-scale perturbation. Some incision data implicate hard bedrock knickpoints, but regional trends point to transient incision signals due to headwater uplift (or equivalent base level fall). Multiple datasets are currently available with which to address the controls on this phenomenon: (1) normalized channel steepness index ( $k_{sn}$ ) analysis used to identify anomalously steep river slopes has revealed a spatial pattern of non-equilibrium stream profiles in the region, (2)  $^{40}\text{Ar}/^{39}\text{Ar}$  ages on basalt-capped surfaces of the Raton-Clayton volcanic field show an onset of more rapid exhumation on the Great Plains starting at about 3.6 Ma, and (3) apatite fission-track data also indicate differential exhumation through time, with moderate rates beginning in the Oligocene followed by more rapid exhumation in the last 5 Ma. These datasets are suggestive of neotectonic uplift and we have used them in combination with new mantle tomographic images from the EarthScope experiment to identify possible dynamic topography above a well-imaged zone of low velocity in the upper mantle (the Jemez anomaly). The spatial patterns evident in the incision and exhumation data correspond to mantle velocity structure and therefore suggest mantle-driven controls on surface modification are at work on the Great Plains. This conclusion may be an important component to understanding the development of late Cenozoic relief across the western U.S. orogenic plateau and may also help constrain rates and processes of neotectonic mantle flow.



## HYDROLOGIC INVESTIGATION AT WHITE SANDS NATIONAL MONUMENT

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The White Sands National Monument (WNSA), located within the Tularosa Basin in southern New Mexico, occupies a portion of the world's largest gypsum dune field. The beauty and uniqueness of the dunes along with the numerous plants and animals that have adapted to this strange environment make the monument a valuable natural resource. Within the dune field, depth to groundwater in inter-dunal areas is generally less than three feet below the surface. This shallow groundwater system, which stabilizes the base of the dunes, is thought to be one of the primary controls on the location and extent of the dune field. There is concern that a lowering of the local water table as a result of an increase in groundwater pumping and surface water diversions in surrounding areas may be detrimental to the preservation of the dune field. Therefore, the water sources that recharge the shallow aquifer within the dunes and the degree of connectivity between the shallow and deeper aquifers are of special interest.

The NM Bureau of Geology and Mineral Resources is conducting a hydrologic study at WNSA to investigate these areas of interest by using a variety of hydrologic, geochemical and geophysical techniques. Continuous water level measurements in monitoring wells within the sand dunes respond quickly to individual storm events, indicating the occurrence of local recharge within the dunes. The infiltration of local precipitation through the dunes to recharge the shallow aquifer is also indicated by water chemistry data, and observed hydraulic gradients in the vadose zone. However, electrical resistivity data suggests that the contribution of local recharge within the dunes is small compared to the relative contribution(s) of one or more additional sources. These other water sources are highly brackish waters that probably represent regional groundwater coming from the north and/or east. Additional chemistry, isotope and age dating data will help us to identify other recharge end members and calculate mixing ratios. Future work also includes the installation of wells that penetrate the basin fill below the dune field. These wells will be used to administer a pumping test to evaluate the connectivity between the shallow and deeper aquifers.

# REGIONAL SPRING SURVEY IN THE CIBOLA NATIONAL FOREST: A GEOCHEMICAL COMPARISON OF SPRINGS IN DIFFERING ENVIRONMENTS FROM ALPINE WILDERNESS TO THE HIGH DESERT

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In the arid southwestern U.S., springs and their associated wetlands play an important role in sustaining diverse ecosystems. Due to increasing encroachment, multiple-use requirements, increasing groundwater depletion, as well as climate change, a better understanding of how the springs function is needed in order to properly manage the springs as a resource. Critical data on spring status (discharge patterns across seasons and water quality) are lacking for most springs. Systematic protocols for spring monitoring are needed and new strategies and environmental sensors can be employed to provide baseline information, as well as continuous data.

We report here on a systematic evaluation of a suite of springs of the Cibola National Forest in Central New Mexico including discharge and water quality. Springs in three different regions (Bear Mountains, Sandia Mountains, and Zuni Mountains) of the Cibola National Forest are being surveyed. The springs vary in many characteristics including a wide range of elevation (2000-2500), vegetation type (high desert to alpine wilderness), average annual precipitation (11-22 inches), impact (livestock use, increased groundwater withdrawal, species of concern, and increased recreational and residential use), and water quality (potable to saline). The geologic setting and associated geologic structures also differ in each region and these affect characteristics of the different aquifers. The survey is being conducted following two separate levels of protocols: Level One for developing a baseline survey for water quality in managed lands (geospatial data, geologic map, systematic photography, discharge estimate and field-determined water quality parameters); and Level Two Impact Evaluation Monitoring (includes high-resolution geologic mapping, major ion chemistry, multiple sampling dates, and real-time autonomous logging of several parameters including temperature, pH, conductance and dissolved oxygen). Data collected from the surveys are stored in a geospatial repository to serve as background for future monitoring of the water resources in the area. In addition to other motivations, the work is prompted by concerns about preservation of vital habitat for the Zuni Bluehead Sucker, as well as other native species in the Cibola National Forest.

COMPARISON OF EARLY EOCENE SAN JUAN BASIN, NM *PHENACOLEMUR JEPSENI* WITH *PHENACOLEMUR CITATUS* AND *PHENACOLEMUR PRAECOX* FROM BIGHORN BASIN, WY -A STUDY OF THE VARIATION AND VALIDITY OF THESE *PHENACOLEMUR* SPECIES

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*Phenacolemur* was a late Paleocene-early Eocene paromomyid plesiadapiform from western North America and Europe. Several species are distinguished by differences in size and subtle differences in tooth morphology. There are questions regarding the validity of at least one species, *P. jepseni*, a taxon originally named from the early Eocene of NM. Some workers have suggested that *P. jepseni* is a junior subjective synonym of *P. citatus* or *P. praecox*. Specimens from the Bighorn Basin are purported to show a continuum in size and morphology that overlap with samples of *P. jepseni* from NM. There are a limited number of *P. jepseni* teeth collected. However, by looking at the larger collections of *P. citatus* and *P. praecox*, I have compared trends using metric data and physical morphology. These results show patterns and variations between the three closely related species. Statistical analyses indicate these three species to be distinct, yet highly variable, with characteristics that show intermediate stages between samples. Morphologically *P. jepseni* specimens are smaller, lack a paraconid on m2 (present on *P. citatus* and *P. praecox*), and have an upper canine not seen in other *Phenacolemur* species. With these results, I argue *P. jepseni* is a valid species.

