New Mexico Geological Society

Proceedings Volume

Uranium in New Mexico: the Resource and the Legacy

2017 Annual Spring Meeting

Macey Center

New Mexico Tech

Socorro, NM

NEW MEXICO GEOLOGICAL SOCIETY
2017 SPRING MEETING
Friday, April 7, 2017
Macey Center
New Mexico Tech Campus
Socorro, New Mexico 87801

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NMGS EXECUTIVE COMMITTEE
President: Matthew Heizler
Vice President: Susan Lucas Kamat
Treasurer: Dan Koning
Secretary: Shannon Williams
Past President: David Ennis

2017 SPRING MEETING COMMITTEE
General Chair: Bonnie Frey
Technical Program Chair: Virginia T. McLemore
Registration Chair: Connie Apache

ON-SITE REGISTRATION
Connie Apache

WEB SUPPORT
Adam Read

ORAL SESSION CHAIRS
Kelsey McNamara, Stacy Timmons, Bruce Allen, David Ennis, Sara Chudnoff, Gary Axen

Registration

Lower Lobby: *7:15 AM - 12:00 PM*

NMGS Business Meeting and Awards Ceremony

Auditorium: *8:00 AM - 8:15 AM*

Welcoming Remarks: Nelia Dunbar, Director of New Mexico Bureau of Geology and Mineral Resources and State Geologist

Auditorium: *8:15 AM - 8:25 AM*

Energy in New Mexico:

Auditorium: *8:30 AM - 9:50 AM*
Chair: Kelsey McNamara

THE UPPER MANCOS SHALE IN THE SAN JUAN BASIN: THREE OIL AND GAS PLAYS, CONVENTIONAL AND UNCONVENTIONAL
— Ronald F Broadhead
8:30 AM - 8:50 AM

GEOTHERMAL POTENTIAL OF THE SOUTHERN SAN LUIS BASIN, TAOS COUNTY, NEW MEXICO
— Shari Kelley and Jeff D. Pepin
8:50 AM - 9:10 AM

URANIUM RESOURCES IN NEW MEXICO IN 2017
— Virginia T. McLemore
9:10 AM - 9:30 AM

THE EVOLUTION OF URANIUM MINERALIZATION IN NEW MEXICO
— Virgil W Lueth and Kelsey McNamara
9:30 AM - 9:50 AM

Watersheds and hydrology:

Galena Room: *8:30 AM - 9:50 AM*
Chair: Gary Axen

TURNING TOYS INTO TOOLS: UNMANNED AIRCRAFTS FOR THE 21ST CENTURY GEOSCIENTIST
— Matthew J. Zimmerer and Jake I. Ross
8:30 AM - 8:50 AM

RELATIONSHIP BETWEEN TREE CANOPY COVER AND DISCHARGE OF UPPER GALLINAS WATERSHED, NEW MEXICO, 1939 – 2015
— Behnaz Yekkeh
8:50 AM - 9:10 AM

WHAT LIES BENEATH THE DUNES? GRAVITY MEASUREMENTS TO CHARACTERIZE SUB-SURFACE DENSITY STRUCTURE AND UNDERSTAND CONTROLS ON DUNE MIGRATION IN WHITE SANDS NATIONAL MONUMENT, NEW MEXICO
— Ryan Dunagin, M. Roy, Shari Kelley, L. Worthington, and J. Butts
9:10 AM - 9:30 AM

THE DEMISE OF THE CUATROCIÉNEGAS GYPSUM DUNE FIELD, AND WHAT IT MEANS FOR THE WHITE SANDS NATIONAL MONUMENT
— Ethan A. Mamer and B. Talon Newton
9:30 AM - 9:50 AM

Key Note:

Auditorium: *9:55 AM - 10:35 AM*

Chair: Bonnie Frey

URANIUM INDUSTRY: OVERVIEW
— Bernard Bonifas
9:55 AM - 10:35 AM

Break: Poster viewing and visiting our vendors

Lobby: *10:35 AM - 10:55 AM*

VENDORS

Samantha Caldwell
New Mexico Tech—SEG
Socorro, NM 87801
samantha.caldwell@student.nmt.edu
859-640-3041

Tammy Legler and Jack Farley
New Mexico Mining Museum
PO Box 297
Grants, NM 87020
discover@grants.org
505-287-4802

Shannon Williams
AMEC Foster Wheeler
8519 Jefferson NE
Albuquerque, NM 87113
shannon.williams@amecfw.com
505-821-1801

John Sorrell
NM American Institute of Professional Geologists
PO Box 12332
Albuquerque, NM 87105
susan.vongonten@state.nm.us
505-476-4389

ORAL PRESENTATIONS

Paleontology in New Mexico:

Galena Room: *10:55 AM - 12:35 PM*
Chair: Bruce Allen

THE PALEOZOIC SECTION AT BELL HILL, SOCORRO COUNTY, NEW MEXICO
— Spencer G. Lucas, Bruce Allen, Karl Krainer, and James E. Barrick
10:55 AM - 11:15 AM

PHYLOGENY OF THE ENIGMATIC EOCENE TESTUDINOID TURTLE *ECHMATEMYS* AND THE ORIGIN OF THE TESTUDINIDAE
— Asher Jacob Lichtig and Spencer G Lucas
11:15 AM - 11:35 AM

NEW EVIDENCE FOR CANNIBALISM IN TYRANNOSAURID DINOSAURS FROM THE LATE CRETACEOUS OF NEW MEXICO
— Sebastian G. Dalman and Spencer G. Lucas
11:35 AM - 11:55 AM

X-RAY AND NEUTRON COMPUTED TOMOGRAPHY OF VERTEBRATE FOSSILS AT THE LOS ALAMOS NEUTRON SCIENCE CENTER, LOS ALAMOS NATIONAL LABORATORY, NEW MEXICO
— Thomas E. Williamson, Stephen L. Brusatte, Michelle A. Espy, Cort Gautier, James Hunter, Adrian S. Losko, Ronald O. Nelson, Katlin Schroeder, and Sven Vogel
11:55 AM - 12:15 PM

FUNCTIONAL CHANGE IN MOLLUSCAN DIVERSITY DYNAMICS OBSERVED ACROSS OAE2
— Nicholas Freymueller and Corinne Myers
12:15 PM - 12:35 PM

Uranium in New Mexico:

Auditorium: *10:55 AM - 12:35 PM*
Chair: David Ennis

WHY I REMAIN A URANIUM BULL
— Michael S. (Mickey) Fulp
10:55 AM - 11:15 AM

GEOCHEMICAL PROCESSES CONTROLLING TRANSPORT AND DEPOSITION OF URANIUM, ESPAÑOLA BASIN, NEW MEXICO
— Patrick Longmire, Virginia T. McLemore, Dennis McQuillan, Stephen Yanicak, and David Vaniman
11:15 AM - 11:35 AM

AN ABANDONED URANIUM MINE SURVEY OF MINE SITES IN NEW MEXICO
— Annelia Tinklenberg and Robert Sengebush
11:35 AM - 11:55 AM

THE CHARACTERIZATION OF ABANDONED URANIUM MINES IN NEW MEXICO
— John Asafo-Akowuah and Virginia T. McLemore
11:55 AM - 12:15 PM

REACTIVATION OF THE MT. TAYLOR MINE – OBSTACLES AND OPPORTUNITIES
— Alan K Kuhn
12:15 PM - 12:35 PM

LUNCH

Copper Room (not included in registration): *12:35 PM - 1:30 PM*

Economic and Environmental Geology:

Auditorium: *1:30 PM - 3:30 PM*
Chair: Sara Chudnoff

URANIUM CONCENTRATIONS IN DUST FLUX ACROSS THE JACKPILE MINE SUPERFUND SITE
— Reid D Brown, Dan Cadol, and Bonnie Frey
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PHYLLIC ALTERATION IN THE COPPER FLAT PORPHYRY COPPER DEPOSIT, SIERRA COUNTY, NEW MEXICO
— Kierran Maher and Chaneil Wallace
1:50 PM - 2:10 PM

PARAGENESIS OF URANIUM MINERALS IN THE GRANTS MINERAL BELT, NEW MEXICO: APPLIED GEOCHEMISTRY AND THE DEVELOPMENT OF OXIDIZED URANIUM MINERALIZATION
— Samantha Caldwell and William X. Chavez, Jr.
2:10 PM - 2:30 PM

GEOCHRONOLOGY AND GEOCHEMISTRY OF THE METASOMATIC PROCESSES RELATED TO EPISYENITES IN CENTRAL NEW MEXICO AND COLORADO
— Adam E. Smith, Matthew T. Heizler, Virginia T. McLemore, Kierran C. Maher, and Frank C. Ramos
2:30 PM - 2:50 PM

^{40}AR/^{39}AR GEOCHRONOLOGY OF MAGMATISM AND ALTERATION IN THE GALLINAS MOUNTAINS WITH IMPLICATIONS FOR RARE EARTH MINERALIZATION
— Alanna Robison, William McIntosh, and Virgil W. Lueth
2:50 PM - 3:10 PM

FORSTERITE AND PYRRHOTITE DISSOLUTION RATES FROM KINETIC TESTING USING MINE TAILINGS: RESULTS FROM GEOCHEMICAL MODELLING
— Rodrigo Frayna Embile, Jr. and Ingar Walder
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Volcanology and Stratigraphy in New Mexico:

Galena Room: *1:30 PM - 3:50 PM*
Chair: Stacy Timmons

DETRITAL SANIDINE ^{40}AR/^{39}AR DATING: TRANSFORMING SEDIMENTARY ROCK GEOCHRONOLOGY
— Matthew T Heizler, Karl Karlstrom, Matthew Zimmerer, Jake Ross, Laura Crossey, and William McIntosh
1:30 PM - 1:45 PM

^{40}AR/ ^{39}AR DETRITAL SANIDINE DATING OF THE OGALLALA FORMATION IN SOUTHEASTERN NEW MEXICO AND WEST TEXAS
— Kevin Henry, Matthew T. Heizler, and Steve T. Cather
1:45 PM - 2:00 PM

IMPLICATIONS OF PAST EXTENTS OF RIO SALADO AND RIO PUERCO DEPOSITS IN THE SOUTHWESTERN CORNER OF THE ALBUQUERQUE BASIN, NEW MEXICO
— David W. Love, Alex Rinehart, Richard Chamberlin, Eda Celep, and Dan Koning
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— Eda Celep, Daniel J. Koning, and David W. Love
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THE ONSET OF RHYOLITE VOLCANISM AND SUBSEQUENT COLLAPSE IN THE SCHOOLHOUSE MOUNTAIN CALDERA, MOGOLLON-DATIL VOLCANIC FIELD, SOUTHWEST NEW MEXICO
— Vanessa M. Swenton, Jeffrey M. Amato, Tara Jonell, and William C. McIntosh
2:30 PM - 2:45 PM

THE "BOX CANYON TUFF" AND ITS RELATIONSHIP TO THE SCHOOLHOUSE MOUNTAIN CALDERA, MOGOLLON-DATIL VOLCANIC FIELD, SOUTHWEST NEW MEXICO
— Jeffrey M. Amato, Vanessa M. Swenton, William C. McIntosh, and Tara N. Jonell
2:50 PM - 3:05 PM

Volcanology and Stratigraphy in New Mexico: continued

5 MINUTE STRETCH

THE LATE MIOCENE- EARLY PLIOCENE UNCONFORMITY IN THE RIO GRANDE RIFT
— Jolante van Wijk, Gary Axen, Dan Koning, and David Coblentz
3:05 PM - 3:20 PM

SEDIMENTOLOGY, STRATIGRAPHY, AND GEOCHRONOLOGY FROM EARLY(?)–MIDDLE EOCENE, POST-LARAMIDE VOLCANIC AND VOLCANICLASTIC STRATA OF THE PALM PARK FORMATION IN SOUTH-CENTRAL NEW MEXICO
— Ryan H Creitz, Brian A Hampton, Greg H Mack, and Jeffrey M Amato
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CORRELATION OF ASH FLOW TUFFS FROM THE MOGOLLON-DATIL VOLCANIC FIELD IN SOUTHWESTERN NEW MEXICO USING LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS): AN ANALYSIS OF SANIDINE PHENOCRYSTS
— Trenton L Haskell and Nancy J McMillan
3:35 PM - 3:50 PM

Formal Poster Viewing, visiting our vendors (listed on p. 4), cash bar and afternoon snacks

Lobby: *3:30 PM - 5:00 PM*

Student Awards Recognition

POSTERS

Uranium in New Mexico Posters:

Lobby: *8:00 AM - 5:00 PM*
Chair: Virginia McLemore

ASSESSING URANIUM CONCENTRATION IN STREAM SEDIMENT ON THE LAGUNA AND ISLETA PUEBLOS
— Brianne Willis
Booth: *1*

ENVIRONMENTAL AQUEOUS GEOCHEMISTRY OF URANIUM IN AQUIFER SYSTEMS, PAJARITO PLATEAU, NEW MEXICO
— Patrick Longmire, Kim Granzow, Stephen Yanicak, David Fellenz, Michael Dale, Megan Green, and Antonio Trujillo
Booth: *2*

SEQUENTIAL CHEMICAL EXTRACTION AS A METHOD TO DETERMINE URANIUM MINERAL LEACHABILITY AND SPECIATION
— Alexandra Rose Pearce, Ingar F Walder, Bonnie Frey, and Virgil W Lueth
Booth: *3*

THE CHARACTERIZATION OF URANIUM MOBILITY AT THE JETER MINE, LADRON MOUNTAIN MINE DISTRICT, SOCORRO COUNTY, NEW MEXICO
— Ashlynne Winton, Ingar Walder, and Bonnie Frey
Booth: *4*

URANIUM RESOURCE POTENTIAL IN NEW MEXICO
— Virginia T. McLemore and John Asafo-Akowuah
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Economic and Environmental Geology Posters:

Lobby: *8:00 AM - 5:00 PM*

THE RECENT ALPINE HIGH OIL AND GAS FIELD DISCOVERY, WEST TEXAS
— Anthony L Benson
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LEGACY MOLYBDENUM MINE TAILINGS IN THE CONTEXT OF THE QUESTA CALDERA: CHALLENGES IN DISTINGUISHING ANTHROPOGENIC FROM BACKGROUND WATER TYPES
— Kylian Nathiel Robinson
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ORIGIN AND MINERAL RESOURCE POTENTIAL OF THE ROSEDALE DISTRICT, SOCORRO COUNTY, NEW MEXICO
— William Zutah and Virginia T. McLemore
Booth: *8*

