New Mexico graduate student abstracts

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

New Mexico Institute of Mining and Technology

SOIL CHRONOSEQUENCE STUDY OF LONG VALLEY, NEW MEXICO: INSIGHTS INTO THE DEVELOPMENT OF SOILS ON PLEISTOCENE AND HOLOCENE MORAINE CATENAS

Feldman, Anthony D., M.S.

The history of glacial advance and retreat cycles in mountain watersheds is recorded in glacial landforms. The Sangre De Cristo mountain range in northern New Mexico contains some of the southernmost expansion of glacial activity in the Southwest during the Quaternary but there have been few studies correlating its glacial chronology to the Rocky Mountain glacial record. Glacial deposits within Long Valley, a glaciated valley in the Sangre de Cristo Mountains, were correlated with the glacial history of the southern Rocky Mountains and Wind River Range utilizing soil and landform properties. A soil profile development index (PDI) was calculated utilizing soil texture, structure, consistency, and color data. Organic carbon, hydroxalamine extractable (FeO) and dithionite extractable (FeD) iron oxides, and clay accumulation were also utilized to differentiate moraine age correlations. Soil development is observed to increase with age between soil catenas and at individual catenary positions. Utilizing the calculated PDI values, chemical and physical proxies, as well as field and DEM observations of moraine morphology, four Pleistocene glacial periods are observed within the Long Valley moraine sequence as well as two smaller rock glacier and peri-glacial periods during the Holocene. These cycles were correlated to the Bull Lake, Pinedale, Oldest Dryas, Youngest Dryas, and two periods during the latter half of the Holocene. Among moraine morphology parameters, summit width and flank slope best distinguished moraines of different ages. Profile mass content of FeD iron and clays increased with age while FeO iron and organic carbon profile mass content decreased with age. The soil PDI chronofunction had the highest correlation with the glacial age determinations, with chronofunctions for clay and the FeO/FeD ratio also representing good age discriminators. organic carbon, FeO, and FeD iron were not as useful in differentiation of moraine ages. Chronofunctions for catenas and moraine summits possessed the best age correlations, while toeslope chronofunctions did not correlate well with age.

USING HEAT AS A TRACER TO QUANTIFY DAILY SURFACE WATER-GROUNDWATER EXCHANGE IN THE EAST FORK JEMEZ RIVER, VALLES CALDERA, NM

Paulino Céspedes, Eva R., M.S.

Studying the temporal and spatial variations of flow is critical to understand the fate and transport of solutes within hyporheic environments. Exchange fluxes can vary with time due to hydrologic drivers such as seasonal variability in regional groundwater flow and discharge changes due to snowmelt and precipitation events. From an observational perspective, exchange fluxes and their dynamics can be estimated with the analysis of temperature time series collected within the stream sediments. In this work, we explore the strengths and limitations of two analytical methods to estimate vertical exchange fluxes from temperature time series. Both methodologies were sensitive to sensor spacing, instrument resolution, and magnitude and direction of the flux which resulted in overestimation, underestimation, or incorrect estimation of the velocity. The methods were used to estimate fluxes in the Jemez River located in The Valles Caldera Natural Preserve, NM, which served as an example of a typical low-gradient, meandering mountain stream where temporal and spatial variability of vertical exchange fluxes were analyzed along a riffle-pool-riffle sequence reach. Vertical fluid velocities varied from –1 to 1 m/d and groundwater-surface water exchange was attributed to pressure gradients due to the topography of the streambed, local groundwater flow systems, and localized small lateral flow paths originated at the meander bends.

HYDROGEOLOGY OF THE QUESTA AREA: END MEMBER MIXING ANALYSIS OF SHALLOW GROUNDWATER

Robinson, Kylian, M.S.

In order to understand a pattern of seasonal well failures at Questa, New Mexico, we developed an endmember mixing analysis (EMMA) model that embraces the small scale geological complexities of the northern Rio Grande Rift. Geochemical measurements from multiple datasets were compared to quantify the connection of surface water with the mountain block aquifer with the alluvial aquifer, and the alluvial aquifer with the volcanic aquifer.

Wells and springs were sampled once for major ions, trace metals, water and sulfur isotopologues, and age tracers ^{14}C and ^{3}H, while hydraulic head was measured seasonally throughout the course of three years. These data were analyzed under the rubric of EMMA to quantify mixing relationships and identify statistically significant differences between water types and data sets.

Multiple lines of evidence supported a close connection between groundwater supplying domestic wells and anthropogenic recharge derived from acequias. Groundwater mounding around the ditches produces a seasonal movement of the groundwater table, corresponding with the yearly groundwater recharge cycle. Water level variations observed in the alluvial aquifer varied significantly with the logarithm of distance from acequia, the well depth, and seasonal applications of flow allotments. Surface waters low in TDS and high in bicarbonate are broadly distributed at these times, driven by infiltration of seasonal snowmelt and peak streamflow. Geochemical mixing analysis suggested that about 27% of the domestic supply control-volume was mixed with water recharged recently from the surface, and this should be regarded as a minimum estimate.