*Key words: Phenacolemur, Eocene plesiadapiform, San Juan Basin NM, Big Horn Basin WY, upper canine, paromomyid morphology*

## GEOCHRONOLOGY, GEOCHEMISTRY AND TECTONIC OCCURRENCE OF LARGE TRAVERTINE DEPOSITS IN NEW MEXICO AND ARIZONA

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New Mexico and Arizona host several large travertine deposits (>20-60 km<sup>2</sup> with thicknesses ranging from 15 to more than 60 m) that provide a record of significant natural fluxes of CO<sub>2</sub>. Studies of these geologic natural CO<sub>2</sub> leakages are important for carbon sequestration studies. Active CO<sub>2</sub> springs provide modern analogs for water/gas compositions and fluxes while ancient travertine deposits offer a unique tool to better understand past CO<sub>2</sub> fluxes in the context of paleohydrology, paleoclimate, and tectonics. Volume estimates based on stratigraphic studies, drilling and GIS are used to calculate the flux of CO<sub>2</sub> that lead to the formation of large volume travertine deposits. Precise new U/Th dating and stable isotope analysis are underway for large travertine platforms at Mesa del Oro, NM (>20 km<sup>2</sup>), Riley, NM (North and South Mesas, >60km<sup>2</sup>), Mesa Aparejo (Belen Quarries), NM (>20 km<sup>2</sup>), and Springerville, AZ (>30 km<sup>2</sup>). At Mesa del Oro, NM, new ages for the travertine deposits are 56 ka, 253 ka, 361 ka and more than 500 ka. U/Th dates from Springerville, AZ, show that major travertine accumulations also occurred over several time intervals: 36-100 ka, 200-280 ka and 300-350 ka. At Mesa Aparejo, uppermost travertines are 350 ka, most of the occurrence is >500 ka. Stable isotope analyses from Mesa del Oro and Riley, NM, and Springerville, AZ, overlap substantially - they exhibit high δ<sup>13</sup>C values, +2.0‰ to +8.3‰, and δ<sup>18</sup>O values ranging from -13.5‰ to -4‰. U/Th and stable isotope data done to date, combined with field settings show that travertine deposition at all of the these localities (Mesa del Oro, Riley, Mesa Aparejo and Springerville) overlapped temporally and indicate CO<sub>2</sub> leakage over much of the Quaternary. The accumulation of large volumes of travertine was not steady, but rather was episodic, with largest volumes forming 50-120 ka, 200-250 ka and 300-350 ka. Preliminary conclusions are that these intervals coincide with wet times, hence the travertines may provide detailed records of climatic fluctuations. From modern analogs we know that CO<sub>2</sub> gas leakage is probably orders of magnitude larger than CO<sub>2</sub> trapped as travertine (i.e., trapping efficiencies are low). Our goal is to continue to refine flux estimates based on additional mapping/stratigraphy and geochronology.

USING FALLOUT RADIONUCLIDE TRACERS TO ASSESS THE EFFECTIVENESS OF SOIL CONSERVATION STRATEGIES, SOIL JORNADA BASIN LTER , SOUTHERN NEW MEXICO, USA

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Historically, dominant grassland communities have been displaced by woody shrubs over the last 150 years in the Jornada Basin, southern New Mexico. As shrubs invade semi-arid perennial grasslands, the length, number and arrangement of connected bare patches increase which creates transport corridors. Increased growth and coalesces of these connected pathways overtime can result in a nonlinear increase in soil loss and redistribution by wind and water erosion. Implementing remediation strategies that disrupt the growth of these connected transport pathways is a potential soil conservation strategy that can lessen the harmful effects of desertification. Small-scale manipulations were conducted in two high sediment transport environments positioned on a wind erosion dominated landform (e.g. Basin floor) and a water erosion dominated landform (e.g. Bajada). Sediment retention structures were deployed on each landform unit in highly eroded unvegetated gaps. Fallout radionuclide tracers (<sup>210</sup>Pb<sub>ex</sub>, <sup>137</sup>Cs, and <sup>7</sup>Be) were used to derive sediment budgets and to quantify the effect of the structures on soil redistribution rates by wind and water transport. Preliminary results, based on sediment budgets reconstructed from fallout radionuclide inventories, indicate that sediment retention structures are more efficient in modifying soil redistribution in wind dominated systems when compare to water dominated systems.

## RUNOFF AND SEDIMENT YIELD IN CONTRASTING VEGETATED HILLSLOPES OF A FIRST ORDER BASIN IN CENTRAL NEW MEXICO

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As part of a project to determine the influence of hillslope aspect and vegetation cover on the evolution of a drainage basin, paired canopy and intercanopy runoff plots were deployed on two opposing hillslopes with clear vegetation contrasts and quasi-exact north facing and south facing aspects. The opposing hillslopes are located in a small first order semi-arid basin in the Sevilleta National Wildlife Refuge and exhibit sharp vegetation differences with juniper/grassland on the north facing slope (NFS) and creosote/grassland on the south facing slope (SFS). A total of eight plots were installed to measure the total runoff and sediment yield under different ground cover types and slope positions. At each slope four plots were distributed in pairs at two different elevations. Each plot-pair is arranged with a canopy covered plot (with a Juniper canopy for the NFS and Creosote canopies for the SFS) and an intercanopy plot partly covered by grasses. The objectives of this study were to determine the effects of ground cover, hillslope aspect and slope position on runoff and sediment yield. The results show higher and more frequent runoff discharges for the SFS, rendering higher sediment yields than the north-facing counterpart. Furthermore, higher sediment yields were observed in the upper slope positions of both north and south facing slopes. Similarly, three out of the four plot pairs show higher sediment yields for the pair member under canopy conditions. The results on runoff and sediment movement provide an insight on the influence of hillslope aspect and vegetation coverage, and the feedback relationships between climate-vegetation-soil and erosion that conducts the basin evolution. The results of this study will assist in land management decisions on semiarid areas.

# PRELIMINARY GEOLOGIC MAP OF THE GILA HOT SPRINGS QUADRANGLE, CATRON AND GRANT COUNTIES NEW MEXICO

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The Gila Hot Springs 7 ½ minute Quadrangle is located in the southeastern part of the Mid-Tertiary Mogollon-Datil volcanic field at the eastern edge of the Gila National Forest and the Gila Wilderness. The quadrangle provides access to the Gila Wilderness and the Gila Cliff Dwellings National Monument via NM highways 15 and 35 from Silver City via Pinos Altos and Mimbres, respectively.

The West, Middle and East Forks of the Gila River join within the quadrangle and exit the southwestern corner of the quadrangle through the main Gila River canyon. The principal geologic features within the quadrangle include: 1) the Gila Hot Springs graben, which is the locus of several hot springs and geothermal wells that have been developed for recreational and domestic use. 2) a segment of the eastern wall of the Gila Cliff Dwellings caldera, which is exposed along the Gila River at the Melanie hot spring about 1 ½ miles below the confluence of the East Fork. 3) the Alum Mountain eruptive center of the Copperas Creek volcanic complex, which is overlapped by younger rocks, including Bloodgood Canyon Tuff, which fills the Gila Cliff Dwellings caldera.

Gila conglomerate fills the Gila Hot Springs graben, and is the host formation for the cliff dwellings, which are just west of the Gila Hot Springs quadrangle, along the West Fork of the Gila river.