NICKEL LEACHING FROM DUNITIC MINE WASTE
— Margaret Tinsley, Ingar F Walder, Franciszka Stopa, Jenna Donatelli, and Rodrigo Embile
Booth: *9*

METAL LEACHING FROM THE VHMS SULITJELMA MINING DISTRICT, NORWAY
— Franciszka Kay Stopa and Ingar Walder
Booth: *10*

DISTINGUISHING CALCITE WITH AND WITHOUT BIOMARKERS USING LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS), GUADALUPE MOUNTAINS, NEW MEXICO
— Brent A. Jackson and Nancy J. McMillan
Booth: *11*

Mapping and Stratigraphy Posters:

Lobby: *8:00 AM - 5:00 PM*

THE CRETACEOUS SECTION AT PLACITAS, SANDOVAL COUNTY, NEW MEXICO
— Spencer G. Lucas and John B. Rogers
Booth: *12*

COMING SOON – GEOLOGIC MAP OF THE MOUNT TAYLOR VOLCANO AREA, NEW MEXICO: CENTERPIECE FOR THE 2020 FALL FIELD CONFERENCE
— Fraser Goff, Shari A Kelley, David J McCraw, Cathy J Goff, Bonnie A Frey, Kate Zeigler, and Virginia T McLemore
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THE PALEOPROTEROZOIC MAZATZAL PROVINCE OF SOUTHERN NEW MEXICO: INSIGHT FROM DETAILED FIELD MAPPING AND ISOTOPE GEOCHEMISTRY
— Colby Howland and Jeff M. Amato
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CHANGE IN PROVENANCE OF PROTEROZOIC METASEDIMENTARY ROCKS IN THE PICURIS MOUNTAINS BASED ON LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS) OF DETRITAL TOURMALINE
— Shoshauna Farnsworth-Pinkerton, Nancy J McMillan, Barbara L Dutrow, and Darrell J Henry
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Hydrogeology in New Mexico Posters:

Lobby: *8:00 AM - 5:00 PM*

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— Joseph Zebrowski, Patti Dappen, and Adrian Sanchez
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— Zach Shephard and Dan Cadol
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A HYDROGEOCHEMICAL ANALYSIS AND RECHARGE EVALUATION OF CIENEGA SPRING LOCATED IN THE SANDIA MOUNTAINS, NEW MEXICO
— Alexandra J Minitrez, Laura J Crossey, and Christopher McGibbon
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3D INVERSE MODELS OF MAGNETOTELLURIC DATA IN THE CENTRAL RIO GRANDE RIFT ILLUMINATE RIFT BASIN GEOMETRY AND POSSIBLE INTERACTIONS BETWEEN DEEP BRINES AND SURFACE WATERS
— Matthew Folsom, Jeff Pepin, Jared Peacock, Mark Person, Shari Kelley, and David Love
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— Brian A. Hampton, Greg H. Mack, and Cody J. Stopka
Booth: *20*

Paleontology Posters:

Lobby: *8:00 AM - 5:00 PM*

STRATIGRAPHY AND AGE OF THE DINOSAUR-DOMINATED FOSSIL ASSEMBLAGE OF THE UPPER CRETACEOUS HALL LAKE MEMBER OF THE MCRAE FORMATION, SIERRA COUNTY, NEW MEXICO
— Spencer G. Lucas, Sebastian Dalman, Asher J. Lichtig, Scott Elrick, W. John Nelson, and Karl Krainer
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FOSSIL TURTLES OF THE UPPER CRETACEOUS MCRAE FORMATION, SIERRA COUNTY, NEW MEXICO
— Asher Jacob Lichtig and Spencer G Lucas
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A NEW CHASMOSAURINE CERATOPSID FROM THE HALL LAKE MEMBER OF THE MCRAE FORMATION (MAASTRICHTIAN), SOUTH-CENTRAL NEW MEXICO
— Sebastian G. Dalman and Spencer G. Lucas
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WATER-DEPTH-BASED DIFFERENCES IN AMMONOID ASSEMBLAGES FROM THE UPPER CRETACEOUS (TURONIAN) BLUE HILL MEMBER OF THE CARLILE SHALE, NORTH-CENTRAL NEW MEXICO
— Michael P. Foley and Spencer G. Lucas
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A POSSIBLE NEW SPECIES OF *DIMETRODON* (EUPELYCOSAURIA: SPHENACODONTIDAE) FROM THE LOWER PERMIAN ABO FORMATION, SOCORRO COUNTY, NEW MEXICO
— Kenneth L McKeighen, Kendra R. McKeighen, Henry W. McKeighen, and Spencer G. Lucas
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LOWER CRETACEOUS (UPPER ALBIAN) NAUTILOIDS FROM CERRO DE CRISTO REY, DOÑA ANA COUNTY, NEW MEXICO
— Paul L. Sealey, Spencer G. Lucas, and Kevin Durney
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— Bruce D. Allen and Spencer G. Lucas
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— Larry F. Rinehart and Spencer G. Lucas
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Magmas and Calderas Posters:

Lobby: *8:00 AM - 5:00 PM*

THE RATON-CLAYTON VOLCANIC FIELD: EVALUATING OPEN-SYSTEM PROCESSES IN MAGMAS DERIVED BENEATH THE GREAT PLAINS
— Sid Pinkerton, Frank C. Ramos, and Matthew Zimmerer
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— Tyler J Askin, Frank C Ramos, and Peter J Stevens
Booth: *31*

A MODEL FOR SOCORRO MAGMA BODY EMPLACEMENT
— Jolante van Wijk, Shuoyu Yao, and Gary Axen
Booth: *32*

USING A NEW TEMPORARY SEISMIC NETWORK TO DETECT EARTHQUAKES IN THE SOCORRO MAGMA BODY REGION
— Rhiannon E Vieceli, Susan L Bilek, Richard C Aster, Lindsay Lowe-Worthington, and Brandon Schmandt
Booth: *33*

STUDENT—INDUSTRY MIXER

Student Awards Recognition

5:00-7:00

Galena Room

This year, we will host an *Evening Student—Industry Mixer* from 5 p.m. to 7 p.m. Pizza and hot Asian hors d'oeuvres will be served (catered by Chartwells), along with a cash bar. We hope this new event will provide a casual but informative venue for students to seek career advice from professionals. Registration for the mixer is required but is free. Students and industry representatives are encouraged to attend. This event would not possible without our donors support.

DONORS

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THE FUSULIND *EOWAERINGELLA* AND THE DESMOINESIAN-MISSOURIAN BOUNDARY IN CENTRAL NEW MEXICO: REEXAMINATION OF THE GOTERA CANYON SECTION, NORTHERN MANZANO MOUNTAINS

Bruce D. Allen[1] and Spencer G. Lucas[2]

[1]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801, bruce.allen@nmt.edu
[2]New Mexico Museum of Natural History, 1801 Mountain Road N.W., Albuquerque, NM, 87104

In New Mexico, the contact between Middle and Upper Pennsylvanian strata is often reported to coincide closely with the top of the Gray Mesa Formation, a widespread Middle Pennsylvanian lithostratigraphic unit in the central to south-central part of the state. This perception is based partly on the fusulinacean biostratigraphy of D.A. Myers (USGS), who worked in the Manzano Mountains during the 1960s through the 1980s. Myers' monograph on the distribution of fusulinids from the Manzano Mountains (USGS Prof. Paper 1446) identifies a single locality where age-diagnostic fusulinids allegedly indicate that deposition of the Gray Mesa Formation lasted throughout Desmoinesian and into earliest Missourian time. In particular, the fusulinid genera *Eowaeringella*, which is restricted to strata near the base of the Missourian Stage, was reported at the top of the Gray Mesa Formation (what Myers initially called the "lower member of the Madera Formation," and, in later maps and reports, the "Los Moyos Limestone"). However, more recent biostratigraphy of Pennsylvanian rocks in the southern Manzano Mountains and in the hills east of Socorro suggest that the Missourian base in those areas is higher in the Pennsylvanian succession; that is, in the lower part of the overlying Atrasado Formation. Consequently, we revisited Myers' locality in order to assess the fusulinid biostratigraphy and the lithostratigraphy near the contact between the Gray Mesa and Atrasado formations at that site. The locality is in Gotera Canyon in the Manzano Mountains, approximately 30 km east of Isleta Pueblo. It was originally documented by Myers during geologic mapping of the Escabosa 7.5' quadrangle (USGS geologic map GQ-795), which included a measured stratigraphic section through the interval containing *Eowaeringella*. Myers' measured section was located and a 70+ m thick interval comprising the uppermost Gray Mesa Formation and the overlying Bartolo, Amado and lowermost Tinajas members of the Atrasado Formation was examined and measured. We were able to locate distinct intervals, including sandstone beds, shown on Myers' measured section, and the *Eowaeringella*-bearing horizon was indeed present, together with additional fusulinid-bearing beds several meters higher containing species of thin-walled, cylindrical *Triticites*, indicating an early to middle Missourian age. The *Eowaeringella* horizon is approximately 50 m above the top of the Gray Mesa Formation, near the contact between the Amado and the overlying Tinajas members of the Atrasado Formation. Interestingly, Myers' graphic section places the *Eowaeringella* zone at the top of the Gray Mesa Formation, but the geologic map itself places the top well below that level, in agreement with the obvious lithostratigraphic boundary evident on outcrop. Indeed, the contact between the Gray Mesa and Atrasado formations at the Gotera Canyon locality, similar to other exposures in the Manzano-Manzanita Mountains, is marked by a relatively thick basal sandstone unit (Coyote Sandstone Bed), followed by a succession of mostly covered (probably shale) intervals that comprise the main part of the Bartolo Member of the Atrasado Formation.

The Pueblo of Isleta granted permission to examine the Gotera Canyon section, and their assistance with gaining access is gratefully acknowledged.

THE "BOX CANYON TUFF" AND ITS RELATIONSHIP TO THE SCHOOLHOUSE MOUNTAIN CALDERA, MOGOLLON-DATIL VOLCANIC FIELD, SOUTHWEST NEW MEXICO

Jeffrey M. Amato[1], Vanessa M. Swenton[1], William C. McIntosh[2] and Tara N. Jonell[3]

[1]Department of Geological Sciences, New Mexico State University, PO Box 30001/MSC 3AB, Las Cruces, NM, 88003, amato@nmsu.edu
[2]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801
[3]Department of Geology and Geophysics, Louisiana State University, Baton Rouge, LA, 70803

Rhyolite tuffs in the Mogollon-Datil volcanic field (MDVF; McIntosh et al., 1991;1992, hereafter M91, M92) and Boot Heel volcanic field (BHVF: McIntosh and Bryan, 2000) were previously correlated based on $^{40}Ar/^{39}Ar$ sanidine geochronology and paleomagnetism. For this project we revisited correlations between tuffs and inferred caldera sources for the time period 33.8–33.7 Ma, focusing on the "Box Canyon tuff" (M92). The southwestern MDVF contains exposures of several ~33.7 Ma tuffs, including Luna, Fall Canyon, Cherokee Canyon, "Kneeling Nun of Hedlund, 1978" (not actually Kneeling Nun), "Sugarlump," Bell Top 6, and Box Canyon. These were grouped as the "Box Canyon tuff" at 33.73 ± 0.13 Ma (M92; formerly 33.51 Ma; all ages recalculated). Most samples were from outflow sheets, but the Cherokee Canyon tuff within the SMC was interpreted as caldera-fill and thus the SMC was inferred as the source of the "Box Canyon" tuffs. McIntosh and Bryan (2000) subsequently noted that the Oak Creek tuff, sourced from the Juniper caldera in the BHVF, also has an age of 33.72 Ma. Thus, there are two potential sources for the 33.7 "Box Canyon" tuff: the SMC and the Juniper caldera. We tested these correlations using electron microprobe analysis of sanidine. The two stratigraphically highest tuffs in the SMC, McCauley Ranch (33.99 Ma, this study) and Cherokee Canyon (33.84 Ma, this study), yielded average compositions of Or_{43} and Or_{55}, whereas the Oak Creek (33.72 ± 0.07 Ma, McIntosh and Bryan, 2000), "Kneeling Nun of Hedlund, 1978" (33.8 Ma, M91), and Bell Top 6 (33.8 Ma M91) tuffs have sanidine compositions in a cluster around Or_{65}. The Oak Creek tuff from the Juniper caldera has sanidine more geochemically similar to other "Box Canyon" tuffs than to the Cherokee Canyon tuff of the SMC, and therefore the SMC is not the exclusive source for the "Box Canyon tuff". Future work will characterize the other "Box Canyon" tuffs to determine if they represent outflow sheets from the SMC. One potential area is Knight's Peak, 20 km south of the SMC. There, the JPB Mountain tuff is 36.3 ± 0.6 Ma (U-Pb zircon). The overlying C-Bar Canyon rhyolite tuff did not yield sanidine. The overlying "Kneeling Nun of Hedlund, 1978" is 33.77 Ma (M91) and thus cannot be Kneeling Nun (~35 Ma). This is overlain by the intermediate lava flows of Malpais Hills that yielded a U-Pb age of 32.6 ± 0.4 Ma. The unrecalculated age of 33.51 Ma (M92) has been long used as the "age" of the SMC (e.g., Chapin et al., 2004). Continuing work on the SMC will determine the age of the caldera collapse and caldera fill deposits.

THE CHARACTERIZATION OF ABANDONED URANIUM MINES IN NEW MEXICO

John Asafo-Akowuah[1] and Virginia T. McLemore[2]

[1]New Mexico Institute of Mining and Technology, Socorro, NM, 87801, aakowuah@gmail.com
[2]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, New Mexico, 87801

Although, the physical safety-hazard of some inactive uranium mines in New Mexico have been mitigated, there still remain other uranium mines that have not been reclaimed. This project characterize samples from waste rock piles in the Lucky Don and Little Davie mines, Chupadero mining district, and Jeter mine, Ladron Mountains (all in Socorro County, NM) as to their mineralogical and geochemical composition, possible release of trace elements into the into the environment, their acid/neutralizing potential, and their stability as a result of erosion and weathering. The waste rock piles consist of heterogeneous mixtures of low-grade ore and waste rock. Mines in the study area have been mined either by surface and/or underground methods from pits, shafts and/or adits, and waste rock piles are located around or near the openings of these features. Waste rock piles at each mine site were sampled in a specific grid pattern tailoring to the size of that particular waste rock pile. Approximately 20-30 discrete samples were combined to form a single composite waste rock sample. This grid pattern sampling method was used in order to maximize surface area coverage, ensuring statistically representative sampling, and to obtain homogenized samples of the waste rock pile in a single sample. Although no evidence of potential acid drainage was observed from waste rock piles in the study areas, field scintillometer mapping indicated elevated radioactivity from some waste rock piles. Analytical techniques employed to answer questions regarding characterization include paste pH and paste conductivity, XRD analyses, electron microprobe analyses and whole-rock geochemical analyses for major and trace elements. Paste pH results from waste rock piles were greater than 5.5 (7-9) indicating a nonacid generating environment. XRD and electron microprobe analyses identified uranium and vanadium minerals in most of the waste rock piles. ICP-MS analyses indicated elevated (>100 ppm) values of uranium and vanadium in most of the waste rock piles.