Likewise, the heterogeneity of higher tritium values in the alluvial aquifer reflects that the groundwater recharge to the domestic well supply derives significantly from vertical infiltration out of the acequia system. Some wells access mixtures more strongly supplied by long-residence time recharge from the mountain block that has flowed across the Sangre de Cristo Fault (SDCF). Groundwater signatures of the endmembers show that solutes derived from primary chemical weathering of the Latir Peak Volcanic Field have the largest mixing fraction just west of the SDCF. Calcium is associated with high sulfate in the ambient geological system, reflecting the presence of gypsum in the caldera source watershed. The areas dominated by the two major background groundwater types, bicarbonate and sulfate, are found downgradient of the regions of recharge through alkaline rock types and metaluminous bodies respectively. This pattern requires significant subsurface connectivity across Quaternary normal faults of the eastern rift.

In the volcanic aquifer, longer-residence groundwater flow predominates. Small but consistent declines in the head of the volcanic aquifer amounting to 0.14 feet/ year were measured over the course of our study. Head levels in this region do not respond significantly to seasonal forcing, except where the aquifer is overlain and partially confined by saturated alluvium. Identification of the key distinguishing tracer boron at the Dacite Fault Zone crosscutting Guadalupe Mountain establishes that the volcanic aquifer receives measurable inflow from a deep-circulating hydrothermal system. Groundwater flow converges on the volcanic complex from northeast to east, as far north as Latir Creek West and as far east as the alluvial

valley where the Red River emerges at the SDCF. These cool and chemically variable waters mix thoroughly with upwelling fluids, creating a geochemically homogeneous solute composition in the volcanic aquifer. We conjecture that the observed aquifer head decline results from decreasing streamflow and watershed discharges observable at gaging stations that bracket the Red River Spring Zone (RRSZ).

Contaminant loading from the tailings impoundment into the RRSZ and elsewhere within the groundwater system increased in recent years (-2017) despite cutbacks in mine-dewatering discharges to the tailings impoundment. We identify two tailings leachate endmembers, one oxidizing and rich in uranium, the other more reducing and high in molybdenum, that correspond with samples from highly productive and poorly productive extraction wells, respectively. The EMMA model tends to under-predict mixing ratios compared with values derived from only the most mobile tracers and molybdenum. Ongoing changes in contaminant levels at the monitoring sites result from at least two independent causes. 1) Mixing relationships can be temporally variable because surfacewater infiltration varies each year with watershed yield. 2) Contaminant retardation due to ion exchange reactions in the subsurface becomes exhausted at some point in the aquifer, allowing progression of contaminants downstream.

Changes in the contaminant plume can be more precisely mapped by including some additional selected constituents in the analytes of the monitoring program, such as water isotopologues, boron, silica, and lithium. Sampling should be regularized to correspond with high and low infiltration seasons, in order to properly assess the different contributions of mixing and retardation to our observations. With a larger sample size and better-constructed covariance groups to support the mathematics, background values and anthropogenic changes alike can be modeled with greater confidence.

GEOMORPHIC HISTORY AND CHRONOLOGY OF QUATERNARY ALLUVIAL DEPOSITS IN THE SOCORRO AREA, CENTRAL RIO GRANDE RIFT, NEW MEXICO

Sion, Bradley D., Ph.D.