## CROSS-SECTION RESTORATION FROM LADRON PEAK TO THE JOYITA HILLS AND INVESTIGATIONS OF THE TIMING AND MECHANISMS OF LOW-ANGLE NORMAL FAULTING IN THE RIO GRANDE RIFT

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Our goal is to understand the extent, timing, and mechanisms of formation of low-angle normal faults in the Rio Grande rift, with initial focus on the Jeter fault system. Fault plane lineations from the Jeter fault system indicate a slip direction oriented toward 150°. We constructed a movement-plane cross-section from the summit of Ladron Peak along the western margin of the rift, through the Joyita Hills mid-rift horst, to the Los Piños eastern rift flank. The cross section shows the low-angle Jeter fault (<35°) and < 20° normal faults in Joyita Hills. Estimated percent extension is about 35%.

Apatite fission-track cooling data from age-elevation transects of the east ridge of Ladron Peak and in Joyita Hills were projected onto the cross-section. AFT data are interpreted here to record a polyphase extensional unroofing of Ladron Peak, with the eastern ridge unroofing from 18-10 Ma. Additional apatite helium dating is underway to refine the lower temperature cooling history.

Four mechanisms for formation of the low-angle faults are considered and may have worked in concert. 1) Initiation and slip along flat normal faults is possible in very weak horizons, which may explain low-angle faults in nearby regions with detachments in salt horizons, but the Jeter and Joyita Hills low-angle faults cut basement and other strong lithologies. 2) Domino-style passive rotation of both faults and bedding from initial ~60° fault dip explains normal fault networks in the Lemitar Mountains to the south, but existing mapping does not show the Jeter system to have the necessary fault system geometry of tilted crustal blocks and overprinting of faults. 3) The rolling hinge model implies that as the hinge migrates into the hanging wall, isostatic uplift rotates older steep faults to lower angle and causes them to become mechanically unfavorable for slip. 4) Observed surface uplift of 1.75 mm/yr over the last few decades could accumulate significant fault rotation if emplacement of numerous mid-crustal magma chambers took place over the last several million years, as suggested by heat flow data. These models will be tested by additional structural studies of low-angle faults on the west side of the Rio Grande rift.



## HYDROGEOLOGIC FRAMEWORK AND DEVELOPMENT OF A 3-D GROUNDWATER FLOW MODEL OF THE SALT BASIN, NEW MEXICO AND TEXAS

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The Salt Basin is a closed drainage basin located in southeastern New Mexico and northwestern Texas. Since the 1950s, extensive groundwater withdrawals have been associated with agricultural irrigation in the Dell City, Texas region, just south of the New Mexico-Texas border. The Salt Basin groundwater system was declared by the New Mexico State Engineer during 2000 in an attempt to regulate and control growing interest in the groundwater resources of the basin. In order to help guide long-term management strategies, the hydrogeologic framework of the Salt Basin was developed by reconstructing the tectonic forcings that have affected the basin during its formation, identifying the depositional environments that formed and the resultant distribution of facies, and compiling information on the surface and subsurface extent of the various hydrogeologic units. The hydrogeologic framework provided insight on the distribution of permeability within the basin and allowed the groundwater flow system to be conceptualized.

The hydrogeologic framework was also used to aid in the development of a three-dimensional groundwater flow model using MODFLOW-2000. The MODFLOW model was used to test the conceptualization of the groundwater flow system. Additional objectives included quantifying the distribution of permeability, and corroborating the radiocarbon groundwater ages calculated by a contemporaneous study using inverse geochemical modeling in NETPATH. MODPATH was used to compute travel times for comparison with radiocarbon groundwater ages. Initial results indicated that the model was able to produce a good match to observed groundwater levels and regional groundwater flow, but was unable to adequately reproduce the radiocarbon groundwater ages. This was believed to be due to the recharge boundary condition applied to the model domain, which was derived from an independent water-balance-based recharge study of the Salt Basin. As a result, an elevation-dependent recharge distribution was investigated. The elevation-dependent recharge model was able to produce a good match to radiocarbon groundwater ages, in addition to observed groundwater levels and regional groundwater flow.

## WESTERN U.S. UPPER MANTLE STRUCTURE: REVEALING LINKS BETWEEN SMALL-SCALE MANTLE CONVECTION AND SURFACE GEOLOGIC ACTIVITY

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We invert P and S teleseismic travel-time residuals from the USArray and more than 1800 additional stations for 3-D mantle velocity perturbations to a depth of 1200 km. The inversion uses recent advances in western U.S. crust models to better isolate the mantle component of travel-time residuals, and frequency-dependent 3-D sensitivity kernels to map residuals, measured in multiple frequency bands, into velocity structure. In addition to separate V<sub>p</sub> and V<sub>s</sub> models, we jointly invert the two datasets for V<sub>p</sub>/V<sub>s</sub> perturbations by imposing a smoothness constraint on the dlnV<sub>s</sub>/dlnV<sub>p</sub> field. The joint inversion helps identify regions where partial melt is probable. The amplitude of V<sub>p</sub>, V<sub>s</sub>, and V<sub>p</sub>/V<sub>s</sub> variations is greatest in the upper 200 km of the mantle and the form of velocity anomalies suggests a provincially heterogeneous lithosphere and widespread occurrence of small-scale convection. Unreasonably large mantle temperature variations, up to ~900 C at 100 km depth, are required if the entire magnitude of velocity structure is attributed to temperature. The results of the joint inversion delineate mantle volumes where partial melt contributes strongly to the imaged velocity structure, and these regions are highly correlated with young volcanic fields. The inferred depth extent of partial melt is consistent with volatile enrichment in the upper mantle and locally elevated temperatures beneath the eastern SRP and Yellowstone. A northeast trending swath of high-velocity upper mantle extends from the central Colorado Plateau to northeastern Wyoming suggesting that compositional heterogeneity in the lithosphere is necessary to reconcile the high mean elevation and negligible geoid anomaly of the region. This swath of high-velocity mantle is juxtaposed against generally low-velocity upper mantle beneath the Basin and Range, Jemez Lineament, Rio Grande Rift, and Colorado Rockies. High-velocity anomalies at sub-lithospheric depths, which are expected to be subducted slabs, are highly dissected and the volume of imaged slab fragments is inadequate to account for plate convergence since the beginning of the Laramide. Several short-wavelength (100-200 km) high-velocity anomalies in the uppermost mantle beneath a diverse range of geologic provinces must represent foundering of lithosphere. We suggest that North America lithosphere and remaining fragments of the subducted Farallon plate are possible origins of these structures. Viscosity reduction resulting from addition of volatiles and advection of heat during emplacement and subsequent removal of the flat Laramide slab provides a potential stimulus for foundering of NA lithosphere. Broader geodynamic implications of our tomography are that the spatial spectrum of convection in the upper mantle appears to have high power at short wavelengths (~100-200 km), and there is strong correlation between small-scale mantle structures and locations of pronounced magmatic activity, surface uplift, and crustal deformation. Thus, small-scale upper mantle convection in addition to classical horizontal tectonic forcing appears to be of fundamental importance to the distribution of surface geologic activity in the western U.S.