Major Elements, Trace Elements, and Sr, Nd, and Pb Isotopes of Whole Rocks From the Doña Ana Mountains: Identifying Potential Connections Between Caldera-Related Igneous Rocks in South-Central New Mexico

Tyler J. Askin[1], Frank C. Ramos[1] and Peter J. Stevens

[1]New Mexico State University, Las Cruces, NM, 88001, tyler537@nmsu.edu

Major and trace element characteristics of whole rocks from the Doña Ana Mountains, south-central New Mexico, range from trachyandesite to rhyolite. The isotopic character of the Doña Ana caldera-fill rhyolite is different than trachyte and trachyandesite in the ~43-41 Ma Palm Park formation, the local country rock in the area. The Doña Ana caldera-fill rhyolite was previously assumed to be the volcanic equivalent of an exposed monzonite pluton, but isotope ratios of feldspar crystals indicate that the caldera-fill rhyolite originates from a distinct source. Haga (1994) suggested that the Doña Ana caldera-fill rhyolite was magmatically related to the Squaw Mountain tuff, a 36.1 Ma tuff associated with the nearby Organ Mountains Caldera. The chemical composition and isotope character of the 36.1 Ma Doña Ana caldera-fill rhyolite, however, is significantly different than the Squaw Mountain rhyolite tuff. Sr, Nd, and Pb isotopes define distinct fields for Doña Ana Mountain volcanic rocks. Overall, rocks of the Doña Ana Mountains are chemically distinct and separate from volcanic rocks of the Organ Mountains caldera system, consistent with two unrelated caldera systems existing near each other at ~36 Ma.

The Recent Alpine High Oil and Gas Field Discovery, West Texas

Anthony L. Benson

University of New Mexico at Taos, PO Box 2848, Taos, NM, 87571, benson1@newmex.com

In September 2016, Apache Corporation announced the discovery of the giant Alpine High oil and gas field in western Reeves County, Texas, about 30 miles north of the town of Alpine. They estimated 3 billion barrels of oil and 75 TCF gas, the largest find ever in the lower United States. Seventeen wells had been completed, mostly in the Devonian Woodford and Mississippian Barnett Shales. The wells produce in the oil and wet gas window at depths between 8,000 and 13,000 feet. Additional pay zones are thought to exist in the shallower Permian Bone Springs and Wolfcamp and in Pennsylvanian black shales, for a total of 5,000 feet of potential pay. The Alpine High is along the eastern edge of the Diablo Platform along the western flank of the Delaware Basin, where one third of the world's active drilling rigs are working on mostly horizontally drilled unconventional plays. Source/reservoir quality is analyzed by cores, logs and after-frac production tests. Woodford shale here is characterized by low clay, high TOC and porosity and fractured high silica content. Maturation history curves show the oil and wet gas window (Ro – 0.7 to 1.6%) was delayed by Mesozoic uplift until subsequent Laramide and Basin and Range deformation. Similar tectonic histories exist from southern New Mexico to Big Bend, Texas. Thermal evolution can be evaluated for individual areas. Geologic and economic parameters for the Alpine High may exceed well-known successes of the Oklahoma Woodford, Pennsylvania Marcellus Shale and south Texas Eagle Ford plays. This structurally high area was highlighted in articles in the West Texas Geological Society guidebooks in 1994 and 1995 for seismic stratigraphy and conventional play potential. A southeast extension of the play concept has been studied by this author for the JM Burguieres Company Hovey Ranches, where previous wells and 3 – D seismic defined a similar multizone oil shale play. An areally large 3 – D seismic survey surrounding the Apache lease block of 182,000 acres is currently underway, and a large leasing effort is going on to the northwest and southeast of the Apache holdings. A vast number of papers have been published on the structural geology of adjacent areas and have an impact on extending this unconventional play concept, dating back to P. B. King's work on the Glass Mountains and Marathon Uplift in the 1930s. NW-SE- trending structures and faults extend from Big Bend National Park to New Mexico, including the Marathon Uplift. These have Laramide through Basin and Range ages and heating events. Many deep wells were drilled following the large gas discoveries like Gomez Field in the 1960s, but were mostly CO_2 gas. Small oil fields were found on the overthrusted Marathon fold belt in the 1990s. There is plentiful data to document the existence of structures and source rock/unconventional reservoirs; with migration timing to be unraveled.

Keywords:

Oil Shale, West Texas, Alpine High

URANIUM INDUSTRY: OVERVIEW

Bernard Bonifas

Energy Fuels, Nichols Ranch ISR Uranium Mines, Linch, WY, bbonifas@energyfuels.com

Electricity generated from nuclear energy is part of the energy mix. How much uranium is needed to feed the world nuclear reactors and where to find uranium ore at a competitive cost remain the challenge for the utilities and the mining industry. For the last 70 years, uranium enrichment has been and is still the most important phase in the uranium cycle. In situ uranium recovery (ISR) has been developed recently in most of the continent with different recovery results.

THE UPPER MANCOS SHALE IN THE SAN JUAN BASIN: THREE OIL AND GAS PLAYS, CONVENTIONAL AND UNCONVENTIONAL

Ronald F. Broadhead

New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801, ron.broadhead@nmt.edu

The Mancos Shale (Upper Cretaceous) covers approximately 12,000 mi^2 in the San Juan Basin of northwestern New Mexico and southwestern Colorado. From its outcrop around the basin flanks, the Mancos dips into the subsurface of the basin. The northwest-southeast trending axis is located in the northern part of the basin where depth to top of the Mancos exceeds 6,500 ft. The Mancos is subdivided into two formations, the Upper Mancos Shale and the Lower Mancos Shale which are separated by an unconformity. The Upper Mancos Shale is 900 to 1,600 ft thick in the San Juan Basin. The Upper Mancos has been productive of oil and natural gas from sandstones and from shales. There are three oil and gas plays in the Upper Mancos Shale: the *Tocito marine bar play*, the *Naturally fractured Mancos shale play*, and the *Offshore Mancos shale play*. The *Tocito marine bar play* is a conventional oil play productive from sandstones in the lowermost part of the Upper Mancos. Reservoirs are northwest-southeast trending shoestring sandstones on the southwestern flank of the basin, deposited offshore of and parallel to the paleoshoreline. The *Naturally fractured Mancos shale play* is located along the southeastern and northwestern flanks of the basin. In these areas, Laramide tectonic uplift that formed the present-day basin outline turned strata upward and initiated fracturing of the more brittle lithologies within the Upper Mancos. Open fractures formed prolifically productive reservoirs produced by vertical wells. The *Offshore Mancos shale play* is located northeast of, or paleo-offshore of, the Tocito marine bars. This is the modern unconventional play within the Upper Mancos Shale. This play extends northward from the Tocito marine bars into the axial part of the basin. Reservoir intervals are organic-rich marine shales with laminations and very thin beds of very fine-grained sandstones and siltstones. Percentage and thickness of sandstone beds decrease to the northeast with increasing distance from the paleoshoreline. Almost all recent exploration is within the Mancos C zone, which constitutes the lowermost part of the Upper Mancos Shale. The Mancos C is 75 to 470 ft thick. The Mancos C is thinnest along the southwestern flank of the basin and thickens to the northeast. The Upper Mancos shales are both the source rocks and the reservoirs in the *Offshore Mancos shale play*. Along the southwestern flank of the basin, the shales within the Mancos C are thermally immature. Peak oil generation in the Mancos C was attained along a trend just northeast of the Tocito marine bar reservoirs. The dry gas window is present in the deeper northern part of the basin. Total organic carbon (TOC) of Mancos C shales ranges from 0.5 to 3.2% and averages 1.8%. Kerogens are a mixture of oil prone, gas prone, and inertinitic types with oil-prone kerogens dominant. Shales of the *Offshore Mancos shale play* have produced subeconomic to marginally economic volumes of oil and gas from scattered historic vertical wells. Most recent exploratory wells have been drilled horizontally with production exceeding that attained in vertical wells.

URANIUM CONCENTRATIONS IN DUST FLUX ACROSS THE JACKPILE MINE SUPERFUND SITE

Reid D. Brown[1], Dan Cadol[1] and Bonnie Frey[2]

[1]New Mexico Institute of Mining and Technology, Earth and Environmental Sciences, Socorro, NM, 87801
[2]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, 801 Leroy Place, Socorro, NM, 87801

Closed mines pose significant risks to the environment and human health. Uranium mine contamination of surface water, groundwater and soil have received moderate attention, but few studies have investigated dust transport of uranium. The latter has immediate implications for remediation efforts and environmental/human health regulators. Frequent dust storms intensify aeolian transport of uranium in arid settings. At the Jackpile Mine in Laguna Pueblo, New Mexico, 15 sets of dust traps have been installed at heights of 0.25 m, 0.5 m, 1.0 m and 1.5 m above the soil surface. Some of these traps are within the mine pit, while others are up to 4 km away; dust from these sites was collected every two months. In addition, soil samples from each site were collected and sieved into eight size classes. All samples were acid digested and the uranium content analyzed using Inductively Coupled Plasma Mass Spectrometry. We investigated whether uranium has an affinity for a particular particle-size class, with interest centered on particles small enough to be completely inhaled by humans. Results show that surface concentrations of uranium vary substantially across the landscape. Distance from the pit shows no correlation with uranium in the upper 5 cm of soil. Other factors appear to control accumulation, such as vegetation height and density and topographic relief, which are known to have a significant impact on wind speeds, soil erosion and dust deposition. Our study site has over 150 m of relief and intricate topography that lead to a range of wind speeds between sites. The soil uranium content determined at 15 sites has been compared to site elevation and vegetation height. Preliminary analysis suggests that elevation and vegetation height may impact local erosion and deposition of uranium. Dust mass was collected at each height and converted into a flux (g/d). The relationship between mass flux and height above ground followed a power-law relationship as supported by previous research (Zingg, 1953; Butterfield, 1999; Dong et al., 2003; Dong et al., 2004a, 2004b). Particle size fractionation during aeolian transport of the dust increased metal concentrations in four of six metals of concern.

Paragenesis of Uranium Minerals in the Grants Mineral Belt, New Mexico: Applied Geochemistry and the Development of Oxidized Uranium Mineralization

Samantha Caldwell[1] and William X. Chavez, Jr.[1]

[1]New Mexico Institute of Mining and Technology, Socorro, NM, 87801, samantha.caldwell@student.nmt.edu

Deposition of reduced uranium ores in the Grants Mineral Belt, New México, was succeeded by locally well-developed oxidation and the generation of secondary or tertiary uranium (vanadium, selenium) minerals. Detailed study of these succeeding-generation minerals indicates that oxidation of reduced uranium mineralization was effected by carbonate- and sulfate-bearing meteoric waters that engendered a series of generally hydrated uranyl-carbonate (e.g., andersonite, ($Na_2Ca(UO_2)(CO_3)_3{\cdot}6H_2O$; Chávez, 1979)) and sulfate (e.g., zippeite-like minerals, Mt. Taylor mine, Chávez, 1988; $K_4(UO_2)_6(SO_4)_3(OH)_{10}{\bullet}4H_2O$; see also Moench and Schlee, 1967, pp. 57-61)) minerals. Initial X-ray diffraction (XRD) analyses of reduced uranium minerals from organic-rich arkosic sandstones of the Westwater Canyon Member of the Jurassic-age Morrison Formation from the Mt. Taylor mine show that various organic compounds are associated with the strongly-reducing environment characterizing primary uranium minerals and associated V, Mo, and Se. Oxidation of these reduced, organic-rich host rocks apparently produced carbonic acid and generated weakly acidic solutions capable of continued oxidation of uranium. Deposition of native selenium (Poison Canyon mine; Tessendorf, 1979) and weakly-crystallized MoS_2 as "jordisite" (Kao et al., 2001) suggests that the oxidation environment was variable immediately following uranium deposition and that weathering-derived supergene solutions served to modify both reduced and initially-oxidized uranium-vanadium ores. Dehydration reactions converted some uranium-vanadium oxides such as tyuyamunite [$Ca(UO_2)_2V_2O_8{\cdot}(5\text{-}8)H_2O$] to their dehydrated equivalents [meta-tyuyamunite, $Ca(UO_2)_2V_2O_8{\cdot}(3\text{-}5)H_2O$]; XRD analyses of green oxide coatings and black ores from the Section 31 mine show that the ores host andersonite and gypsum, indicating that CO_3^{2-}(aq) and SO_4^{2-}(aq)-bearing, oxidizing groundwaters were responsible for developing a series of paragenetically-complex carbonate and sulfate minerals that reflect local groundwater compositions and composition changes through time. Comparison of Grants Mineral Belt uranium mineralogy with the paragenesis of U-V minerals in other regions of the Colorado Plateau suggests that regional oxidation (Adams and Saucier, 1981) was likely responsible for uranium transport and later oxidative replacement of reduced uranium minerals (compare to Arizona Strip breccia pipe-hosted U-(Cu, Ag, Ni, Co) mineralization; e.g., see Van Gosen and Wenrich, 1989; Wenrich, Van Gosen, and Finch, 1992). Latest oxidation is attributed to supergene processes coinciding with the onset of regional uplift and erosion in Laramide times of the southern portion of the Colorado Plateau.