Fluvial terraces in the central Rio Grande rift record important Quaternary climatic and tectonic signals. Age control among Rio Grande terrace sequences in central and southern New Mexico is limited, so regional correlations are unreliable and important process-related questions about the mechanisms and rates controlling terrace formation and deformation cannot be addressed. I present a terrace chronology from the central New Mexico Socorro Basin from ^{36}Cl surface-exposure and ^{14}C ages to establish a firm foundation for Socorro Basin terrace stratigraphy, provide terrace correlations to adjacent rift basins, and test climate response models of terrace formation. Terrace stratigraphy and ^{36}Cl ages imply climatic controls on river incision from terraces that have surface-exposure ages of 26–29, 64–70, and 135 ka. Carbon-14 ages from detrital charcoal show that the most recent aggradation event persisted until at least 3 ka during the transition from glacial to modern climate conditions. Our terrace chronology supports existing climate-response models of terrace formation in arid environments and links tributary responses to the axial Rio Grande system throughout the central Rio Grande rift. Soil characteristics from dated terrace surface provide rates of dust and carbonate accumulation for durations of 0.5-800 kyrs. Soil development in arid and semiarid regions of the southwestern United States is predominantly controlled by influx of eolian dust. I use the ^{36}Cl and ^{14}C soil ages presented in Chapter 2, coupled with soil textures and the profile development index (PDI), to estimate rates of soil development in the Socorro area. The silt-and-clay and profilemass carbonate contents of the soils increase with soil age and yield power-law slopes of 0.33–0.34. The PDIs also increase at rates of 0.33 with increasing soil age and can be used to roughly estimate the ages of undated soils. The rate of soil development in the Socorro area is less than that estimated for soils in higher latitude regions of New Mexico, but is roughly similar to that estimated for soils farther south. This may be due in part to a regional climate gradient presently manifested by greater mean annual precipitation and cooler mean annual temperatures at higher latitudes and/or slower rates of eolian dust accumulation into the soil profile. Rio Salado terraces preserved at the surface and above the Socorro magma body (SMB) provide paleo-geodetic markers to interrogate the longevity of magmatism in the Socorro area. High-resolution elevations from Rio Salado terraces that cross surface-uplift contours document a prehistoric surface-uplift event above the SMB. Longitudinal terrace patterns are consistent with an arching event that began after 26 ka and ceased before 3 ka and cannot be explained by tectonic or fluvial mechanisms. This late Pleistocene-early Holocene surface uplift is related to a magma-emplacement event that predates modern magmatism and is collocated with geodetic uplift. The two temporally distinct surface-uplift events likely record episodic intrusion below the Socorro area since late-Pleistocene time. Magmatic activity may be rejuvinated via a stationary plumbing system inferred from seismic data. This study shows that the magmatic source-feeder system is stable and active over timescales of 10^4 yrs and demonstrates the utility of terraces as strain markers of low-amplitude, large-wavelength deformation caused by mid-crustal magmatic activity.

A TWO-YEAR STUDY OF FLASH FLOOD CHARACTERISTICS IN NEW MEXICAN AND ISRAELI EPHEMERAL CHANNELS

Stark, Kyle, M.S.

The Arroyo de los Piños has been chosen as a prime location to study sediment flux in New Mexico. It is a direct tributary of the Rio Grande and routes through typical formations found in the middle Rio Grande Valley. Two years of observations reveal a channel that floods 3–5 times a year from summer monsoon rains. Rainfall and water depth were recorded continuously at two locations in the watershed. According to these instruments, a minimum rainfall intensity of 3.5 mm/15min is required to generate runoff, regardless of location in the basin. Water depth, velocity, and vertically integrated suspended sediment samples were collected at the basin outlet. In total, 35 suspended sediment and 180 depth and velocity measurements were collected from nine events. A rating curve was developed using the discrete depth and velocity measurements and the resulting calculated discharges are used to compare the suspended sediment concentration (SSC) between samples. SSC ranged from 4,040 mg/L to 74,000 mg/L. Samples collected during the falling limb of the hydrograph were well correlated to discharge ($r^2 = 0.72$) while samples collected during the rising limb were moderately correlated ($r^2 = 0.39$).

Prior to the third year of study, a new sediment monitoring station was completed near the Piños watershed outlet. The new station includes seven different methods of measuring bedload and three methods to measure suspended load. Direct measurements of bedload are collected using Reid-type slots samplers while direct measurements of suspended are collected using automated water samplers. These direct measures are used to calibrate a host of surrogate technologies including microphones, geophones, seismometers, and hydrophones. Few ephemeral channels are studied worldwide and no ephemeral channel has been studied more than the Nahal Eshtemoa in the Negev desert in Israel. Sediment transport dynamics in the channel have been studied for over 25 years. Plate microphones, a surrogate technology to measure bedload flux, are calibrated in the Eshtemoa. Two methods of calibration were tested: a time-averaged method which has been traditionally used, and a mass-averaged method which is new to calibration in the Eshtemoa. The mass-averaged method is shown to be better in almost every way. It is more robust, particularly at lower transport rates, it is effective at all flood stages (rise, max, and fall of the hydrograph), and it is more consistent across events.

INFLUENCE OF LITHOLOGY AND DIAGENESIS ON MECHANICAL AND SEALING PROPERTIES OF THE THIRTEEN FINGER LIMESTONE AND UPPER MORROW SHALE, FARNSWORTH UNIT, OCHILTREE COUNTY, TEXAS

Trujillo, Natasha Andrea, M.S.

This thesis focuses on an evaluation of the caprock for a commercial-scale carbon storage project at the Farnsworth Unit (FWU) in Texas. The FWU is currently in the injection phase of this Southwest Regional Partnership for Carbon Storage (SWP) project, and the goal is to inject 1 million metric tons of anthropogenic CO_2 into

the Morrow B sandstone reservoir. The main lithologies within the caprock are mudstone, cementstone, and some coal. The mechanical properties of these lithologies, along with an understanding of the diagenetic history of each lithology, help determine how the caprock will react to stress perturbation resulting from elevated pore pressure due to injection of supercritical CO_2 into the underlying reservoir.