## INCREASING INTERACTION OF ALKALINE MAGMAS WITH LOWER CRUSTAL GABBROIC CUMULATES OVER THE EVOLUTION OF MT. TAYLOR VOLCANIC FIELD, NEW MEXICO

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The Mount Taylor Volcanic Field at the southeastern edge of the Colorado Plateau, New Mexico erupted diverse alkaline magmas from ~3.8 to 1.5 Ma (Crumpler, 1980; Perry et al., 1990). The earliest eruptions include high silica topaz rhyolites of Grants Ridge (plagioclase, quartz, biotite) and Si-undersaturated basanites and trachytes at Mt Taylor stratovolcano. Mt. Taylor was later constructed of stacks of thick, trachyandesitic to rhyolitic lava flows that were subsequently eroded into a ~4-km across amphitheatre opening toward the southeast. Early Mt. Taylor rhyolitic lavas exposed within the amphitheatre contain quartz, plagioclase, hornblende, and biotite ( $\pm$  sanidine) phenocrysts. Later cone-building trachydacite to trachyandesite lavas are crystal-rich with plagioclase and augite megacrysts ( $\pm$  hornblende,  $\pm$  quartz) and record an overall trend of decreasing  $\text{SiO}_2$  with time. The last eruptions ~1.5 Ma from the stratovolcano (Perry et al. 1990) produced thick (>70 m), viscous lava flows that contain up to 50% zoned plagioclase phenocrysts. While  $\text{SiO}_2$  decreased among the silicic magmas, the degree of silica saturation increased among peripheral basaltic magmas from basanite to ne-normative hawaiite and hy-normative basalts. Evidence of increasing crustal contamination within the basalts includes zoned plagioclase megacrysts, augite and plagioclase cumulate texture xenoliths with accompanying xenocrysts. These textures within the basalts combined with abundant, complex plagioclase among the cone-building silicic magmas imply interaction and mixing with a gabbroic cumulate mush pile in the lower crust beneath Mt. Taylor Volcano. Contemporaneous basanitic to trachytic volcanism in the northern part of the volcanic field at Mesa Chivato (Crumpler, 1980) was more widely distributed, smaller volume, and produced mainly aphyric magmas. The lower crustal gabbroic cumulates either do not extend northward beneath Mesa Chivato, or they were not accessed by lower magma flux rate in that part of the volcanic field.

CONIACIAN AMMONITES AND INOCERAMIDS FROM THE MANCOS SHALE  
BELOW THE TOCITO SANDSTONE LENTIL, SANDOVAL COUNTY, NEW MEXICO  
DEMONSTRATE THAT *FORRESTERIA PERUANA* EXTENDS FROM THE UPPER  
TURONIAN INTO THE LOWER CONIACIAN

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The rare ammonite *Forresteria peruana* as well as *Scaphites preventricosus*, *Baculites yokoyamai* and *Cremnoceramus deformis erectus* were collected from the Mancos Shale just below the Tocito Sandstone Lentil on the northeastern side of Mesa Prieta, Sandoval County, New Mexico. Also, *Inoceramus erectus* (*C. deformis erectus*) and *Forresteria hobsoni* have been reported from the Tocito Sandstone Lentil a short distance north of our localities. There are conflicting reports as to whether *F. peruana* extends from the upper Turonian into the lower Coniacian or is restricted to the upper Turonian. In 1991, Kennedy and Cobban listed a locality with *F. peruana* occurring with *Inoceramus* (*Cremnoceramus*) *erectus* (*C. deformis erectus*) just below the Tocito Sandstone Lentil in Sandoval County, New Mexico (same as our locality). *C. deformis erectus* is the index taxon of the lowermost, lower Coniacian inoceramid zone. Another report (Cobban et al., 2008) shows *F. peruana* occurring in part in the lower Coniacian, in the *C. deformis erectus* Zone and mentions that *F. peruana* straddles the Turonian-Coniacian boundary. But, other reports (Walaszczyk and Cobban, 2000; Cobban et al., 2006, USGS 2006-1250; Walaszczyk et al., 2010) show *F. peruana* only in the upper Turonian in the *Mytiloides scupini* inoceramid Zone. In two of these reports, *F. hobsoni* is reported to extend from the upper Turonian into the lower Coniacian. *Prionocyclus germari* and *M. scupini* (*Inoceramus frechi*) occur together in the Montezuma Valley Member of the Mancos Shale and, a little higher stratigraphically, *F. peruana* and *M. scupini* do occur together at the base of the Gallup Sandstone west of Albuquerque in Bernalillo County. But, our collections of ammonites and inoceramids from the Mancos Shale just below the Tocito Sandstone Lentil show that *C. deformis erectus* and *F. peruana* do indeed occur together along with *S. preventricosus*. Furthermore, the *S. preventricosus* ammonite Zone and *C. deformis erectus* inoceramid Zone are both of early Coniacian age. Therefore, Coniacian ammonites and inoceramids from the Mancos Shale just below the Tocito Sandstone Lentil on the northeastern side of Mesa Prieta demonstrate that *F. peruana* extends from the upper Turonian into the lower Coniacian.

SANTONIAN AMMONITES FROM THE SATAN TONGUE OF THE MANCOS SHALE,  
LA VENTANA, SANDOVAL COUNTY, NEW MEXICO

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Late Cretaceous ammonites were collected from the Satan Tongue of the Mancos Shale near La Ventana where the Satan Tongue is ~170 m thick between the El Vado Member of the Mancos Shale (below) and the Point Lookout Sandstone (above). The ammonite fauna includes *Clioscaphtes vermiformis*, *Glyptoxoceras novimexicanum*, *G.* sp., *Placenticerias syrtales*, *P. placenta*, *Desmoscaphtes erdmanni*, *D. bassleri*, *Scaphites leei* I, II, ?III, *Baculites codyensis*, *B. thomi* and *B. haresi*. Thus, the Satan Tongue includes the following ammonite zones locally: *Clioscaphtes vermiformis* Zone (~ lower 10 m), *Desmoscaphtes erdmanni* Zone (~ 60-70 m above base) and *Desmoscaphtes bassleri* Zone (~110-130 m above base) possibly overlain by the zone of *Scaphites leei* III (upper ~ 20 m). The *Clioscaphtes vermiformis* Zone also occurs in the Satan Tongue in the Ortiz Mountains in Santa Fe County. *C. vermiformis*, in association with *Baculites codyensis* and *Glyptoxoceras novimexicanum*, has also been reported from the upper shale unit of the Smoky Hill Member of the Niobrara Formation in the Raton Basin. The type specimen of *G. novimexicanum* was collected from the upper part of the Mancos Shale near Waldo in Santa Fe County. *Placenticerias syrtales* has been reported from the upper part of the Mancos Shale in the upper Rio Grande Valley. *Desmoscaphtes erdmanni*, along with *Baculites thomi*, has also been reported from the upper shale unit of the Smoky Hill Member of the Niobrara Formation in Colfax County. *Desmoscaphtes bassleri* has been reported to occur in the Mancos Shale east of Shiprock in San Juan County. *D. bassleri* has also been reported from the upper shale unit of the Smoky Hill Member of the Niobrara Formation in the Raton Basin. *Scaphites leei* I and II have been reported from the uppermost part of the Mancos Shale in north-central New Mexico. *Scaphites leei* III has been reported from the Mancos on the eastern side of the San Juan Basin and the Ortiz Mountains. *Baculites haresi* occurs in the upper part of the Mancos Shale in the San Juan Basin and upper Rio Grande Valley. *B. haresi* also occurs in the lower Campanian in the Western Interior and *Placenticerias placenta* also occurs in the lower to upper Campanian in the U.S. The *C. vermiformis* Zone is middle Santonian and the *D. erdmanni* and *D. bassleri* zones are upper Santonian. The *S. leei* III Zone is lowest lower Campanian.