LITHOFACIES ANALYSIS OF THE SIERRA LADRONES FORMATION NEAR THE SEVILLETA NATIONAL WILDLIFE REFUGE HEADQUARTERS (SOUTHERN ALBUQUERQUE BASIN, NEW MEXICO): IMPLICATIONS FOR CLIFF FAULT MOVEMENT DURING THE EARLY PLEISTOCENE

Eda Celep[1], Daniel J. Koning[2] and David W. Love[2]

[1] Department of Earth and Environmental Science, NM Tech, 801 Leroy Place, Socorro, NM, 87801, eda.celep@student.nmt.edu
[2]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801

The north-striking, 19 km-long Cliff fault passes 1.5 km west of the Sevilleta National Wildlife Refuge headquarters. My study uses stratigraphic relationships to interpret tectonic activity of the Cliff fault during the early Pleistocene. Previous work had suggested the latest movements occurred during the late and middle Pleistocene (Machette, 1978), but early Pleistocene activity remained uncertain. It is necessary to use Santa Fe Group stratigraphy because potential early Pleistocene activity on the Cliff fault antedates preserved geomorphic surfaces or fault scarps. The Cliff fault is the easternmost of a trio of Quaternary normal faults in the southwestern Albuquerque Basin, the other two being the east-down Loma Pelada and Loma Blanca faults to the west. Because these faults have been mapped as extending southward into the northern Socorro Basin, interpreting their long-term displacement behavior is important in understanding how strain is transferred between the Albuquerque and Socorro Basins. Long-term (10^6-10^7yr) paleoseismic records of the fault trio can also be used to evaluate if fault activity has migrated towards the center of the basin. The Cliff fault offsets strata of the Sierra Ladrones Formation, a Pliocene-early Pleistocene deposit composed mainly of sand with lesser gravel and silt-clay. The studied sediment lies stratigraphically above a sample locality of a 3 Ma tooth fossil. My field research illustrates several lithofacies in the Sierra Ladrones formation, including two different types of channel fills, floodplain deposits, hyper-concentrated or debris flow deposits, and possible colluvium and slope wash deposits. The two different types of channel fills are: (1) sandstone-dominated and trough cross-stratified, with southerly paleoflow and abundant chert clasts, and (2) gravel-dominated with mostly tabular-lenticular bedding, southeasterly paleoflow, and 10% - 20% chert clasts. Floodplain deposits consist of interbedded fine sand and clay. Paleosols are locally observed and characterized by accumulations of calcium carbonate. Hyper-concentrated flow and debris flow sediments are matrix-supported pebbly sand deposits that lack sedimentary fabric within a given bed. We group these lithofacies into the following lithofacies assemblages: axial-fluvial, distal alluvial fan, and fault-scarp sediments. Using clast counts and paleocurrent data, the alluvial fan deposits are correlated with the Rio Salado paleo-drainage. The axial-fluvial assemblage includes floodplain deposits and channel fills associated with: (1) a S-flowing Rio Puerco and (2) relatively large, gravelly channels exiting the Rio Salado fan and flowing E-SE-S on the basin floor. In contrast to interpretations by Machette (1978), we did not find evidence of deposits derived from the Joyita Hills. Suggestions for early Pleistocene movement of the Cliff fault are mainly inferred from the immediate hanging wall. Certain lithologic units increase in thickness and/or coarsen laterally towards the fault. Also, local angular unconformities are also observed on the immediate hanging wall. Lastly, the southward displacement gradient along the fault, inferred from our mapping near the Refuge headquarters, suggests that the Cliff fault does not extend as far south as previously mapped.

Sedimentology, Stratigraphy, and Geochronology From Early(?)–Middle Eocene, Post-Laramide Volcanic and Volcaniclastic Strata of the Palm Park Formation in South-Central New Mexico

Ryan H. Creitz[1], Brian A. Hampton, Greg H. Mack and Jeffrey M. Amato

[1]New Mexico State University, Department of Geological Sciences, P.O. Box 30001, Las Cruces, NM, 88003, rcreitz@nmsu.edu

A middle Eocene phase of intermediate volcanism marks the transition from deformation associated with the Laramide orogeny to the late Eocene initiation of the Rio Grande Rift in south-central New Mexico. This tectonic transition is recorded by a suite of volcanic/subvolcanic, volcaniclastic, gypsiferous, and carbonate strata that make up the Palm Park Formation and age-equivalent Orejon Andesite, Cleofas Andesite, and Rubio Peak Formation. A number of studies have focused on constraining the timing and geochemistry of the late Eocene initiation of the Rio Grande Rift in southern New Mexico, yet little is known about the eruptive and depositional history following cessation of Laramide deformation and preceding the onset of rifting. Presented here are new geochronologic, sedimentologic, and stratigraphic data from the Palm Park Formation and Orejon Andesite in south-central New Mexico. The base of the Palm Park is marked by a progressive (erosional) unconformity with underlying basement rocks that range in age from Permian–Paleocene (Abo/Hueco and Love Ranch Formations). These basal strata consist of matrix-supported, pebble-cobble conglomerate units that contain Permian marine fossiliferous limestone clasts suspended in a granule-sandy, volcaniclastic matrix. Conglomeratic units are overlain by nonmarine, fossiliferous limestone and gypsum-bearing strata. This lower stratigraphic interval is interpreted to represent shallow lake sedimentation and episodic moderate- to high-energy lahar debris flows that contained a mix of intermediate volcanic debris and clasts of Permian bedrock. Lake and lahar deposits are overlain by a succession of interbedded volcanic lava flows, pyroclastic flows, and volcaniclastic conglomerate and sandstone, all of which have intermediate compositions. These rocks are interpreted to represent lava flows, basal surge deposits, and high-energy lahar debris flows. Volcanic tuffs are very rare throughout the Palm Park and have only been observed near the base and top of the formation. The youngest stratigraphic intervals in the Palm Park are dominated by volcaniclastic mudstone, sandstone, and granule–pebble conglomerate that range in thickness from 0.01–0.5 meters. These strata are interpreted to represent low-energy lahar hyperconcentrated flows and water-laden sheet flows. Igneous zircons from an ash-fall tuff near the top of the Palm Park yield a U-Pb age of 39.6 ± 0.5 Ma whereas volcanic flows near the base yield a U-Pb age of 44.0 ± 1.5 Ma. Volcanic flows and porphyry deposits in the middle parts of the Palm Park yield ages ranging from 41.6 ± 0.7–41.0 ± 0.6 Ma, respectively (errors 2σ). U-Pb detrital zircon ages from volcaniclastic intervals exhibit primary peaks between 41–44 Ma with secondary peaks between 1600–1800, 1350-1550, and 1000-1250 Ma. Paleozoic–Mesozoic age zircons are present in nearly all samples but do not make up statistically-relevant peaks. Middle Eocene peaks are interpreted to represent detrital contributions from stratovolcano sources. Rare Proterozoic and Paleozoic detrital contributions are interpreted to reflect recycled zircons that were derived from relict, inactive Laramide uplifts and support previous models that call for the termination of Laramide deformation by the middle Eocene in south-central New Mexico.

A New Chasmosaurine Ceratopsid From the Hall Lake Member of the McRae Formation (Maastrichtian), South-Central New Mexico

Sebastian G. Dalman[1] and Spencer G. Lucas[2]

[1]New Mexico Museum of Natural History and Science / Fort Hays State University, Hays, Kansas, 1801 Mountain Road N.W., Albuquerque, NM, 87104, sebastiandalman@yahoo.com
[2]New Mexico Museum of Natural History and Science, 1801 Mountain Road N.W., Albuquerque, NM, 87104

We document a new chasmosaurine ceratopsid from the Upper Cretaceous Hall Lake Member of the McRae Formation, New Mexico. The chasmosaurine fossils consists of much of the skull, several vertebrae, ribs, and incomplete forelimbs. The fossils were collected from a red mudstone bed ~24 m above the base of the Hall Lake Member, south of McRae Canyon, Sierra County. Based on the occurrence of a tyrannosaur equivalent in body size to *Tyrannosaurus rex* and the sauropod *Alamosaurus sanjuanensis*, the Hall Lake Member is dated as Lancian (late Maastrichtian). The new chasmosaurine taxon is distinguished by a short but robust supraorbital horncore that is anteroposteriorly wide and mediolaterally compressed, premaxilla with a short pronounced ridge on the lateral surface, pterygoid with flat posteromedial ridge, robust jugal with pronounced posterolateral ridge, robust epijugal, and a long fenestrated frill with a strongly convex median parietal bar, and transversely narrow squamosal with a pointed end and elongate episquamosals. Cladistic analysis recoverses the McRae Formation chasmosaurine ceratopsian as a sister to *Pentaceratops* and places it within the *Coahuilaceratops*+*Utahceratops* clade based on the transversely narrow squamosal and the transversely expanded frill posteriorly. The discovery of the new taxon adds to the diversity of chasmosaurine ceratopsians during the final stage of the Late Cretaceous and to the poorly known dinosaur fauna of the McRae Formation.

NEW EVIDENCE FOR CANNIBALISM IN TYRANNOSAURID DINOSAURS FROM THE LATE CRETACEOUS OF NEW MEXICO

Sebastian G. Dalman[1] and Spencer G. Lucas[2]

[1]New Mexico Museum of Natural History and Science / Fort Hays State University, Hays, Kansas, 251 Hendren Ln NE, Albuquerque, NM, NEW MEXICO, 87123, United States, sebastiandalman@yahoo.com
[2]New Mexico Museum of Natural History and Science, 1801 Mountain Road N.W., Albuquerque, NM, 87104

An isolated proximal caudal centrum and an isolated right femur pertaining to tyrannosaurid dinosaurs from the Upper Cretaceous deposits of the San Juan Basin, New Mexico, preserve several elongate lesions, which are interpreted as bite marks or feeding traces made by another tyrannosaurid. The femur was recovered from the Upper Campanian deposits of the De-na-zin Member of the Kirtland Formation, whereas the isolated caudal centrum was recovered from the Maastrichtian deposits in the Naashoibito Member of the Ojo Alamo Formation. The lack of associated cranial material with the bones precludes their generic identification. The absence of bone surface healing around the lesions indicates the biting most likely took place post-mortem. Intensely tooth-marked bones clearly show that the San Juan Basin tyrannosaurids fed upon the remains of not only ceratopsians, hadrosaurs, and sauropods, but also conspecifics. The bite marks described here represent three categories: "bite-and-drag", "puncture", and "bite-and-crush." The "bite-and-drag" marks are located in the anteroventral and in the anteroventral regions of the centrum. Some of these bite marks are short-and-shallow, whereas others are long-and-deep. Most of the "puncture" marks are located in the anterodorsal region of the centrum, whereas some others are located within the "bite-and-drag" marks. The "bite-and-crush" mark is represented by a single, large, ovoid-shaped lesion containing a small "puncture" mark. The bite marks on the right femur are located on the anterior, posterior, and dorsal surfaces of the femoral neck and head, including the lesser trochanter, at the midshaft, and largely on the distal condyles and crista tibiofibularis. The specimens provide new evidence for cannibalism among tyrannosaurids and add to previous knowledge of the feeding behaviour of these iconic predators based on inferred bite marks.

WHAT LIES BENEATH THE DUNES? GRAVITY MEASUREMENTS TO CHARACTERIZE SUB-SURFACE DENSITY STRUCTURE AND UNDERSTAND CONTROLS ON DUNE MIGRATION IN WHITE SANDS NATIONAL MONUMENT, NEW MEXICO

Ryan Dunagin[1], M. Roy[1], Shari Kelley[2], L. Worthington[1] and J. Butts[1]

[1]University of New Mexico, 2112 Gold St, Albuquerque, NM, 87106, rdunagin@unm.edu
[2]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, 801 Leroy Place, Socorro, NM, 87801

White Sands National Monument is home to the largest gypsum sand dune field in the world. This unique landscape is both a popular tourist destination and a valuable natural resource shaped by complex interactions between erosion, climate, and groundwater extraction. The underlying basin structure and geology of the region must influence the evolution of the dunefield by controlling the supply and transport of the gypsum sands. This study we focus on how sub-surface structure, as illuminated by gravity measurements and forward models, may influence the transport and migration of the dunes. Specifically, we target two locations within White Sands National Monument where the dunefield has not moved significantly in the past 50 years, to see if subsurface structures in these areas may play a role in causing this stagnation. In each survey area, we analyze observed gravity variations (after drift, tide, elevation, and latitude corrections) using simple forward models of the effect of the terrain. In some cases, we remove a regional (long-wavelength) linear fit to the data. The resulting complete Bouguer anomalies are calculated by discretizing the terrain into right-rectangular prisms based on a LIDAR point-cloud for the study area. We interpret the complete Bouguer anomalies for our study areas in terms of shallow subsurface density variations (possibly caused by faulting). In each study area, we then assess the role of subsurface structure in controlling the migration of the dunes.

FORSTERITE AND PYRRHOTITE DISSOLUTION RATES FROM KINETIC TESTING USING MINE TAILINGS: RESULTS FROM GEOCHEMICAL MODELLING

Rodrigo Frayna Embile, Jr.[1] and Ingar Walder[2]

[1]New Mexico Tech, Earth and Environmental Sciences Department, Socorro, NM, 87801, RodrigoJr.Embile@student.nmt.edu
[2]New Mexico Tech, 801 Leroy Place, Socorro, NM, New Mexico, 87801

Mineral dissolution rates of pure minerals such as forsterite and pyrrhotite abound in the literature. In contrast, the use of mine tailings containing these minerals to assess mineral dissolution rates has received little attention. In this study, we investigate forsterite and pyrrhotite dissolution rates using actual mine tailings from a nickel mine in Norway. Kinetic testing using these tailings was conducted for seventy weeks. Weekly leachate chemistry was used as input parameters for inverse modelling using PHREEQC. Results from inverse modelling suggest that Mg and Fe are mostly associated with forsterite and pyrrhotite dissolution respectively. Pyrrhotite dissolves faster than forsterite by an order of magnitude, slower than commonly found in the literature. This result could be due to the fact that when present with other minerals, grain interactions and the degree of surface area in contact with water and oxygen can enhance or limit the dissolution of these minerals. This approach of using dissolution rates from kinetic testing can be used to provide more accurate field values than the commonly used laboratory dissolution rates.