The principal objective of this work is to understand the lithologic and diagenetic controls on mechanical attributes of the caprock. Important diagenetic processes that have affected the rock include: carbonate precipitation, as concretions and possibly laterally extensive cementstone layers, as well as fracture fills. The fracture fills are commonly fibrous calcite "beef" filling subhorizontal fractures. These may have formed during an overpressurization event and are found throughout the Thirteen Finger Limestone. The carbonate cementstone lithology within the Thirteen Finger Limestone is largely authigenic and was sampled from the core in grid patterns to infer lateral continuity. Because most of the grids have an asymmetric shape, the layers may be laterally extensive. However, it cannot be ruled out that some of the "layers" are part of larger concretions. The elastic properties of all the different lithologies within the caprock can be used to determine the brittle/ductile nature of these rocks. The cementstone is the most brittle lithology within the caprock, whereas the mudstones are the most ductile. Fracture analysis of the core from the characterization wells constrain paleo-stress conditions and induced fractures from the core helped determine current stress conditions within the subsurface. Determining the three principal stress orientations and magnitudes help predict critically oriented fractures and faults that could reactivate from injection of CO_2.

Determining seal potential for the FWU involved evaluation of seal geometry, capacity, and integrity for the upper Morrow Shale and the Thirteen Finger Limestone. The mudstone lithologies overlying the fluvial reservoir facies are marine in origin and the cementstones are of diagenetic origin. As the caprock covers the sandstone reservoir, which is laterally restricted by deposition in a paleo-valley, the caprock lithologies are laterally extensive enough to form an effective trap. Therefore, the principal issues related to the ability of the caprock to inhibit the upward migration of petroleum and CO_2 are the sealing capacity of the caprock lithologies, and the likelihood of any seal bypass features, such as interconnected fracture networks. With the above constraints, I conclude that the seal capacity is excellent for the principal caprock lithologies.

Understanding geomechanical properties of the caprock and attendant fracture gradients help constrain the maximum injection pressure possible without fracturing, as well as the likelihood of seal bypass. The maximum pore pressure that can be attained at the reservoir/caprock interface without fracturing the caprock is 6518 psi (44.9 MPa). The caprock lithofacies at the boundary between caprock and reservoir is predicted to behave in a ductile fashion, and is therefore not conductive to creation of fracture bypass systems. Seal bypass from existing fault/fracture reactivation is the largest threat to this caprock system. If the operator of FWU continues to stay below the fracture gradient for the caprock, then there should be no issue with loss of seal integrity.

ESTIMATION OF FOCUSED RECHARGE FOR NEW MEXICO USING A SOIL-WATER-BALANCE MODEL: PYRANA

Xu, Fei, M.S.

Determining the rate and distribution of groundwater recharge helps in water planning, sustainable development in the future, and preventing contaminants from entering the aquifer. Regional statewide in-place groundwater diffuse recharge estimation has been attempted by using a distributed-parameter soil-water-balance model that simulates recharge on the daily time-step at a resolution of 250 x 250 m. The model, which is called the Evapotranspiration and Recharge Model (ETRM), used gridded precipitation, reference evapotranspiration, and soil property data as the main inputs. Because focused recharge (i.e., transmission loss in ephemeral channels) is an important contributor to groundwater recharge in semiarid-to-arid environments, a stochastic rainfall-runoff generation algorithm was developed to substitute for the original Hortonian overland flow scheme in the ETRM runoff generation procedure. The change in the core algorithm of the ETRM made the model able to incorporate both diffuse recharge and transmission losses in the first-order basin scale into the statewide recharge estimation. Thus, Python Recharge Assessment for New mexico Aquifers (PyRANA) is proposed to be a more appropriate name for the new version of the ETRM model. PyRANA results show high recharge in the mountainous areas and the karst landscape of the state up to about 20% of annual precipitation. The rest of the semiarid part of the state recharged around 4% of annual precipitation. Arid parts of the state received little in-place recharge. PyRANA recharge results are close to previous point studies conducted in southern New Mexico. The amount of focused recharge at larger scales (2nd to 3rd order streams and higher) can be calibrated on the watershed basis by comparing PyRANA runoff and flume records. The rainfall-runoff generation regime was developed using data from the Walnut Gulch Experimental Watershed, which is under a semiarid to arid climate setting. Therefore, future work should focus on validating PyRANA by adding statistical analysis of rainfall-runoff generation procedure in the mountainous areas.

CRUSTAL DEFORMATION RELATED TO EMPLACEMENT OF THE SOCORRO MAGMA BODY

Yao, Shuoyu, M.S.