## RELATING ARGON DIFFUSION AND FELDSPAR MICROTEXTURE IN THE SHAP GRANITE

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The Multiple Domain Diffusion (MDD) method of  $^{40}\text{Ar}/^{39}\text{Ar}$  thermochronology yields thermal histories from single K-feldspars by modeling natural and laboratory Ar release as a function of thermally activated diffusion from discrete subgrains of varying size. Tectonic studies rely on accurate and detailed thermal history data and thus are highly dependent on the fundamental assumptions from which thermal histories are derived.

To this end, determination of diffusion boundaries within complex mineral systems remains a worthy goal. The boundaries of these subgrains are not physically defined and thus constitute a major criticism of the method and model. In lieu of a physical understanding of diffusion boundaries, the robustness of MDD-derived thermal histories comes from internally consistent data and corroboration by other methods. More complex and poorly consistent results provide new challenges that can be understood by conducting detailed age spectrum analysis on microtexturally characterized crystal fragments. A case study presented here utilizes the ca. 400 Ma Shap granite, England. The Shap contains orthoclase subgrains with well-defined film perthite, which yield nearly flat 400 Ma age spectra. In contrast, coarsened, microporous microcline subgrains yield more complex spectra with assigned ages between about 380 and 400 Ma. These experiments show that discrete structural and chemical textures common to alkali feldspars can be closely related to complicated Ar age spectra and provide insight into diffusion boundaries, dimensions, and Ar kinetic parameter variations between samples.

THE UPPER TRIASSIC WHITAKER (*COELOPHYSIS*) QUARRY, GHOST RANCH,  
RIO ARRIBA COUNTY, NEW MEXICO IS NORIAN

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The Upper Triassic Whitaker (= Ghost Ranch, = *Coelophysis*) quarry is known for its large accumulation of fossil bones of the theropod dinosaur *Coelophysis*. Developed in the Rock Point Formation (Chinle Group), the Whitaker quarry has received much attention that has yielded a deep understanding of the fauna of the quarry and its biostratigraphic importance. Indeed, both vertebrate (principally tetrapods) and invertebrate (conchostracans) biostratigraphy agree that the Whitaker quarry is Norian in age. Specimens of the phytosaur *Redondasaurus* have been recovered from the quarry and place it within the Apachean land-vertebrate faunachron and indicate a Norian or Rhaetian (latest Triassic) age for the assemblage. The presence of the conchostracan genus *Shipingia* from the quarry further constrains the age of the assemblage and allows correlation to the Sevatian (late Norian), based on global conchostracan biostratigraphy. Recently, workers have advocated a Rhaetian (latest Triassic) or even Hettangian (earliest Jurassic) age for the quarry based on magnetostratigraphy. The Hettangian age in particular runs counter to both the vertebrate and invertebrate biostratigraphy. In addition, they correlated the Rock Point (which they refer to as the “inferred” Rock Point) Formation to the Moenave-Wingate interval based on paleomagnetic pole similarities. However, this confounds chronostratigraphy with lithostratigraphy, and runs counter to basic stratigraphic principles, by assigning a lithosome to a stratigraphic unit based on its inferred age and not on its lithologic characteristics and stratigraphic position. The conclusion that the Rock Point Formation, and thus the Whitaker quarry, is Rhaetian or Hettangian in age based on magnetostratigraphy is not corroborated by the litho- or biostratigraphic data. Thus, three datasets, the vertebrate biostratigraphy, invertebrate biostratigraphy and regional lithostratigraphy, all indicate a Norian age for the Rock Point Formation and the Whitaker quarry.

## A NEW COPROLITE ICHNOFAUNA FROM THE UPPER PENNSYLVANIAN (MISSOURIAN) TINAJAS LOCALITY, CENTRAL NEW MEXICO

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Pennsylvanian strata in NM are interbedded marine and nonmarine sediments deposited in basins of the ancestral Rocky Mountain orogeny that contain several significant fossil localities in the central part of the state. The Kinney Brick Quarry, NMMNH locality 345, in the Manzanita Mountains of Bernalillo County, preserves a diverse body-fossil fauna and vertebrate coprofauna. The Tinajas locality, NMMNH locality 4667, is in the Tinajas Member of the Atrasado Formation (upper Missourian) in Socorro County. A lacustrine black shale at the locality yields a diverse fossil biota of vertebrates, invertebrates, plants and coprolites. The Tinajas locality yields at least six morphotypes of coprolites, at least three of which are distinct enough to be described as new ichnotaxa. The most distinctive morphotype is represented by two examples that are ovoid in cross section, between 15 and 20 mm long and up to 11 mm wide and contain a large number of conchostracan valves. This is an undescribed form of coprolite. The majority of coprolites represent spiral forms, and four morphotypes can be distinguished: (1) large, heteropolar coprolite that has approximately 10 evenly-spaced spirals – there is only one example of this anomalously large and distinct morphotype and it was found at a separate locality from the rest of the collection; (2) small, heteropolar ovoid coprolites with one-to-two, weakly-developed spirals at the anterior pole – two specimens; (3) short, broad, heteropolar coprolite with an acutely tipped anterior pole known from only one specimen; and (4) an elongate cylindrical morphotype with a spiral cross section also only known from one specimen. In addition, there are a variety of ovoid coprolites with widths subequal to lengths and up to 12 mm long. The Tinajas locality has a diverse ichthyofauna of acanthodians (*Acanthodes* spines and bones), a xenacanth (*Orthocanthus* tooth), palaeonisciforms (Elonichthyidae, Haplolepididae and cf. Platysomidae scales and bones) and sarcopterygians (scales, teeth, skull elements of *Greiserolepis* or *Megalichthyes* and cf. *Strepsodus*). Possible attributions of the coprolites are: (1) conchostracan-bearing forms produced by acanthodians; (2) spiral coprolites produced by xenacanths or sarcopterygians; and (3) ovoid forms produced by palaeonisciforms.