Keywords:

dissolution rates, kinetic testing, tailings

CHANGE IN PROVENANCE OF PROTEROZOIC METASEDIMENTARY ROCKS IN THE PICURIS MOUNTAINS BASED ON LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS) OF DETRITAL TOURMALINE

Shoshauna Farnsworth-Pinkerton[1], Nancy J. McMillan[1], Barbara L. Dutrow[2] and Darrell J. Henry[2]

[1]Geological Sciences, New Mexico State University, Box 30001, MSC 3AB, Las Cruces, NM, 88003, shohauna@nmsu.edu
[2]Department of Geology & Geophysics, Louisiana State University, Baton Rouge, LA, 70803

Assembly of southwestern Laurentia during the Paleoproterozoic Yavapai and Mazatzal orogenies is well-documented. An additional tectonic event, the Mesoproterozoic Picuris Orogeny, has been proposed (Daniel et al., 2013, GSA Bulletin, 125:1423-1441) based on 1600-1475 Ma detrital zircons in the Piedra Lumbre Formation of the Hondo Group, Picuris Mountains, northern New Mexico. These ages are consistent with source rock derivation from Australia and Antarctica. Units underlying the Piedra Lumbre Fm., including the Rinconada Formation, contain detrital zircons with a unimodal age of ca. 1710 Ma (Daniel et al., 2013), most likely sourced from local rocks of Yavapai age. This study evaluates the change in provenance by analyzing detrital tourmalines from the Rinconada and Piedra Lumbre Fms in the Copper Hill Anticline, Picuris Mountains. Tourmaline is an ideal mineral for sediment provenance studies because it forms in a wide pressure-temperature-composition range, incorporates a fingerprint of its host rock chemistry, has very slow diffusion rates, and is resistant to abrasion. By focusing on distinct detrital cores in tourmaline grains, reflecting the original lithologic association in which tourmaline formed, a change in source region can be evaluated. Laser-Induced Breakdown Spectroscopy (LIBS) spectra are rich in information, including the concentrations of all elements, isotopic ratios, and information on the structure of the analyzed material, thus helping to identify source lithology and changes in provenance. LIBS spectra are modeled using Partial Least Squares Regression (PLSR) in a matching algorithm developed to identify the lithology in which the tourmaline crystallized. In this study, 209 spectra were collected from the Rinconada Fm. and 50 of those spectra were tourmaline. Of the 50 tourmaline spectra from the Rinconada Fm., 24 crystallized in pelitic metamorphic rocks, 4 crystallized in calcareous metamorphic rocks, 8 crystallized in Li-poor pegmatites and silicic igneous rocks, and 14 crystallized in hydrothermal and miscellaneous rocks. In contrast, none of the 3274 spectra collected from the Piedra Lumbre Fm. were tourmaline. Source regions for the Rinconada and Piedra Lumbre Fms are interpreted to be different due to the presence of tourmaline in the Rinconada Fm. and the lack of tourmaline in the Piedra Lubmre Fm.

WATER-DEPTH-BASED DIFFERENCES IN AMMONOID ASSEMBLAGES FROM THE UPPER CRETACEOUS (TURONIAN) BLUE HILL MEMBER OF THE CARLILE SHALE, NORTH-CENTRAL NEW MEXICO

Michael P. Foley[1] and Spencer G. Lucas[1]

[1]New Mexico Museum of Natural History, 1801 Mountain Rd NW, Albuquerque, NM, 87104, pfooley@gmail.com

In north-central New Mexico (Santa Fe and Sandoval counties), the Upper Cretaceous Blue Hill Member of the Carlile Shale is up to 33 m thick and consists of olive gray shale with numerous limestone concretions and septarian nodules, intercalated locally with the offshore bar deposits of the Semilla Sandstone Member. The Blue Hill Member yields middle Turonian ammonoid assemblages of the (ascending order) *Collignoniceras praecox* and *Prionocyclus hyatti* zones. Extensive collections of ammonoids from the Blue Hill Member in north-central New Mexico reveal striking differences in the composition and relative abundances of key ammonoid taxa at different localities. Thus, at Galisteo Dam (T14N, R7E), the assemblages are dominated by *P. hyatti* with few to no specimens of *Spathites puercoensis* and *Coilopoceras springeri*. Along the Rio Puerco (T14N, R3W), however, *P. hyatti* is not common, but *S. puercoensis* and *C. springeri* are abundant. In contrast, at Marquez Wash (T15N, R1W) and on the Ojo del Espiritu Santo Land Grant (T16N, R1W), *S. puercoensis* is common but decreases in abundance northward, *C. springeri* is uncommon, and *P. hyatti* is common, but progressively dominated by larger individuals northward. Furthermore, at Marquez Wash and northward on the Ojo del Espiritu Santo Land Grant, a turritellid limestone, indicative of relatively shallow water, is present where *Spathites* is most abundant. The differences in the ammonoid assemblages also correlate with the presence/absence of the Semilla Sandstone Member, which is thick and present at Marquez Wash and along the Rio Puerco. We hypothesize that the more heavily ornamented *P. hyatti* , with its strong ribs and massive ventolateral horns, is a deeper water ammonoid than the nearly smooth, unornamented *S. puercoensis* and *C. springeri*, and that Blue Hill Member outcrops where the Semilla Sandstone is present and relatively thick represent shallower water than the outcrops where the Semilla is extremely thin or absent. Those inferences support the conclusion that the differences among the age-equivalent ammonoid assemblages of the Blue Hill Member in north-central New Mexico reflect differences in water depth, with distinct deeper water (*P. hyatti*-dominated) and shallower water (*S. puercoensis*- and *C. springeri*-dominated) ammonoid assemblages

3D Inverse Models of Magnetotelluric Data in the Central Rio Grande Rift Illuminate Rift Basin Geometry and Possible Interactions Between Deep Brines and Surface Waters

Matthew Folsom[1], Jeff Pepin[1], Jared Peacock[2], Mark Person[1], Shari Kelley[3] and David Love[3]

[1]New Mexico Institute of Mining and Technology, Socorro, NM, New Mexico, 87801, United States, mattfolsom99@gmail.com
[2]United States Geological Survey
[3]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801

A 17-station broadband (10^3 – 10^{-3} Hz) magnetotelluric survey over the Central Rio Grande rift has been modelled using 1D, 2D and 3D inverse methods. The results have been interrogated using 3D forward modelling routines. The resistivity models are dominated by sedimentary structures related to the Albuquerque, Socorro and La Jencia Basins. Evidence of evolved brines hosted in syn-rift basin fill are apparent by bulk resistivity values less than 1 ohm-m, most notably in the southern Albuquerque and northern Socorro Basins. Along the so called 'Socorro Constriction', where a rise in inferred low-permeability basement marks the transition between the Albuquerque and Socorro Basins, these brines appear to interact with the Loma Pelada fault and the San Acacia spring system. Conduits such as these may allow for evolved basin brines to mix with the Rio Grande near this point, which has been suggested by previous researchers. The survey is also located over a zone of vertical surface uplift (1-3 mm/yr) related to the Socorro Magma Body, although only minimal structures are imaged below 10 km depth. Rock units in the upper 10 km and under this area of uplift exceed 10^3 ohm-m, suggesting these units are both dry and competent. An anomalous conductor has been identified on the eastern edge of the La Jencia Basin, although interrogation of the feature is ongoing. It is likely that the presence of conductive basins masks out finer details in the resistivity structure beneath them, but to what extent is currently unknown.

Keywords:

magnetotelluric, inverse methods, sedimentary basin, Rio Grande rift, basin brines

Functional Change in Molluscan Diversity Dynamics Observed Across OAE2

Nicholas Freymueller[1] and Corinne Myers[1]

[1]University of New Mexico, Albuquerque, NM, 87131, nickfreymueller@unm.edu

Ocean Anoxic Events (OAEs) are periods in time when the earth's ocean basins became largely or entirely depleted of dissolved oxygen. These periods lasted several million years in some cases and have contributed to major die-offs such as the End-Permian Mass Extinction. The middle Cretaceous is characterized by a series of OAEs; however, the biotic impact of these events is unclear. Utilizing the Paleobiology Database (PBDB), we analyzed both species-level and generic-level global diversity of mollusks across the Bonarelli event (OAE2) at the Cenomanian-Turonian (C/T) stage boundary. In order to test whether survivorship across the OAE was influenced by paleoecological factors, diversity data was collected within the parameters of faunality (i.e., surface vs. burrowing lifestyle), mobility, and feeding strategy. Species and generic databases were sample-standardized, and diversity was statistically compared via a Mann-Whitney U. Significant ($p<0.001$) diversity losses and negative effect sizes ($-1.669<E.S.<-0.358$) were observed when comparing both total diversity, and across many paleoecological contexts with some exceptions. Diversity of epifaunal, semi-infaunal, stationary taxa, suspension feeders, chemosymbionts and omnivores did not significantly change ($p>0.05$) across the C/T boundary at the generic level. Preliminary analysis of the influence of paleoecological factors on extinction indicates that infaunal and actively mobile taxa were hit the hardest (E.S.= -1.669 and -1.408 respectively.) This contrasts to periods of gradual environmental change without anoxia such as the upper Campanian-Maastrichtian transition. Across this stage boundary, we find that there was a significant unilateral increase in total diversity at both the species- and generic level, with positive effect sizes ($0.502<E.S.<4.908$), as well as within all paleoecological categories. The few exceptions include omnivorous and carnivorous feeding strategies and nektonic lifestyle, which showed a loss in diversity (E.S.= -1.07). In contrast to previous research suggesting that OAE2 only caused minor impacts to global diversity patterns, these results support the Bonarelli Event as a significant driver of extinctions in Molluscan taxa.

WHY I REMAIN A URANIUM BULL

Michael S. (Mickey) Fulp

MercenaryGeologist.com, LLC, Albuquerque, NM, 87105, mickey@mercenarygeologist.com

Uranium has undergone severe bull and bear market cycles in the 21st Century with the spot price ranging from $10/lb U_3O_8 in 2000-2004, $135 in 2007, $40 in 2009-2010, to $73 in February 2011. It reached a 12-year low of $18 in late 2016 and currently stands at $25/lb. The nuclear reactor incident at Fukushima in March 2011 caused a crash of uranium stocks and subsequently, the price. This unique event ushered in a bear market for uranium with decreased demand from Japan, which once used 12% of world uranium in 55 reactors and now has three reactors online. Germany halved its demand by shuttering eight of 17 reactors. Despite a short-term oversupplied market, the uranium outlook is quite positive for the mid- to long-term. In 2015, nuclear reactors provided 11.5% of world electrical energy and 19.5% in the US. We consumed 29% of world supply, about 49 million pounds U_3O_8 for 99 operating reactors, but produced less than 7% of domestic needs. Furthermore, security of supply is tenuous. Six of the top ten producing countries have corrupt and/or unstable governments unfriendly to the USA. 59% of 2015 world uranium came from Kazakhstan (39%), Niger, Russia, Uzbekistan, China, and Ukraine. There are 447 operable nuclear power plants worldwide, 14 more than pre-Fukushima. 59 plants are under construction; 164 are planned. Yellowcake demand is projected at 3-4% annualized growth. With increased demand, new supply will come from both mined uranium and secondary supplies. Enrichment underfeeding will continue to be significant; recycling and reprocessing will produce only a minor part of supply. Mining will remain the major contributor but prices must increase before new projects come on stream. Major uranium districts face challenges in developing new projects because of economics, sustainability, and/or timing to production. They include: large ISR mines in Kazakhstan; the largest and highest grade unconformity mines of the Athabasca Basin; Niger's world-class sandstone uranium mines; Namibia's hard rock, low-grade, open-pit mines; and giant, high-grade unconformity deposits of Australia's Northern Territory. The USA has uranium resources to return to self-sufficiency, but I question whether we can muster the political will once prices inevitably rise. Our sandstone-hosted resources include two very large, high-grade and three large, ISR-grade deposits in the Grants Mineral Belt; many small, moderate-grade deposits in Utah and Colorado; high-grade breccia pipes of the Arizona Strip; small ISR mines in Wyoming, Nebraska, and South Texas, and a large, high-grade deposit in Virginia. Commodity cycles ebb and flow but increasing demand for electricity continues unabated. There are 85 million more humans on Earth every year and one out of four people still retire at dark and rise at dawn. That paradigm is changing rapidly with urbanization in China and India. For at least the next two to three decades, nuclear energy will remain the planet's primary source of environmentally friendly base-load electricity. And that is why I remain a uranium bull.

Keywords:

uranium, uranium spot price, supply and demand, nuclear power, electricity, resources, geologist, Mercenary Geologist

COMING SOON – GEOLOGIC MAP OF THE MOUNT TAYLOR VOLCANO AREA, NEW MEXICO: CENTERPIECE FOR THE 2020 FALL FIELD CONFERENCE

Fraser Goff[1], Shari A. Kelley[2], David J. McCraw[2], Cathy J. Goff[3], Bonnie A. Frey[2], Kate Zeigler[4] and Virginia T. McLemore[2]

[1]Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, 801 Leroy Place, Socorro, NM, 87801, candf@swcp.com
[2] New Mexico Bureau of Geology and Mineral Resources, 801 Leroy Place, Socorro, NM, 87801
[3]Independent Consultant, 5515 Quemazon, Los Alamos, NM, 87544
[4]Zeigler Geologic Consulting, 14500 Oakwood Place NE, Albuquerque, NM, 87123

Mount Taylor (3445 m) is a relatively prominent stratovolcano that formed along the Jemez volcanic lineament during Plio-Pleistocene time. Six recently completed 7.5-min geologic maps encompassing the greater Mount Taylor area were completed from 2007 to 2014. These, combined with petrography, 216 chemical analyses, 107 $^{40}Ar/^{39}Ar$ dates, 82 paleomagnetic measurements, and final field checking and photogrammetry were complied into a map that will be published as NMBGMR Geologic Map 80. Eruptive products span basanite to alkali rhyolite compositions but trachybasalt, trachyandesite and trachydacite dominate the upper parts of the volcanic complex. Volcanism is divisible into four phases: 1) development of the volcano floor (3.72–2.90 Ma); 2) initial growth of the cone (2.90–2.75 Ma); 3) final growth of the cone (2.75–2.50 Ma); and 4) terminal mafic volcanism (2.50–1.26 Ma). Most of the volcano formed during the Gauss normal magnetic chron (3.58 to 2.58 Ma) but the last eruptions in the edifice and most of the phase 4 mafic eruptions are magnetically reversed (Matayama chron, 2.58 to 0.78 Ma). Present volume of the stratovolcano is about 25-30 km^3, surrounded by an equivalent volume of mafic lavas. Pyroclastic rocks constitute <5% of the volcano, erupted primarily during phases 1 and 2. The edifice is constructed of an eroded central stock, a plexus of radiating dikes, and surrounding domes and flows. The edifice contains a large eastward-facing amphitheater created by erosion during and after phase 3. Volcaniclastic deposits form an apron interlayered with lava flows around much of the volcano but are thickest east and southeast of the amphitheater. No glacial deposits were identified in the volcaniclastic package. More than 15 maar volcanoes formed on flanking mesas near the end of the Pliocene (c.a. 2.5 Ma). Their presence probably indicates a higher water table and wetter climate during the Plio-Pleistocene transition than today. Mount Taylor overlies well-exposed, moderately deformed Jurassic to Cretaceous strata that display classic transgressive-regressive depositional sequences and host the Grants uranium district. Significant coal deposits exist in regional Cretaceous rocks and were mined from the Crevasse Canyon Formation around the western volcano. More than 340 million pounds of U_3O_8 were extracted between 1952 and 2002, primarily from the Westwater Canyon Member of the Jurassic Morrison Formation. The Grants uranium district is possibly the 7th largest in total world production and was once the largest producer in the United States. Our map sections show that depth to ore-bearing strata is about 975 m northwest of the volcano and roughly 1400-1600 m beneath the north flank of Mount Taylor. The 2020 NMGS fall field conference will cover several topics. On Day 1 attendees will examine Mesozoic stratigraphy west and northwest of Mount Taylor and discuss human activities associated with localized uranium extraction. On Day 2 the group will cross the northwest sector of Mount Taylor stratovolcano to look at diverse magmatic products. Day 3 will focus east of the volcano near Laguna Pueblo to present recent geomorphic and geochemical research on uranium transport in and around the Jackpile mine.