The Socorro magma body is the second-largest known crustal magma body on Earth. It covers 3400 square kilometers, has a thickness of ~130 m, and is situated at 19 km depth below the surface. The magma body is located within the Rio Grande rift zone, in the crust below the southern Albuquerque basin, the Socorro basin, and the accommodation zone connecting these two basins. Previous surface-leveling and InSAR studies suggest that the Socorro magma body is still active; causing surface uplift with a maximum rate of 2.5–3.0 mm/year centered around San Acacia, New Mexico. The Socorro seismic anomaly is a seismically very active region of mainly upper crustal earthquakes above the magma body.

In this study, Socorro magma body emplacement processes are studied, constrained by the sill-related surface uplift and seismicity patterns. I use the general finite-element software package Abaqus® to build models of crustal deformation. The fundamental analysis method used for all experiments is a fully-coupled thermal-stress analysis, in which results from thermal analysis depend upon displacement results and vice versa. The 2-D elastic models are composed of two parts: the crustal block, and the sill which is embedded into the crustal block at 19 km depth. Surface uplift above the Socorro magma body is caused by thermal expansion of the crustal material and/or a direct effect from inflation of the sill (magma addition). The two effects, thermal and mechanical, are both also modeled separately to understand their individual contributions, and combined in one model. The models predict thermal evolution, crustal deformation, and associated stresses.

The modeling results show the following crustal evolution upon sill emplacement: (1) A thermal aureole develops around the sill, resulting in thermal expansion. The uplift pattern caused by thermal expansion during the sill emplacement phase is wider, and the uplift rate is larger, than the observed uplift pattern; (2) After cooling of the emplaced sill starts, surface uplift rates are at least an order of magnitude smaller than observed uplift rates, and are below InSAR detection limits; (3) Net uplift caused by sill inflation is an approximately linear function of magma overpressure; (4) The temperature evolution suggests that the sill solidifies on a time scale of a few hundred years after an injection event; (5) Sill inflation causes crustal stresses, with a zone of horizontal compression directly above the sill, and horizontal tension between ~13 km depth and Earth's surface; (6) The average surface uplift rate during one heating-cooling cycle of the sill emplacement due to the combined effect of thermal expansion and inflation is similar to the observed uplift pattern.

Based on these results, I develop a new model for Socorro magma body emplacement. Because a newly emplaced sill cools down rapidly to temperatures below those associated with

the formation of a crystal mesh, the currently imaged fluid sill must be younger than several hundred years, or, if it is older, a significant magma injection event must have occurred in the last few hundred years to maintain the molten status of the sill. The ongoing seismicity above the sill is interpreted to result from injection events, which stress the crust so that slip along favorably oriented faults occurs. If this is true, magma injection occurs every 5–10 years or so, concurrent with seismic swarms. The current surface uplift above the sill results from sill inflation, and longer-term thermal expansion.

New Mexico State University

PROVENANCE AND SEDIMENT DISPERSAL TRENDS FROM EARLY PERMIAN (WOLFCAMPIAN) NONMARINE STRATA OF THE ABO FORMATION (AND AGE-EQUIVALENT STRATA) IN NEW MEXICO

Bonar, Alicia L, M.S.

The Early Permian (Wolfcampian) nonmarine, clastic strata of the Abo Formation (and age-equivalent strata) record the final stage of synorogenic sedimentation associated with the Ancestral Rocky Mountain orogeny (ARM) in New Mexico. During this time, ARM deformation was characterized by at least eight basement-block uplifts that exposed a number of Proterozoic basement provinces throughout southwestern Laurentia. Sandstone modal composition trends and U-Pb detrital zircon geochronology from these strata provide a basis for constraining uplift history and detrital contributions from basement blocks to create a new sediment dispersal model for the Early Permian stage of ARM orogenesis in New Mexico.

Sandstone modal composition for the Abo Formation (and age-equivalent strata) is dominated by quartz and feldspar grains, with rare lithic fragments (Q=56%, F=42%, L=2%). Northern samples contain a majority of the potassium feldspar grains (K=19%), and there is an absence of potassium feldspar in southern samples (K<l%). Southern samples deposited in the Orogrande basin underwent diagenetic alterations, including albitization. Bulk U-Pb age trends (n=662) from Early Permian strata reveal a primary peak age of 1689 Ma (Mazatzal-Yavapai province), with secondary peaks at 1247 Ma (Grenville province/De Baca Group) and 1378 Ma (Granite-Rhyolite province/Mesoproterozoic granitoids). However, despite the lithologic homogeneity of these strata, U-Pb age spectra from individual samples (N=7) vary considerably throughout New Mexico. Strata in northeastern New Mexico exhibit a primary peak age of 1376 Ma (Sierra Grande uplift), whereas strata in south-central New Mexico have a primary peak age of 1251 Ma (Pedernal uplift). Strata in north-central New Mexico have primary peak ages of 1692–1694 Ma (southern Uncompahgre uplift), while strata in west-central New Mexico have a primary peak age of 1706 Ma with a secondary peak at 1451 Ma (northern Uncompahgre uplift). Two samples in southern New Mexico exhibit no primary peaks, but have a wide range of ages from 270–3106 Ma, and are both locally and distally sourced (Pedernal, Uncompahgre uplifts).