## GEOMICROBIOLOGY OF THE GIANT NAICA CRYSTALS: AN EXAMPLE OF THE GEOLOGICAL PERSISTENCE OF MICROORGANISMS

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How long can microorganisms remain viable in sediments, fluid inclusions, rock fractures, ice, or other geological materials? This is a question for which we have little direct evidence, but great interest. Reports of long duration microbial survival in salt crystals and other materials have been greeted with skepticism because the standards of proof are so rigorous and materials like salt are subject to plastic deformation and flow over geological time. Any hint of surface contamination undermines the ability to claim that recovered organisms are indeed survivors from past environments. However, as such instances slowly mount up in the scientific literature, the plausibility, indeed probability, of extremely long term survival and viability is strengthened.

Our recent work on living microorganisms and sequenceable DNA from fluid inclusions in enormous selenite crystals, Fe oxide and clay rich wall material, and black solid inclusions in crystals in a high temperature cave environment is a new entry in the list of potential long-term survival of microorganisms in geological time capsules. Over 30 mixed cultures have been retrieved from these materials in several caves intersected by mining activities in Naica, Chihuahua, Mexico. These cave chambers were drained of hot (>50° C) hydrothermal water during mining of zinc, lead, minor silver and copper, thus allowing access to the chambers about a decade ago. Growth rates of the crystals and their maximum age (~500 ky) has been estimated. Using these values, we estimate the age of the fluid inclusions we sampled at approximately 50 ky old.

The Chihuahuan Desert environment of Naica is similar to that in the Chihuahuan Desert of New Mexico in terms of both climate and vegetation type and there are some broad similarities in various geological features. In the case of the Naica system, a large magma body ascending from great depth served to fracture the parent limestone. Ascending metal rich thermal waters and gases percolated into the fractures, creating the caves and the ores, and setting the stage for the spectacular mineralogical developments and unusual microbial communities. This is an extraordinary example of the dramatic geochemical and biological influences that mantle-derived materials can ultimately have on shallower geology and microbiology.

## DISTINGUISHING BETWEEN GEOLOGIC AND ANTHROPOGENIC SALT LOADS IN THE RIO GRANDE USING SULFUR ISOTOPE GEOCHEMISTRY

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The Rio Grande is the fourth longest river system in United States and is the primary source of irrigation water for the Rio Grande Valley. Evaporation, groundwater recharge associated with salt-rich sedimentary rocks, geothermal heating, and flood irrigation are believed to increase the solute content of the river. To assess the salt loads from various geologic and anthropogenic sources in the Rio Grande Valley, we have been working to determine the chemistry and S isotope composition ( $\delta^{34}\text{S}$  of  $\text{SO}_4^{2-}$ ) for the Rio Grande and its shallow aquifers in New Mexico and West Texas. Our results suggest that  $\text{SO}_4^{2-}$  fluxes in the Rio Grande are mainly controlled by surface sulfide weathering in upstream locations ( $\delta^{34}\text{S} < -2 \text{‰}$ ) and application of fertilizers during irrigation in downstream locations ( $-2$  to  $+4 \text{‰}$ ). The sedimentary  $\text{SO}_4^{2-}$  flux associated with thermal and non-thermal flows ( $+8$  to  $10 \text{‰}$ ) appears to be minor, but does account for some of the increase of  $\delta^{34}\text{S}$  (up to  $5 \text{‰}$ ) in the distal end of Mesilla Basin at the end of the non-irrigation season. The geothermal flows in the Mesilla Basin are characterized by high  $\text{Cl}^-$  (up to  $578 \text{ mg/L}$ ) and lower  $\text{SO}_4^{2-}$  concentrations (up to  $236 \text{ mg/L}$ ), thus, they cannot account for significant  $\text{SO}_4^{2-}$  increase ( $546 \text{ mg/L}$ ) observed in this basin. However, agricultural drains in the Mesilla show considerably high  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  concentrations (up to  $1203 \text{ mg/L}$  and  $1531 \text{ mg/L}$ , respectively) suggesting the important salt loads to the Rio Grande from the near-surface environment. In addition to geological sources, the elevated  $\text{Cl}^-$  fluxes can also be partly linked to anthropogenic sources such as fertilizers and municipal waste discharges.

## URANIUM-SERIES DATING OF TRAVERTINE FROM SODA DAM, NEW MEXICO: CONSTRUCTING A HISTORY OF DEPOSITION, WITH IMPLICATIONS FOR LANDSCAPE EVOLUTION, PALEOHYDROLOGY AND PALEOCLIMATOLOGY

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Uranium series dating of travertine at Soda Dam, New Mexico yield precise new incision rates for the Jemez River, a tributary of the Rio Grande River, through San Diego Canyon. The emerging travertine record also documents past intervals of high spring discharge, inferred to reflect wet paleoclimate intervals. Travertine deposits at Soda Dam occur along the intersection of the Soda Dam fault, part of the Jemez fault zone, and the Jemez River. Modern travertine-depositing hot springs indicate this system is part of the Valles geothermal system, which extensive volcanic and travertine deposits indicate has been active throughout the Quaternary. Previous U-series dates (Goff et al., 1987) on the Soda Dam travertines were: Soda Dam=  $4.8 \pm 0.2$  ka, Deposit A (west side)=  $215 \pm 40$  ka and  $>350$  ka; Deposit B (east side)=  $98 \pm 7$  ka near top and  $58 \pm 3$  ka in the core; Deposit C (southeast side)=  $107 \pm 5$  ka near base. New dates are: Deposit A=  $200.6 \pm 2.1$  ka for travertine rinds on river cobbles just above the bedrock strath at the cave, and  $183.1 \pm 2.1$  ka for a sparite sill that cuts the gravels. The strath is 30 m above the river yielding an average bedrock incision rate of 150 m/Ma over the last 200 ka. Outcrop B=  $138.4 \pm 1.1$  ka near the base, and  $78.2 \pm 1.6$  ka at the top. Outcrop C=  $103.2 \pm 0.5$  ka at the base and  $101.7 \pm 0.5$  ka at the top. The bedrock strath below outcrop C is 16.5 m above the river, yielding an incision rate of 160 m/Ma over the last 100 ka. Longer term average incision for the Jemez River are 195 m/Ma over the last 1.2 Ma and 230 m/Ma over the last 0.64 Ma. Our results produce incision rates that are generally consistent with previously reported incision rates and suggest semi-steady bedrock river incision, with perhaps a slight slowing over the last 200 ka. Additional implications of our continued dating efforts will be to: 1) provide better paleohydrologic and paleoclimate records of key climatic transitions (200-100 ka and last 10 ka) by obtaining stable isotope and other proxy records for well dated banded vein system; 2) refine the time duration of deposit A to infer possible linkages between Soda Dam spring deposition in relationship to Valles caldera paleolakes and the evolving Valles hydrothermal system; 3) continue to refine Quaternary incision history of the Jemez River using dated strath terraces.