Keywords:

Mount Taylor, stratovolcano, Plio-Pleistocene, alkalic volcanism, Jurassic-Cretaceous, uranium, coal

Provenance Trends From Upper Cretaceous Nonmarine Strata in Southern New Mexico: Implications for Drainage Evolution and Sediment Dispersal Along the Southwestern Margin of the Western Interior Seaway

Brian A. Hampton[1], Greg H. Mack[1] and Cody J. Stopka

[1]New Mexico State University, Dept. of Geol, Las Cruces, NM, 88003-8001, bhampton@nmsu.edu

Upper Cretaceous nonmarine strata in southern New Mexico mark the final phase of Late Cretaceous (Cenomanian–Campanian) sedimentation associated with the Sevier orogeny. Presented here are U-Pb detrital zircon ages, sandstone modal composition, and paleocurrent measurements from the Dakota Sandstone, Tres Hermanos Formation, and Crevasse Canyon Formation (Lower Member and Ash Canyon Member). The Dakota Sandstone is dominated by monocrystalline quartz (84%) with minor volcanic and metamorphic lithic grains (15%) with rare occurrences of feldspar (1%). Paleoflow measurements show east-directed (108°) to northeast-directed flow (50°). Detrital zircon age peaks occur at 1732, 1651, 1416, 1050, 626, 412, 230, and 103 Ma. The calculated rage of maximum depositional ages (MDAs) for the Dakota Sandstone is 103–104 Ma. The Tres Hermanos Formation is composed primarily of monocrystalline quartz (63%) with volcanic and metamorphic lithic grains (27%) and minor feldspar (10%). Paleoflow measurements reflect east-directed (93–109°) and southeast-directed (166°) flow. Peak detrital zircon ages occur at 1709, 1420, 1085, 169, and 94 Ma. MDAs for the Tres Hermanos range from 93–96 Ma. The Lower Member of the Crevasse Canyon Formation is composed of monocrystalline quartz (50%) along with volcanic and metamorphic lithic grains (41%) and minor abundance of feldspar (9%). Paleoflow measurements show primarily east-directed flow (100°). Detrital zircon age peaks occur at 1702, 1420, 1067, 167, and 91 Ma. MDAs for the Lower Member of the range from 91–92 Ma. The Ash Canyon Member of the Crevasse Canyon Formation is composed of monocrystalline quartz (48%) with volcanic and metamorphic lithic grains (46%) and minor occurrences of feldspar (6%). Paleoflow trends show a east- to southeast-directed flow (108–118°). Peak detrital zircon ages were determined to be 1682, 1415, 1108, 169 and 90 Ma. MDAs for the Ash Canyon Member range from 80–91 Ma. Precambrian to Paleozoic zircons overlap in age with the Yavapai, Mazatzal, Granite-Rhyolite, and Grenville provinces (and age-equivalent ~1.0 Ga rocks). Neoproterozoic, Early Paleozoic, and some Mesoproterozoic-age detritus was originally derived from Appalachian-Ouachita sources and transported to parts of the southwestern U.S. (e.g., Mesozoic eolianites of the Colorado plateau). Second-order recycling of Mesozoic eolianites has been reported from Lower Cretaceous strata of the Bisbee Rift which exhibit U-Pb detrital zircon spectra that very similar to Mesozoic strata of the Four Corners region. Permo–Triassic age detritus overlap in age with granitoid rocks of the Cordilleran magmatic arc that outcrop in California and Arizona. Jurassic to Cretaceous age zircons overlap with the mid-Mesozoic Cordilleran magmatic arc and the Sierra Nevada batholith. Based on the provenance trends summarized above, a sediment dispersal model is favored where the Dakota Sandstone was derived largely from recycled Lower Cretaceous strata of the Bisbee Rift of southeastern Arizona and southwestern New Mexico (present-day Mogollon highlands). Overlying strata of the Tres Hermanos and Crevasse Canyon Formations were sourced primarily from Jurassic–Cretaceous parts of the Cordilleran arc with secondary contributions from recycled strata of the Bisbee Rift and possible the McCoy basin of southern Arizona and southwestern New Mexico.

Keywords:

Sevier, Cretaceous, Provenance, Dakota

Correlation of Ash Flow Tuffs From the Mogollon-Datil Volcanic Field in Southwestern New Mexico Using Laser-Induced Breakdown Spectroscopy (LIBS): an Analysis of Sanidine Phenocrysts

Trenton L. Haskell[1] and Nancy J. McMillan[1]

[1]New Mexico State University, 1555 Monte Vista Ave. apt 112, Las Cruces, NM, 88001, trent_geologist@yahoo.com

Correlation of wide spread ash flow tuffs can be very challenging and often requires expensive and time consuming geochemical analysis (such as radiometric dating). LIBS is a relatively new and efficient analytical technique that requires little to no sample preparation as well as very low running costs; handheld models can be used on location. LIBS uses laser ablation to create a short-lived plasma that releases photons of light as it cools. These photons can be captured and analyzed using chemometric techniques to discover hidden trends within the spectra. Thirty-seven samples from fourteen ash flow tuff units located within the MDVF (Mogollon-Datil volcanic field) were originally collected by Chapin et al. (2004) for Ar^{40}/Ar^{39} dating and were donated for this study by William C. McIntosh. All samples were crushed to expose the sanidine phenocrysts; sanidines were separated using heavy liquids (lithium metatungstate) and mounted in epoxy for LIBS analysis. A multivariate chemometric technique called PLSR (partial least-squares regression) was used on the LIBS spectra to create an algorithm that is a series of binary models that each distinguish between one tuff and all the other tuffs. Three separate algorithms were created; the 4-sample model (all tuffs with 4 or more samples from different locations), the 3-sample model (3 or more samples per tuff), and the all-sample model, which yielded success rates of 100%, 79.2%, and 69.4%, respectively. Fourteen of the samples were also analyzed using electron microprobe to support the validity of the LIBS spectra. The concentrations of K_2O, Na_2O, and CaO from the microprobe data were used to create a ternary diagram that is comparable to a ternary diagram constructed with intensities of K, Na, and Ca peaks from LIBS spectra. Ba and Sr concentrations from the electron microprobe that were above detection limits were also compared with Ba and Sr spectra peaks. Both the microprobe concentrations and the LIBS spectra yielded similar results. The results of the algorithms suggest that the success rate of each algorithm is dependent on the amount of samples that were analyzed. The results further suggest that with enough samples a successful algorithm can be created which can be used as a tool for correlation of ash flow tuffs.

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DETRITAL SANIDINE $^{40}Ar/^{39}Ar$ DATING: TRANSFORMING SEDIMENTARY ROCK GEOCHRONOLOGY

Matthew T. Heizler[1], Karl Karlstrom[2], Matthew Zimmerer[1], Jake Ross[1], Laura Crossey[2] and William McIntosh[1]

[1]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801, matt.heizler@nmt.edu
[2]University of New Mexico, Albuquerque, NM, 87131

Several pilot studies and recently published papers are demonstrating the potential to transform sedimentary rock geochronology via detrital sanidine (DS) $^{40}Ar/^{39}Ar$ dating. Discrete volcanic ash layers are relatively lacking in the sedimentary record and thus only provide a limited opportunity for chronostratigraphic studies. In contrast, detrital sanidines appear to be ubiquitous is western USA sedimentary rocks younger than about 300 Ma. These represent cryptic tephra layers and also grains transported by wind and rivers thus potentially providing the age of the rock unit and important provenance information. Current studies have primarily focused on late Cretaceous/Paleocene rocks from the San Juan Basin and post 10 Ma river terrace deposits from NM, AZ, CO, UT and WY. Combined, these studies reveal the tremendous potential of the method as youngest age populations often equal or approach actual depositional ages and are up to 100 times more precise than detrital zircon U/Pb analyses. Thus DS grains can be linked to individual ignimbrites sources. Also, comparison of DS maximum deposition ages to river terraces dated by low precision and costly cosmogenic nuclide burial isochrons demonstrates unprecedented accuracy of DS to determine the terrace age with remarkable improvement in precision. Thus far our studies of river incision rate, paleodrainage patterns, biostratigraphy and neotectonics are indicating that we are on the verge of a geochronology revolution similar to the impact that has been made by detrital zircon geochronology during the past couple of decades. In order to fully utilize the potential of DS geochronology, several steps are required. Ultra-high precision dating of ignimbrites is needed so that individual DS grains can be better linked to source rocks. A complete and comprehensive interactive database of sanidine location, age, and composition is required to provide simple means of linking DS grains to potential source rocks. Improvements in workflow efficiency, especially the picking of sanidine grains from bulk K-feldspar separates is needed and we propose this can be accomplished robotically. Lastly, a more comprehensive chemical fingerprint of DS grains that expands the commonly obtained K/Ca ratio to elements such as Na, Sr, and Ba for each DS grain will be more diagnostic of source. To accomplish this we intend to measure Ne, Kr and Xe noble gases that are produce during irradiation of Na, Sr, and Ba, respectively. Over the next decade, research utilizing DS geochronology, coupled with technique advances, will become the next revolutionary breakthrough in geochronology.

Keywords:

$^{40}Ar/^{39}Ar$, sanidine

^{40}Ar/^{39}Ar Detrital Sanidine Dating of the Ogallala Formation in Southeastern New Mexico and West Texas

Kevin Henry[1], Matthew T. Heizler[2] and Steve T. Cather[2]

[1]New Mexico Tech, Socorro, New Mexico, 87801, kevin.henry@student.nmt.edu
[2]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801

Despite the potential for the use of the Ogallala Formation as a constraint on the sedimentary response to uplift of the Southern Rocky Mountains during the Tertiary, primary age and provenance data for New Mexico Ogallala units are sparse. The current estimated depositional age of the southern Ogallala is between ~13 and 5 Ma based on vertebrate biochronology in the northeastern part of the Llano Estacado in west Texas. In an effort to improve the age constraints, detrital sanidine (DS) ^{40}Ar/^{39}Ar geochronology is utilized on samples from the western escarpment of the Llano Estacado and elsewhere in NM. Coupling DS age and associated K/Ca data (determined from measuring ^{39}Ar/^{37}Ar) and comparing this to age and K/Ca data of regional volcanic units allows estimates of maximum depositional age (MDA) and provenance. This information is utilized to better understand the evolution of the Pecos River system. DS data were determined from the Bridwell and Couch formations of the Ogallala Group near Lubbock, TX (samples courtesy of Dr. Tom Lehman). Based on biostratigraphy, the Bridwell formation is Hemphillian (10.3-4.9 Ma) and the Couch is Clarendonian (13.6-10.3 Ma). DS data yield an MDA of 6.77 Ma thus restricting the sampled interval of the Bridwell to no older than 6.77 Ma In contrast, the MDA of the Couch formation sample is 27.1 Ma with no Miocene DS grains detected. Four Miocene DS grains are found in samples from Mescalero Ridge in SE New Mexico and they provide an 11.44 MDA for Ogallala Formation in this area. The combined DS data and lithologic (eolian) similarities suggest that the Ogallala of SE New Mexico is correlative to the upper Couch Formation of west Texas. The 6-8 Ma youngest grains in the Bridwell formation indicate a New Mexico Peralta tuff source, whereas significant late Cretaceous DS grains are likely derived from reworked Cretaceous or younger sedimentary rocks. The 11.44 Ma DS grains from the Llano Estacado may be derived from Socorro area volcanics or perhaps much more distal Yellowstone Hotspot Track eruptions in Idaho, although long transport of sanidine is tephra is problematic. As a whole there are multiple DS ages between the Oligocene and Eocene that could reflect derivation from several regional volcanic fields. In detail, age and K/Ca data of Trans-Pecos volcanic field sanidines provide the best matches to some of the DS data, thereby implying an overall southern source for the Ogallala sediments. This coupled with paleocurrent data supports a north flowing paleo-Pecos river system that has been proposed by Cather (2011). Several samples from north-central New Mexico that are mapped as Ogallala yield Pleistocene DS ages with grains likely sourced from Valles Caldera eruptions. The young ages demonstrate the difficulty of correctly mapping the Ogallala and suggest that these units are likely either the Blackwater Draw or Blanco formation.