Data support a model in which the Uncompahgre, Sierra Grande, and Pedernal uplifts in New Mexico were actively contributing sediment during the Early Permian, while the Defiance-Zuni and Peñasco uplifts were inactive and onlapped before the end of Abo deposition. Fluvial systems flowed from north to south, and drainage networks were complex and interconnecting, transporting sediment from central Colorado to southern New Mexico by the Early Permian.

EVALUATING ALONG-ARC TRENDS IN SUBDUCTION CONTRIBUTIONS TO THE SOUTHERN CASCADES: INSIGHTS FROM BASALTIC MAGMA GEOCHEMISTRY

Cole, Meredith, M.S.

The Cascade arc is a continental volcanic arc, extending from northern California to British Columbia, formed by subduction of the Juan de Fuca plate and the Gorda and Explorer micro-plates under the North American plate. The traditional model for generating arc magmas requires mantle melting resulting from fluid-fluxing of the mantle with a "subduction component" consisting of H_2O-rich fluids and/or melts (e.g., Plank and Langmuir, 1993; Plank et al., 2005). In a "hot slab" subduction zone, such as Cascadia, the subducting slab is young and relatively hot, such that complete dehydration of the slab should occur in the forearc, leading to a reduced capacity for fluid-flux melting of the sub-arc mantle wedge (Syracuse et al., 2010). However, basalts with elevated H_2O contents and trace element compositions consistent with subduction component contributions are associated with volcanoes in the southernmost arc as well as monogenetic vents in central Oregon (Grove et al., 2002; Leeman et al., 2005; Ruscitto et al., 2010; Ruscitto et al., 2011; Walowski et al., 2016). Segmentation of the arc and possible variation in mantle source enrichment also complicate magma generation in the Cascades. A variety of mafic lava types are erupted in the Cascades, including low potassium tholeiites (LKT), intraplate basalts (IPB) and calc-alkaline basalts (CAB), which have implications for styles of melt generation. This thesis uses whole-rock and melt inclusion major and trace elements, melt inclusion volatile contents, whole-rock isotopic compositions, and $^{40}Ar/^{39}Ar$ eruption ages in order to investigate trends in subduction component contributions and mantle sources within the southern Cascades between Mt. Shasta and central Oregon. Water contents are lower (<2.8 wt.%) than the Cascade arc average (3.2 wt.% H_20; Plank et al., 2005); however, CAB and LKT magmas have evidence (elevated Sr, Ba, Pb) for varying levels (2–6%) of subduction component contributions. Intraplate basalt magmas have minimal evidence for subduction contributions, and instead represent decompression melts of an enriched sub-arc mantle. Along the arc, subduction component contributions appear to decrease from south to north. There is also a change in mantle source enrichment along the arc, with magmas from central Oregon deriving from a more enriched mantle than those from northern California and southern Oregon. It also appears that subduction component contributions may have decreased over time, while mantle source enrichment, at least in central Oregon, may have increased. Although the Cascades are a "hot" subduction zone, this thesis finds that both magmas with evidence for subduction contributions (CAB, LKT) and those without (IPB) are erupted within the arc and that subduction contributions to CAB and LKT magmas decrease northward along the arc.

INFLUENCE OF INHERITED CRUST ON THE MAZATZAL PROVINCE INTRUSIVE ROCKS: EVIDENCE FROM ZIRCON XENOCRYSTIC CORE AGES AND ISOTOPE GEOCHEMISTRY

Howland, Colby R., M.S.

U-Pb geochronology, zircon Hf isotope compositions, whole-rock geochemistry, and geologic mapping were used to understand the formation of the Mazatzal province in southern New Mexico and provide insight into lithospheric crustal growth during the Paleoproterozoic. The data indicate three pulses of Paleoproterozoic magmatism occurred in southern New Mexico at 1675 Ma, 1655 Ma, and 1630 Ma. These pulses of magmatism formed during different tectonic regimes. 1675 Ma igneous rocks are pervasively deformed felsic gneisses with more evolved Hf isotopes (εHf=+4.3) and contain xenocrystic (1737 ± 16 Ma and 1778 ± 13 Ma) zircon cores suggesting a component of recycling of Yavapai-age crust or sediment during their formation. Through time, Mazatzal-age plutons show an increase in their apparent $^{176}Lu/^{177}Hf$ ratios, indicating the progressive mixing of juvenile lithosphere with older evolved crust. Field relationships and U-Pb ages suggest that the deformation of the orthogneiss, schist, and amphibolite units in the northern San Andres Mountains occurred as a result of the Mazatzal orogeny (1670–1650 Ma). The 1655 Ma pulse of magmatism consists of 'S-type' or 'two mica' undeformed granites with high $Si0_2$ and Al_20_3, low MgO, and Nd model ages generally between 1.9–2.1 Ga. These data suggest the reworking of earlier 1675 Ma crust during crustal melting in a syn- or post-orogenic setting. The final pulse of magmatism (1630 Ma) is bimodal (mafic and felsic igneous rocks), has juvenile Hf compositions, and trace element geochemistry similar to a rift setting indicating that orogenic collapse of the overthickened Mazatzal lithosphere may have occurred at 1630 Ma.