# PRELIMINARY ANISOTROPY OF MAGNETIC SUSCEPTIBILITY (AMS) AND PALEOMAGNETIC DATA FROM MAFIC DIKES IN THE CHILI QUADRANGLE, RIO ARRIBA COUNTY, NEW MEXICO

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Migration of magma at shallow levels of the crust is a fundamental process that has bearing on the construction of volcanoes, the associated hazards in active volcanic terranes, as well as igneous mass redistribution into near surface environments. This study examines a suite of Miocene dikes in the Española Basin, north-central NM, where Rio Grande Rift faulting has complicated the sourcing of mafic magmas. The problem addressed by this research involves a two-fold approach: 1) collect paleomagnetic data from thirty basaltic dikes with the intent to discern components of vertical-axis rotation across structural blocks, between separate dikes, and along strike within individual dikes, and 2) obtain anisotropy of magnetic susceptibility (AMS) data, thin section, and field observations, to infer magma flow within individual dikes and document any variation in magma flow patterns in the swarm. We plan to test the following hypotheses: 1) the mafic dikes experienced some degree of vertical axis rotation associated with rifting and 2) that the magma flow pattern within the dikes reflects lateral emplacement with flow directed away from the magma ascent location. Low-field susceptibility versus temperature results from the dikes yield a spectrum of temperature dependence reflecting typical thermomagnetic behavior of intermediate composition titanomagnetite while others exhibit a more complex behavior with the presence of two or more magnetic phases. Curie point estimates range from ~ 100°C to 575°C indicating a range of moderate Ti- to low Ti- titanomagnetite compositions as well as evidence of a Fe-sulfide phase. AMS fabric data reveal a combination of both prolate and oblate susceptibility ellipsoids. At several sites, the fabrics are oblate from the paired dike margins and reveal a unique magma flow direction. Susceptibility values are high and consistent with a ferromagnetic phase, likely low-Ti titanomagnetite, providing encouraging data that the remanence is likely a primary thermoremanent magnetization (TRM) and geologically stable. Paleomagnetic analysis is underway and should help further constrain the emplacement of the dikes and tectonic evolution of the study area. Additional paleomagnetic data will aid in constraining the tectonic and thermal history of the dikes and provide insight into the regional deformation of the area. AMS data should document the direction of magma flow within each intrusion allowing us to deduce the source region of the magma body.

## THE EFFECT OF PEDOGENIC CALCIUM ON HYDROLOGICAL PROPERTIES OF ARID SOILS, SEVILLETA NATIONAL WILDLIFE REFUGE, CENTRAL NEW MEXICO

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A study was conducted in the Sevilleta National Wildlife Refuge to remotely identify soil map unit boundaries using root zone soil moisture derived from the Surface Energy Balance Algorithm for Land (SEBAL) model over the course of several moisture events. Some boundaries identified using the SEBAL code do not appear to correlate with current landform or previously identified soil map unit boundaries. Field validation of one transect crossing several of the unexplained boundaries indicated that the amount and distribution of calcium carbonate varied and may influence the identification of boundaries using root zone soil moisture. The objective of this study is to determine if changes in calcium carbonate content correlate with changes in soil hydrologic properties.

Particle size distribution analysis of samples containing carbonate and with carbonate removed show there is a significant increase in the percentage of clay-sized particles in a soil when carbonate has been removed. The pedogenically induced changes in apparent soil texture has considerable implications on soil hydrological properties including saturated and unsaturated hydraulic conductivity and moisture retention. These results suggest that changes in soil physical properties can be reflected in soil hydrologic properties identified using the SEBAL code.

## EARLY PALEOCENE (TORREJONIAN) ANT-HILL VERTEBRATE ASSEMBLAGES FROM THE NACIMIENTO FORMATION, NEW MEXICO

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Paleontologists have long taken advantage of the harvester ant's habit of armoring their nest mounds (ant-hills) with small pebbles and other objects gathered from the surrounding landscape. Ants sometimes incorporate fossils consisting of isolated fossilized teeth of small mammals and other vertebrates that have weathered from nearby exposures of bedrock. However, ant-hill vertebrate assemblages have not been previously reported from the Nacimiento Formation, which is renowned for its early Paleocene mammal faunas. During the 2009 and 2010, we collected approximately 100 kg of sediment from ant-hills developed near exposures of the Nacimiento Formation on the East Flank of Torreon Wash (New Mexico Museum of Natural History [NMMNH] localities 7844, 7845, and 8279). These localities are from the *Pantolambda bathmodon* – *Mixodectes pungens* zone, a middle Torrejonian (To2) horizon that is underrepresented by microvertebrate fossils. Ant-hill samples were wet-screened and picked under a binocular microscope. Over 56 identifiable mammal specimens, all consisting of isolated teeth or tooth fragments, representing more than 14 taxa were recovered. Most specimens are of small, well-known mammals including the mioclaenid “condylarth” *Promioclænus acolytus* and the mixodectid euarchontan *Mixodectes malaris*. However, several specimens are of rare and poorly known taxa (e.g., the stem-primate *Anasazia*) or possibly represent new taxa.

We compared the ant-hill assemblages to those from a microvertebrate site (NMMNH locality L-7583) from a nearby channel-hosted microfossil bonebed from approximately the same stratigraphic horizon in order to assess potential collecting biases. Ant-hill teeth occupied a narrow size range of about 2-5 mm in maximum diameter, which is near the smallest size of specimens typically collected through surface collecting techniques, but significantly larger than the smallest specimens collected from typical microfossil bonebeds (< 1 mm), resulting in significant differences in composition. This preliminary work indicates that ant-hills can provide significant fossils of small, underrepresented Paleocene taxa of the Nacimiento Formation.

## ROLE OF FAULTS IN CONTROLLING HYDROTHERMAL FLUID FLOW, HELIUM, AND CO<sub>2</sub> TRANSPORT WITHIN THE ALBUQUERQUE BASIN

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Groundwater salinity and <sup>3</sup>He/<sup>4</sup>He anomalies (R<sub>A</sub> values between 0.3 and 0.5) reported in the Albuquerque Basin is a probable indication of complex mixing of mantle and crustal fluids. A suite of new noble gas and water samples were recently collected from Socorro and Sedillo Springs in the Socorro Basin as well as from the recently completed geothermal slim hole near the NMT campus to help determine the flux of mantle derived fluids. High CO<sub>2</sub> levels measured at the travertine depositing spring at Tierra Amarilla near San Ysidro on the Nacimiento fault provide further indication of mantle degassing.