THE PALEOPROTEROZOIC MAZATZAL PROVINCE OF SOUTHERN NEW MEXICO: INSIGHT FROM DETAILED FIELD MAPPING AND ISOTOPE GEOCHEMISTRY

Colby Howland[1] and Jeff M. Amato[1]

[1]New Mexico State University, Las Cruces, NM, 88003, howlandc@nmsu.edu

Analysis of Paleoproterozoic rocks exposed in southern New Mexico can provide key insight into the formation of the Mazatzal province and the assembly of southwestern Laurentia, including the type of crust involved, the timing of accretion, and the history of deformation. The San Andres Mountains in southern New Mexico contain Paleoproterozoic rocks that were exposed by a west-tilted normal fault block that is the result of Rio Grande Rifting. In the vicinity of Salinas Peak, previous mapping at 1:62,500 scale combined most of the Proterozoic rocks into one unit (Scholle, 2003). More detailed mapping at 1:6000 scale has revealed that this unit contains many different types of rocks including amphibolite, schist, gneiss, and several granites. The amphibolite unit is typically boudinaged and is interlayered with the schist. Schists typically strikes S45E and has a dip of 45° SW. The gneissic unit is highly deformed and shear sense data are being collected. A gray fine-grained granite contains 1-2 mm garnets and cuts the schist, amphibolite and gneissic units. A pink coarse-grained granite is less deformed, contains large potassium feldspar grains (1 to 10 cm), and cuts the gray granite. A pink granite dike cuts the schist and amphibolite units and is folded with an axial surface parallel to the foliation in the schist. Thus, field observations of the rocks around Salinas peak in the northern San Andres Mountains indicate a complex history of magnetism, deposition and deformation. We obtained whole-rock Nd isotope data from five 1.67–1.63 Ga felsic igneous rocks in the San Andres Mountains, Kingston District, Caballo Mountains, and Kingston District. They all had e_{Nd} ranging from -1.8 to +1.2. These values are close to Bulk Earth and indicate little contamination with or derivation from older crust, consistent with juvenile magmatism. Previous geochronology (Ottenfeld, 2015) indicated U-Pb zircon ages from 1684–1624 Ma throughout the southern Mazatzal province. We acquired preliminary Hf isotope data on zircons from 16 of these samples. These analyses had e_{Hf} values ranging from 5 ± 2 to 10 ± 1, close to depleted mantle values that are in agreement with Nd whole-rock isotope data.

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DISTINGUISHING CALCITE WITH AND WITHOUT BIOMARKERS USING LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS), GUADALUPE MOUNTAINS, NEW MEXICO

Brent A. Jackson[1] and Nancy J. McMillan[1]

[1]New Mexico State University, Las Cruces, NM, 88003, brentj@nmsu.edu

In a cave environment, speleothems may form by inorganic precipitation of calcite or by precipitation through microbial action. Laser-induced breakdown spectroscopy (LIBS) is an analytical technique that may be used to differentiate between these two types of speleothems. LIBS is a type of atomic emission spectroscopy that uses a high-powered laser to generate an ablation plasma on a sample surface. The emissions from the ablation plasma can then be analyzed to determine both the type and abundance of elements present in that sample. LIBS has several advantages over traditional analytical techniques in that it offers a rapid, portable, and in-situ method of analyzing samples in the field. This study uses LIBS to analyze a total of 40 samples collected from two caves in the Guadalupe Mountains of southeastern New Mexico. Under permit from the U.S. Forest Service 20 samples were collected from Cottonwood Cave and another 20 samples from Black Cave. Samples were selected to include speleothems suspected of being both biologic and non-biologic in origin and include stalactites, soda straws, calcite gravels, cave popcorn, pool fingers, and u-loops. Samples were transported to New Mexico State University and examined using a Hitachi T-1000 scanning electron microscope (SEM) to look for microbial textures such as rods, filaments, cocci, and biofilms. One-hundred shots per sample were taken using LIBS. The spectra collected using LIBS were used to construct and train a model using the multivariate technique of partial least regressive squares (PLSR) and the SEM data were used to validate this model. Using these techniques, we were able to successfully discriminate samples with microbial textures vs. inorganic textures with a 78% success rate for Cottonwood Cave and a 90% success rate for Black Cave.

MICROBIALLY INDUCED SEDIMENTARY STRUCTURES OF THE MESOPROTEROZOIC LANORIA FORMATION, FRANKLIN MOUNTAINS, EL PASO COUNTY, TEXAS

Eric J. Kappus[1], Spencer G. Lucas[2] and Matthew R. Stimson[3]

[1]The University of Texas at El Paso, 5823 N. Mesa, #707, El Paso, TX, TX, 79912, eric_kappus@hotmail.com
[2]New Mexico Museum of Natural History, 1801 Mountain Road N.W., Albuquerque, NM, 87104-1375
[3]New Brunswick Museum, 277 Douglas Ave., Saint John, New Brunswick, E2K1E5, CANADA

The Middle Proterozoic Lanoria Formation, preserved in the Franklin Mountains of El Paso County, Texas, is at least 750 m thick. It consists of metamorphosed sandstone, siltstone and mudstone. These strata were deposited in an array of shallow marine, nearshore and tidal flat paleoenvironments on a gently sloping shelf in the foreland basin of the Grenville orogeny. Geochronology of detrital zircons, cross-cutting granites, and overlying rhyolites constrain the age for the Lanoria Formation to the Stenian period. The fourth member of the Lanoria Formation at NMMNH locality 10809 contains abundant Microbially Induced Sedimentary Structures (MISS). These include the following: wrinkle structures (aff. *Rugalichnus*), multidirectional ripple marks, several types of syneresis cracks (elongate, spindle, and polygonal, and sinusoidal aff. *Manchuriophycus*), mat roll-ups (and possible "cigar rolls"), gas domes, discoidal microbial colonies and associated merged gas domes, elongate microbial surface trails with levees, lobate radial projections (or tool marks), and impressions of filamentous extracellular polymeric substances. Sinusoidal traces (similar to *Cochlichnus*) are found on some bedding planes, crossing ripples, but appear to be surface traces and are probably sinusoidal microbial trails. Similar sinusoidal traces from mid-Proterozoic rocks have been reported as metazoan burrows, but these are disputed, as is the molecular evidence for a mid-Proterozoic origin of metazoans. Thus, we take a conservative approach and describe the Lanoria structures that resemble metazoan burrows as sinusoidal wrinkle structures or microbial traces. This is the first report of MISS from the Proterozoic of the Franklin Mountains.

Keywords:

MISS, Lanoria Formation, Proterozoic

GEOTHERMAL POTENTIAL OF THE SOUTHERN SAN LUIS BASIN, TAOS COUNTY, NEW MEXICO

Shari Kelley[1] and Jeff D. Pepin[2]

[1]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801, shari.kelley@nmt.edu
[2]Hydrology Department, New Mexico Tech, Socorro, NM, 87801

Understanding New Mexico's geothermal potential has been a high priority over the last decade due to increasing demand for renewable energy. Subsurface temperatures and groundwater flow in the southern San Luis Basin in the vicinity of Taos are evaluated in this study using 18 new and 19 published temperature profiles; chalcedony geothermometer estimates and published groundwater discharge temperatures are also included in this assessment. Thermal manifestations include well-known hot springs (33-41°C) in the center and along the southern margin of the basin and boreholes with high geothermal gradients (50-75°C/km) and high discharge temperatures (27-31 °C) on the western margin of the basin adjacent to the Tusas Mountains near Tres Piedras. This zone of elevated gradients extends eastward from Tres Piedras toward the Rio Grande, paralleling U.S. Highway 64. Geothermal gradients in the southern part of the basin south of the Rio Pueblo are generally low to average (24 to 32°C/km) and the thermal profiles are commonly disturbed by subsurface groundwater flow. Similarly, gradients north of the Rio Pueblo and east of the Rio Grande are 28 to 36°C/km, which are average values for the Rio Grande rift. In general, temperatures in wells north of the Rio Pueblo are warmer than those to the south. Geothermal gradients in the Miranda graben southwest of Ponce de Leon hot springs are elevated (32 to 58°C/km); again the gradients are disturbed by flowing groundwater. Many of the deep monitoring wells that are close to the Sangre de Cristo Mountain front on the east side of the basin are characterized by thermal profiles that suggest downward groundwater flow (i.e. recharge); many of these same wells also have indications of lateral flow of cold water, particularly in the basalt flows in Servilleta Formation. Two deep wells toward the center of the basin east of the Rio Grande that are proximal to faults have thermal profiles that are indicative of weak groundwater upflow. The cause of the elevated gradients on the western margin of the basin is uncertain and requires further investigation. Youthful basaltic cinder cones that erupted between 191±4 ka and 232±8 ka (Matthew Zimmerer, personal communication, 2017) are located about 30 km to the west of Tres Piedras, but the heat associated with these small-volume eruptions has long since dissipated. The wells with elevated geothermal gradients near Tres Piedras lie in a structural setting that is similar to that of the Ojo Caliente thermal springs to the south. Both areas are on the east margin of the Tusas Mountains. Although the fault that acts as the conduit for warm water at Ojo Caliente is obvious, similar faults near Tres Piedras have not yet been identified, likely because such structures are buried. Reservoir temperatures calculated using the silica concentrations of groundwater in the southern San Luis Basin are generally low (30-80°C). The chalcedony geothermometer estimates derived from warm wells near Tres Piedras are 90 to 110°C. Overall, the geothermal potential of this region is seemingly greatest along the western margin of the basin near Tres Piedras.

REACTIVATION OF THE MT. TAYLOR MINE – OBSTACLES AND OPPORTUNITIES

Alan K. Kuhn

Alan Kuhn Associates LLC, 13212 Manitoba Dr. NE, Albuquerque, NM, 87111, akkuhn41@gmail.com

The Mt Taylor Mine near San Mateo, NM, the largest and deepest uranium mine in the US, was mined in the 1980s but has been on Standby status since 1990. In 2013, Rio Grande Resources Corp. submitted an application to revise its Mine Permit to Active status. The mine has in excess of 100 million pounds of recoverable uranium in the Morrison Formation, Westwater Member at 3200 feet. Good-quality ground water must be removed to access the ore, and this water will be available, after minimal treatment to human health standards, for a number of off-site uses. The mine has overcome a number of obstacles to return to Active status. Several NGOs and local citizens oppose the mine, primarily because of legacy issues concerning environmental and alleged human health impacts from the earlier (1950s-1980s) mining era in the Grants District. Shallow aquifers are being depleted, so many citizens worry that the mine will contaminate or further reduce their water resources. Mt Taylor is sacred to several tribes in the area, prompting its designation as a Traditional Cultural Property, which limits mining on the mountain. The New Mexico Mining Act designates the Mining and Minerals Division as the lead mine regulatory agency but provides the Environment Department with essentially veto authority over mining permits, leading to substantial overlapping and sometimes conflicting authority. The mine is located on private land and patented claims, so the mine is regulated by state agencies; however, a number of federal (e.g., Clean Water Act) permits are also required. In the decades since uranium was mined in the Grants District, essentially all the experienced miners have died, retired or moved away, so an entirely new work force must be recruited and trained. Finally, the mine itself presents obstacles – located very deep in or below three aquifers, temperatures of 140°F, and radon – that require extensive dewatering and ventilation equipment and operating costs. Despite these obstacles, the mine offers a number of opportunities to the community, the state and the nation. If the nation is to reduce carbon emissions, it must have nuclear power to replace coal for base-level generation. Mt Taylor Mine uranium can supply a substantial amount of that fuel source. Water produced by the mine can satisfy the water needs of a number of local users to an extent not possible with presently available resources. The Grants area is economically depressed and needs well-paying jobs that the mine can provide for a long time, and the Severance Tax and payroll taxes paid by the mine will help the statewide economy, as well. Rio Grande Resources has prepared a plan to reactivate the Mt Taylor Mine that satisfies all regulatory requirements. This plan includes collection and single-point isolation of radiologically contaminated materials, upgrades of water management and treatment facilities, and reduction of future waste rock and contaminated sediments. This plan will overcome the obstacles and promote the opportunities associated with the Mt Taylor Mine.

Fossil Turtles of the Upper Cretaceous McRae Formation, Sierra County, New Mexico

Asher Jacob Lichtig[1] and Spencer G. Lucas[1]

[1]New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM, 87124, ajlichtig@gmail.com

Nonmarine siliciclastic strata of the Upper Cretaceous McRae Formation are exposed in south-central New Mexico in Sierra County, primarily across the Cutter sag, between the Fra Cristobal Mountains and Caballo Mountains. Dinosaur fossils have been known from the Hall Lake Member for more than a century and have been long regarded as of late Maastrichtian (Lancian) age, but no other vertebrates have been reported. Recent collecting has recovered fragmentary but identifiable turtle fossils from the Hall Lake Member. These include several small carapace fragments referable to the paracryptodire genus *Compsemys*, which is a Campanian-Paleocene taxon. A small carapace fragment referable to *Denazinemys* or a similar, pustulose-textured baenid, which are known from the Campanian-Paleocene. A large turtle is represented by substantial portions of the carapace and plastron and is tentatively identified as a bothremydid based on the lack of fusion of the shell, the size and surface sculpture. Bothremydids are known from the Campanian and Maastrichtian of North America. In addition, an indeterminate frontal bone of a turtle was found. These turtles provide a lower limit on the age of the Hall Lake Member of Campanian and add to the sparse record of Late Cretaceous turtles in the southern portion of the Western Interior.

PHYLOGENY OF THE ENIGMATIC EOCENE TESTUDINOID TURTLE *ECHMATEMYS* AND THE ORIGIN OF THE TESTUDINIDAE

Asher Jacob Lichtig[1] and Spencer G Lucas[1]

[1]New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM, 87124, ajlichtig@gmail.com

Turtles of the genus *Echmatemys* have long been ignored in phylogenetic analysis, so we analyze the phylogenetic placement of seven species of these turtles. We find that the genus is diphyletic. The species from the lower Eocene San Jose Formation in the San Juan Basin, New Mexico, are stem Testudinidae rather than geoemydids as previously hypothesized. Furthermore, *Hadrianus majusculus* is actually the most primitive tortoise known, lacking common, more derived tortoise traits such as costal wedging. Given the primitive state in North American tortoises, we suggest that Testudinidae (tortoises) originated in southern North America from one of the geoemydid-like forms lumped in the genus *Echmatemys*, which first appear in the earliest Wasatchian. This is contrary to the conventional wisdom that tortoises originated in Asia, where their most basal member (based on genetic studies) lives today. We suggest an alternative interpretation that tortoises arose in North America and subsequently emigrated to Asia and Europe during the second thermal maximum in the later part of the Wasatchian land-mammal "age." This warm period slightly preceding the deposition of the Bridgerian-equivalent units that yield the oldest tortoises in Europe and Asia. From Europe, immigration to Africa and from Africa to South America would follow in the Oligocene and later. Reports of unpublished Paleocene material in Asia may indicate that tortoises originated in Asia and then, together with some members of their stem lineage, immigrated to North America and then onward to Europe. This explains members of its stem-lineage co-occurring with tortoises in the San Jose Formation. In short, our understanding of tortoise origins is still limited but is improving as older material is being reanalyzed in the light of more recent discoveries.