University of New Mexico

NEW GEOCHEMICAL AND ISOTOPIC APPROACHES TO SHALLOW CRUST LANDFORM EVOLUTION
Decker, David, Ph.D.

Many researchers have studied the Guadalupe Mountains in detail and starting with King (1948), many of them have speculated about the timing of the uplift of the Guadalupe block. There are several competing hypotheses including Laramide, Basin and Range, and Rio Grande Rifting uplift scenarios. Using uranium-lead dating of scalenohedral spar found in small vug caves throughout the study area, I have dated the episodes of spar formation to two major phases, 36 to 33 Ma and 30 to 27 Ma. These two episodes of spar formation are in good agreement with the time frame of the ignimbrite flare up during the formation of the Basin and Range. I have also dated several older phases, all the way back to ~180 Ma, which all correspond to nearby (<100 km) known volcanic activity and provide a good argument for the hydrothermal genesis of the spar. By determining the depth of formation of the spar through a new speleogenetic model (supercritical CO_2), age dating the cave spar through U-Pb dating techniques, and finding the temperature of formation of the spar through a newly calibrated $\delta^{88}Sr$ thermometer and fluid inclusion assemblage analysis, I have been able to develop a thermochronometer in a region that has not had the typical apatite fission track and apatite thorium-helium methods available. Using this new method, along with U-Pb dating of calcite vein spar from the Border Fault Zone, I have constrained the timing of the uplift of the Guadalupe block to between 27 and 16 million years.

DENSE-ARRAY TELESEISMIC IMAGING OF THE SOUTHERN ALBUQUERQUE BASIN
Finlay, Tori S., M.S.

The southern Albuquerque basin is a complex area of high extension, multiple orogenies, and ongoing uplift from a midcrustal magma body in which geophysical coverage is sparse. In this thesis, I capitalize on recent innovations in dense-array processing techniques to create virtual source reflection profiles from five teleseismic events during the deployment of the Sevilleta array. The Sevilleta array consisted of ~800 vertical component nodes with ~300 m spacing deployed for 10 days in February of 2015. Virtual source reflection profiles are created by using the free surface of the earth as a virtual seismic source, yielding profiles that mimic active source seismic surveys. From the seventeen virtual source reflection profiles created, I am able to resolve mapped and buried geologic structures throughout much of the southern Albuquerque and northern Socorro basins. Furthermore, I present a unique case of teleseismic P-wave to Rayleigh wave conversion, which is a dominating feature along the western margin of the two basins. The dense instrument spacing makes it possible to detect these arrivals, which likely occur due to the strong impedance contrast between the rift basin sediments and bounding basement-cored fault blocks.

A SPELEOTHEM RECORD OF CLIMATE VARIABILITY IN SOUTHWESTERN NORTH AMERICA DURING MARINE ISOTOPE STAGE 3
Peinado, Justin G., M.S.

During Marine Isotope Stage 3 (MIS-3) of the last glacial period, there were rapid transitions between warm and cold climates referred to as Dansgaard-Oeschgerr (DO) events. In Southwestern North America (SWNA), two speleothem paleoclimate records document changes in moisture source delivery in response to DO-events during MIS-3, but do not address potential changes in effective moisture for the region. In this study, we introduce a new high-resolution speleothem paleoclimate record from Carlsbad Cavern in the Guadalupe Mountains. The speleothem, sample BC-5, grew continuously from 46–31 kya during the latter half of MIS-3, based on U-Th dating. We also tied stable isotope ($\delta^{18}O$ and $\delta^{13}C$) and trace element (Sr/Ca, Mg/Ca, and Ba/Ca) analysis to the U-series chronology to produce multiple high-resolution time-series. Our data further strengthens the shifting westerly storm-track hypothesis and suggest that DO-events led to changes in effective moisture. The stable isotope time-series displays DO-events and are clearly tied to other speleothem records from SWNA and the NGRIP ice core record. When compared to a Holocene speleothem record (BC-11) and a speleothem Asian Monsoon record, it becomes apparent that $\delta^{13}C$ is a record of local changes in effective moisture and vegetation. $\delta^{13}C$ also suggests an atmospheric ρCO_2 control on vegetation and speleothem calcite during the last glacial as has been suggested in other studies. Trace element analysis of BC-5 further supports the stable isotope interpretations. Sr/Ca, Mg/Ca, and Ba/Ca all strongly covary, indicating that they are controlled by similar processes, and are likely connected to changes in effective moisture and local karst processes.