A series of east-west and north-south basin-scale, cross-sectional hydrologic models were constructed along the Rio Grande Rift in the Albuquerque and Socorro Basins to assess the relative importance of a faults as conduits for meteoric and deep endogenic fluids. The north-south cross sectional model was developed from geologic maps, well bore lithologic logs, as well as gravity and seismic-surveys. Separate east-west cross sectional models were developed for the sub-vertical normal faults and lystric faults in the Albuquerque Basin to quantify how differently CO<sub>2</sub> and helium transport responds in each fault system using the same hydrologic parameters. Groundwater salinity, temperature, <sup>3</sup>He/<sup>4</sup>He, and <sup>14</sup>C data provide the ground truth to calibrate these models. The cross-sectional models used in this study illustrate the importance of deeply penetrating, moderately permeable fault zones (10<sup>-14</sup> to 10<sup>-16</sup> m<sup>2</sup>) in advective transport of groundwater and mantle volatiles to shallow crustal levels.

## PALEOTOPOGRAPHY IN THE LATE TRIASSIC: MAGNETOSTRATIGRAPHIC DATA AND STRATIGRAPHIC OBSERVATIONS FROM THE DRY CIMARRON VALLEY, UNION COUNTY, NEW MEXICO

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Magnetostratigraphic data for the Upper Triassic Chinle Group of New Mexico are interpreted to indicate that multiple, and often subtle, disconformities are common in the Chinle Group and, in conjunction with recent detrital zircon age information, that deposition of these strata may have been more sporadic than previously assumed. Comparison of magnetic polarity chronologies among the Four Corners area, north-central New Mexico (Chama Basin) and eastern New Mexico (Mesa Redonda) implies a substantial disconformity between the Petrified Forest Formation and the uppermost strata preserved in the Chama Basin. We speculate that strata that would be time equivalent to the Late Norian Redonda Formation of eastern New Mexico and the Owl Rock and type Rock Point Formations of Arizona and Utah are not preserved in northern New Mexico. Instead, much younger strata sit above the Petrified Forest Formation and may be partially age equivalent to the Rhaetian-Hettangian Moenave Formation of Utah. A possible explanation of these stratigraphic relations is that a roughly north-south trending topographic high existed in central New Mexico and separated the Tuumcari area from western New Mexico, Arizona and Utah, in late Norian and perhaps early Rhaetian time. Such a paleohigh may have resulted in either erosion or nondeposition of Redonda-Rock Point equivalent strata in northern New Mexico. Baldwin and Muehlberger (1959) reported a striking angular unconformity between Upper Triassic redbeds and the Middle Jurassic Exeter (=Entrada) Sandstone in the Dry Cimarron Valley, NE New Mexico. Triassic redbeds are folded in open anticlines and synclines with trending fold axes. The overlying Jurassic Exeter Sandstone varies substantially in thickness (nonexistent to tens of meters) along the length of the Dry Cimarron Valley. We hypothesize that Exeter Sandstone deposits filled an erosional surface that mimicked the topography of deformed pre-upper Norian strata, resulting in a widespread unconformity, locally with well-developed angular relations. The presence of a disconformity in the Chama Basin together with evidence for deformation of Upper Triassic strata in northeastern New Mexico is interpreted to indicate that a paleotopographic high in central New Mexico resulted in substantial changes in depositional patterns during the late Norian to early Rhaetian in this area.



## PREHISTORIC TRAVERTINE PENDANTS FROM CENTRAL NEW MEXICO: POTENTIAL RELATIONSHIPS WITH KNOWN TRAVERTINE DEPOSITS

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Prehistoric sites in New Mexico have yielded dozens of elongate, banded travertine objects, some of which were perforated for use as pendants. These objects are usually found singly, suggesting that they are not components of an item such as a necklace, but may instead be ritual objects. The rarity of these travertine artifacts, coupled with their widespread distribution throughout the southwestern United States, suggest that they were important as a ritual tool across a wide geographic area. Pendants in the Maxwell Museum's collections have been collected from Pottery Mound and Tijeras Pueblo, NM. Our goal is to identify the most likely travertine deposit as a source for these pendants. Preliminary examination suggests that these items come from a single source as they all exhibit similar patterning of even, horizontal black bands (likely manganese oxide/hydroxide) alternating with buff-colored bands. They do not exhibit crenulations typically observed in travertine flowstone, but could be vein materials associated with travertine deposits. Based upon existing knowledge of travertine deposits in New Mexico, travertine locations in central New Mexico that are the most likely source for these pendants include Mesa Aparejo and Mesa del Oro travertines on the west side of the Rio grande rift, west of Belen. As a preliminary means of describing the subtle variations in these pendants and in hand samples from various travertine deposits in central New Mexico, we have developed a set of measurements and descriptive quantifiers for pendant characteristics such as length, diameter, degree of taper, degree of human interaction, width of bands and band distribution. Future provenance identification should be possible using geochemical typing of travertine.

# THE ERUPTIVE HISTORY AND EVIDENCE FOR PROTRACTED PLUTON EMPLACEMENT ASSOCIATED WITH THE ORGAN CALDERA, SOUTH-CENTRAL NEW MEXICO

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Ar/Ar dating of volcanic and plutonic rocks related to the Organ caldera, south-central New Mexico, indicates that magmatism spanned at least 2 Ma between 36.4 and 34.4 Ma. The volcanic sequence consists of three zoned caldera-forming ignimbrites and small erosional remnants of pre- and postcaldera volcanic rocks. Numerous zoned and nonzoned plutons intruded the intracaldera sequence and are now exposed along the eastern caldera margin. Preliminary results constrain the timing of processes associated with compositionally zoned igneous suites.

Ages of the three caldera-forming ignimbrites provide the timing of peak magmatic activity. The oldest caldera-related ignimbrite is the Cueva Tuff, which erupted at 36.4 Ma. Following this eruption two larger volume ignimbrites, the Tuff of Achenbach Park and Squaw Mountain Tuff, were emplaced at 36.2 and 36.1 Ma, respectively. Numerous small-volume compositionally diverse lavas were erupted between 36.2 and 35.7 Ma. The ages of postcaldera lavas indicate that volcanism occurred immediately after caldera formation and continued for at least 500 ka. Precaldera andesites were dated, but age spectra are discordant and do not provide robust results.

Exposed caldera-related intrusions represent the remnants of the caldera-forming magma chamber and the growth of a postcaldera batholith during the waning stages of magmatism. The largest intrusion is the Organ Needle pluton, which is compositionally zoned from a monzodiorite to an alkali feldspar granite (AFG). The AFG was previously interpreted to be nonerupted Squaw Mountain Tuff because of similarities in geochemistry. Biotite cooling ages of the AFG are indistinguishable in age to the Squaw Mountain Tuff, supporting that the two units are coeval intrusive/extrusive pairs. Thermally reset biotite from a Precambrian granite adjacent to the Organ Needle pluton yielded an age 36.1 Ma, which also supports that the Organ Needle pluton is related to the differentiation and eruption of the Squaw Mountain Tuff. Using biotite Ar/Ar ages, the younger postcaldera plutons were emplaced between 35.4 to 34.6 Ma. None of the exposed plutons are interpreted to be nonerupted remnants of the Cueva Tuff or Tuff of Achenbach Park. Pluton emplacement ages will be further evaluated using laser-ablation U-Pb dating of zircon.