BIRTH AND EVOLUTION OF THE VIRGIN RIVER: ~1 KM OF POST-5 MA UPLIFT OF THE WESTERN COLORADO PLATEAU
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The uplift history of the Colorado Plateau has been debated for over a century with still no unified hypotheses for the cause, timing, and rate of uplift. $^{40}Ar/^{39}Ar$ dating of semi-continuous basaltic volcanism over the past ~6 Ma within the Virgin River drainage system, southwest Utah and southern Nevada, provides a way to calibrate differential river incision and compare patterns of basaltic migration, mantle velocity structure, channel steepness, lithology, incision history and the birth and evolution of the Virgin River. New detrital sanidine ages constrain the arrival of the Virgin River across the Virgin Mountains to a maximum depositional age of 5.9 Ma. Incision magnitudes and rates of the Virgin River show a stair-step increase in bedrock incision as the river crosses multiple N-S trending normal faults. Average calculated rates are 23 m/Ma in the Lake Mead block, 85 m/Ma in the combined St. George and Hurricane blocks, and 338 m/Ma in the Zion block. Block-to-block differential incision adds cumulatively such that the Zion block has been deeply incised ~1 km (~315 m/Ma) over 3.6 Ma relative to the Colorado River confluence. We test two hypotheses: 1) observed differential incision magnitudes and rates along the Virgin River system are a measure of mantle-driven differential uplift of the Colorado Plateau relative to sea level over the past ~5 Ma. 2) Observed differential river incision relates to river integration across previously uplifted topography and differential rock types with no post 5 Ma uplift. Strong correlations exist between high channel steepness (ksn) and low mantle velocities throughout the Virgin River drainage while weaker correlations exist between high ksn and resistant lithologies. Basaltic volcanism, which has migrated at a rate of ~18 km/Ma parallel to the Virgin River between ~13 and 0.5 Ma suggests a possible mantle-driven mechanism for the combined observations of differential uplift across faults and additional young Colorado Plateau epeirogenic uplift tracked by headward river propagation. Thus, we interpret the Virgin River to be a <4.5 Ma disequilibrium river system responding to ongoing upper mantle modification and related basalt extraction, which is driving ~1 km of young uplift of the western Colorado Plateau.

GLOBAL SEAWATER REDOX TRENDS DURING THE LATE DEVONIAN MASS EXTINCTION DETECTED USING U ISOTOPES OF MARINE CARBONATES
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The Late Devonian extinction ranks as one of the 'big five' Phanerozoic extinctions affecting up to 80% of marine species and occurred during five distinct pulses spanning /or widespread marine anoxia. We test the marine anoxia hypothesis by analyzing uranium isotopes ($\delta^{238}U$) across a ~7 My interval of well-dated Upper Devonian marine carbonates from the Devil's Gate Limestone in Nevada, USA.

The measured $\delta^{238}U$ curve shows no co-variation with local anoxic facies, water-depth dependent facies changes, redox-sensitive metals, TOC, or diagnostic elemental ratios indicating the $\delta^{238}U$ curve was not controlled by local depositional or diagenetic processes and represents global seawater redox conditions. Two negative $\delta^{238}U$ shifts (indicating more reducing seawater) are observed with durations of ~3.8 My (late Frasnian) and ~1.1 My (early Famennian), respectively. Steady-state modeling of the observed -0.2 to -0.3‰ shifts in $\delta^{238}U$ points to a ~5–15% increase in the total area of anoxic seafloor during these excursions. The

late Frasnian negative shift is broadly coincident with the first extinction pulse (late rhenana Zone or lower Kellwasser event), whereas the early Famennian negative shift (lower-middle triangularis zones) does not coincide with the most intense Frasnian-Famennian boundary (F-F) extinction pulses (upper Kellwasser event). Compilations of local sediment redox conditions from Upper Devonian marine deposits with conodont zone-level age control indicates that the extinction pulses were coincident with widespread anoxic deposits accumulating in subtropical epeiric sea and some open-ocean settings supporting previous interpretations that widespread marine anoxia had an important influence on the Late Devonian extinction. The temporal relationships between global ocean redox trends represented by the $\delta^{238}U$ curve and the newly compiled subtropical marine redox sediment trends indicates Late Devonian global oceans and epeiric seas were in relatively good redox communication for the majority of the study interval except for a brief interval (<500 ky) spanning the F-F boundary.