Environmental Aqueous Geochemistry of Uranium in Aquifer Systems, Pajarito Plateau, New Mexico

Patrick Longmire[1], Kim Granzow[2], Stephen Yanicak[2], David Fellenz[2], Michael Dale[3], Megan Green[2], and Antonio Trujillo[2]

[1]New Mexico Environment Department; Ground Water Quality Bureau, 1190 St. Frances Drive, Santa Fe, NM, 87502, patrick.longmire@state.nm.us
[2]New Mexico Environment Department; DOE Oversight Bureau, 1183 Diamond Drive, Suite B, Los Alamos, NM, 87544
[3]New Mexico Environment Department; Hazardous Waste Bureau, 1183 Diamond Drive, Suite B, Los Alamos, NM, 87544

Los Alamos National Laboratory (LANL) has conducted multidisciplinary research on uranium since the mid-1940s. Treated and non-treated industrial aqueous discharges, mainly containing isotopically natural uranium with a $^{238}U/^{235}U$ atom ratio = 137.8813, have been discharged to Acid, Pueblo, Los Alamos, and Mortandad Canyons. These discharges provide recharge to shallow alluvial and perched-intermediate depth groundwater and the regional aquifer at typical depths of <24 meters (m), 183 m, and 296 m, respectively. Background water chemistry in the regional aquifer varies from an oxidizing (median Eh = 332 mV), calcium-sodium-bicarbonate to a sodium-calcium-bicarbonate composition. Small amounts of enriched uranium, containing a $^{238}U/^{235}U$ atom ratio <137.8813, have been locally measured in alluvial groundwater within Mortandad Canyon. The Environmental Protection Agency drinking water standard for total uranium and the New Mexico Water Quality Control Commission standard for dissolved uranium is 0.126 µM (0.030 mg/L). Upper tolerance limits have been calculated by the New Mexico Environment Department and LANL for numerous solutes naturally present in the regional aquifer. These include total dissolved uranium (5.336 nM, 0.00127 mg/L), dissolved oxygen (0.253 mM, 8.10 mg/L), nitrate(N) (0.056 mM, 0.78 mg/L), chloride (0.084 mM, 2.98 mg/L), perchlorate (4.324 nM, 0.00043 mg/L), and sulfate (0.061 mM, 5.84 mg/L). Background concentrations of dissolved uranium in the regional aquifer increase with average groundwater age, especially east of the Rio Grande. Concentrations of dissolved uranium(VI) elevated above background, with a maximum value of 0.0504 µM (0.012 mg/L), have been detected in several regional aquifer monitoring wells installed in Pueblo, Los Alamos, and Mortandad Canyons. Concentrations of nitrate, perchlorate, and/or tritium coreleased with aqueous uranium(VI) species are elevated above background in the regional aquifer at several monitoring wells. Thermochemical calculations suggest that uranyl carbonate-carbonato complexes, including $UO_2CO_3^0$, $UO_2(CO_3)_2^{2-}$, $Ca(UO_2)_2(CO_3)_3^0$, and $UO_2(CO_3)_3^{4-}$, dominate in the regional aquifer. These uranyl complexes are mobile under oxidizing and circumneutral pH conditions characteristic of the regional aquifer at Los Alamos. Concentrations of natural reductants, including dissolved hydrogen sulfide, dissolved ferrous iron, dissolved organic carbon, and solid organic matter are not sufficient to enhance reduction of uranium(VI) to uranium(IV) aqueous complexes (UOH^{3+} and $U(OH)_4^0$). The regional aquifer is undersaturated with respect to amorphous UO_2, uraninite, and coffinite. Background concentrations of dissolved uranium(VI) in upper sections of the regional aquifer are initially controlled by partial dissolution of soluble volcanic glass followed by specific adsorption of uranium(VI) complexes onto hydrous ferric oxide and cation exchange of uranyl cation with calcium on smectite surfaces. Upper sections of the regional aquifer beneath the Pajarito Plateau are enriched in silica and groundwater shows variable saturation with respect to uranophane ($Ca(H_3O)_2(UO_2)_2(SiO_4)_2 \cdot 3H_2O$) and is oversaturated with respect to haiweeite ($Ca(UO_2)_2Si_6O_{15} \cdot 5H2O$) depending on pH and calcium and silica activities.

Keywords:

uranium, groundwater, environmental aqueous geochemistry, adsorption, precipitation

GEOCHEMICAL PROCESSES CONTROLLING TRANSPORT AND DEPOSITION OF URANIUM, ESPAÑOLA BASIN, NEW MEXICO

Patrick Longmire[1], Virginia T. McLemore[2], Dennis McQuillan[3], Stephen Yanicak[4], and David Vaniman[5]

[1]New Mexico Environment Department; Ground Water Quality Bureau, 1190 St. Frances Drive, Santa Fe, NM, 87502, patrick.longmire@state.nm.us
[2]New Mexico Bureau of Geology and Mineral Resources; New Mexico Tech, Socorro, NM, 87801
[3]New Mexico Environment Department; Office of the Secretary, 1190 St. Frances Drive, Santa Fe, NM, 87502
[4]New Mexico Environment Department; DOE Oversight Bureau, 1183 Diamond Drive, Suite B, Los Alamos, NM, 87544
[5]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA, 91011

Uranium is an actinide of considerable environmental interest present in aquifer systems worldwide. Dissolved concentrations of natural (background) uranium vary from less than 8.40e-09 M (2.0 µg/L) to 7.65e-06 M (1.82 mg/L) in groundwater east of the Rio Grande within the Española Basin, New Mexico. Total dissolved concentrations of natural uranium range from 5.04e-10 M to 5.76e-09 M (0.12 µg/L to 1.37 µg/L) in the regional aquifer beneath the Pajarito Plateau west of the Rio Grande. Dominant uranyl aqueous complexes consisting of $UO_2(CO_3)_2^{2-}$, $Ca(UO_2)_2(CO_3)_3^0$, and $UO_2(CO_3)_3^{4-}$ are mobile under circumneutral pH and oxidizing conditions characteristic of the Santa Fe Group (Tesuque Formation). Oxidative dissolution of uranium(IV) minerals and hydrolysis of uranium(IV)-bearing silicates and oxides associated with Proterozoic granitic rocks in the Sangre de Cristo Mountains enhanced mobilization of uranium from source material. Hydrolysis of soluble uranium-bearing volcanic ash and granitic detritus present in the Tesuque Formation also contribute to highly variable uranium concentrations occurring in Santa Fe Group groundwater. Uranium(IV, VI) is associated with clay galls, opal, chert, fossil bone, carbonaceous material, smectite, and ferric (oxy)hydroxide in the San Jose mining district (Arroyo Seco and Oxide Butte) exposed as outcrops in the present-day vadose zone. The dominant uranium(VI) minerals identified in this mining district include carnotite ($K_2(UO_2)_2V_2O_8{\cdot}3H_2O$), metaautunite ($Ca(UO_2)_2(PO_4)_2{\cdot}2\text{-}6H_2O$), and schröckingerite ($NaCa_3(UO_2)(CO_3)_3(SO_4)F{\cdot}10H_2O$). Evapoconcentration of porewater in the Santa Fe Group likely was a critical process that enhanced solute saturation leading to precipitation of uranium(VI) minerals that have higher aqueous solubilities compared to uranium(IV) minerals, including uraninite and coffinite. Results of deionized (DI) water-leach tests and EPA 3050 partial digestions (pH1) performed on oxidized sediments collected from the San Jose mining district show that concentrations of dissolved uranium range from 3.21 to 52.21 µg/g and from 8.48 to 107.8 µg/g, respectively, using a ratio of 150 mL DI and acid to 100 g solid. Based on X-ray diffraction analyses, smectite varies from 45 to 68 weight percent in two samples collected from Oxide Butte, whereas this clay mineral is only present up to 1-2 weight percent in two samples collected from Arroyo Seco. Lower leachate concentrations of dissolved uranium suggest that this metal is strongly adsorbed and/or precipitated as uranyl phases on smectite surfaces abundant in the Oxide Butte samples. Higher concentrations of uranium were leached from the smectite-poor Arroyo Seco samples, suggesting weak adsorption of this actinide onto mineral surfaces. Desorption/dissolution coefficients for uranium based on ratios of 3050 digestion acid- to DI-leach results range from 3.10 to 5.74 mL/g and from 3.16 to 3.96 mL/g, for the Arroyo Seco and Oxide Butte samples, respectively. Oxyanions of arsenic, selenium, and vanadium represent competing adsorbates that may limit uranium(VI) adsorption onto smectite and ferric (oxy)hydroxide present at Oxide Butte. Higher concentrations of dissolved uranium(VI) occurring in oxidizing groundwater in other areas of the Española Basin are associated with increasing concentrations of dissolved sodium and decreasing concentrations of dissolved calcium. This suggests that exchange reactions result in adsorption of Ca^{2+} onto exchange sites and release of Na^+ and UO_2^{2+} to groundwater.

IMPLICATIONS OF PAST EXTENTS OF RIO SALADO AND RIO PUERCO DEPOSITS IN THE SOUTHWESTERN CORNER OF THE ALBUQUERQUE BASIN, NEW MEXICO

David W. Love[1], Alex Rinehart[1], Richard Chamberlin[1], Eda Celep[2] and Dan Koning[1]

[1]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, 801 Leroy Place, Socorro, NM, 87801, david.love@nmt.edu
[2]Department of Earth and Environmental Science, New Mexico Tech, 801 Leroy Place, Socorro, NM, 87801

The southwestern part of the Albuquerque Basin of the Rio Grande rift between the Ladron Mountains and Rio Grande Valley is cut by three major and several lesser-known north-south normal faults with Quaternary offsets: Loma Pelada, Loma Blanca, and Cliff (from west to east). Each fault block exposes different sedimentary deposits ranging in age from mid-Miocene to early Quaternary. Deposits in the footwall of the west-down Cliff fault adjacent to the modern Rio Grande Valley consist of two kinds of southeast-directed channels and floodplain deposits of the ancestral Rio Puerco and Rio Salado and mixtures. The two channel types presumably joined the ancestral Rio Grande west of the Joyita Hills. The floodplain/basin-floor deposits are time- and in-part lithologically correlative with the broad fluvial fan of the Ceja Formation and Llano de Albuquerque to the north; they predate development of high-level terraces of the Rio Grande and modern west-east Rio Salado Valley to the south. Clasts are distinctive for the two types of stream channels, although locally some become mixed. Rio Puerco gravels commonly are well-rounded siliceous pebbles (at least 20 % chert) less than 8 cm long with a few larger pebbles; rare pebbles of 3.26-Ma Grants obsidian are present in upper exposures. Rio Salado clasts include larger, subangular-subrounded pebbles to boulders of limestone, sandstone, granite, quartzite, other Proterozoic metamorphic rocks, ash-flow tuffs, intermediate and basaltic volcanic rocks, and rare travertine. To determine the path(s) of the two channel types upstream from the exposures at the north end of the Cliff fault, we looked for similar suites of clasts between the Cliff and Loma Blanca faults and between the Loma Blanca and Loma Pelada faults. Northeast-directed Rio Salado deposits meet and overlie Rio Puerco deposits along the southern margins of the Rio Puerco Valley west of the Cliff fault and may be traced southwest to the east side of the Loma Blanca fault north of the Rio Salado Valley. Between the Loma Blanca and Loma Pelada faults, two possible levels of northeast-trending bluff-lines with Rio-Salado-type gravel deposits south of the bluffs suggest northeastward-directed paths toward the Rio Puerco. However, in the underlying deposits that clearly predate piedmont gravels shed from the Ladron Mountains, similar suites of "Rio Salado" clasts indicate northward transport. The transport direction shifts northeastward near AT&T road. North of AT&T road, clasts similar to the "Rio Salado" suite are directed southeast and probably were reworked from separate exposures northeast of the Ladron Mountains. Rio Puerco channels on both sides of the Loma Blanca fault are also directed southeast. We conclude that there may be several origins for clasts of the "Rio Salado suite" exposed in the footwall of the Cliff fault and that paleogeographic maps of fluvial contributors to deposits of the southern Albuquerque Basin may need revision.

Keywords:

Albuquerque Basin, Rio Puerco, Rio Salado, Cliff fault, Loma Blanca fault, Loma Pelada fault, basin-fill sediments

Stratigraphy and Age of the Dinosaur-Dominated Fossil Assemblage of the Upper Cretaceous Hall Lake Member of the McRae Formation, Sierra County, New Mexico

Spencer G. Lucas[1], Sebastian Dalman[1], Asher J. Lichtig[1], Scott Elrick[2], W. John Nelson[2] and Karl Krainer[3]

[1]New Mexico Museum of Natural History, 1801 Mountain Road N.W., Albuquerque, NM, 87104, spencer.lucas@state.nm.us
[2]Illinois State Geological Survey, 615 East Peabody Drive, Champaign, IL, 61820
[3]Institute of Geology, Innsbruck University, Inssbruck, Austria

The Upper Cretaceous McRae Formation is fluvial sediments exposed in south-central New Mexico in Sierra County, primarily across the Cutter sag, between the Fra Cristobal Mountains to the north and Caballo Mountains to the south. Total thickness of the McRae Formation is at least 1 km, and it is divided into a lower, Jose Creek Member up to 120-m thick overlain by an upper, Hall Lake Member at least 850-m thick. Dinosaur fossils have been known from the Hall Lake Member for more than a century and have been long regarded as of late Maastrichtian (Lancian) age. Recent collecting has augmented the Hall Lake Member dinosaur fauna, and stratigraphic analysis puts many of the dinosaur fossils into a precise and detailed lithostratigraphic framework. These fossils are from a nonmarine facies composed of commonly crossbedded conglomerate and sandstone representing fluvial channel fills, and thick siltstone-mudstone intervals, representing floodplain or overbank deposits, locally containing pedogenic carbonate beds. Most of the dinosaur fossils come from a thin stratigraphic interval 23-43 m above the base of the Hall Lake Member. This includes *Tyrannosaurus rex*, a new ceratopsian genus similar to *Torosaurus* and an abundance of indeterminate ceratopsid fossils. Stratigraphically higher fossils, about 140-150 m above the base of the Hall Lake Member include the titanosaur *Alamosaurus*. Other dinosaurs, mostly indeterminate ceratopsids and hadrosaurids, are also known from Hall Lake Member localities that cannot be placed into the detailed stratigraphic framework because of faulting and/or Quaternary cover. *Tyrannosaurus* and *Alamosaurus* are not known from pre-Lancian strata, so their presence reaffirms a Lancian age for the lower part of the Hall Lake Member. Fossil turtles from the Hall Lake Member include *Compsemys* and an indeterminate bothremydid and only indicate a Campanian to Maastrichtian age. A recently reported $^{206}Pb/^{238}Pb$ age of a tuff bed 9 meters above the base of the Hall Lake Member is 74 Ma, about 7 million years older than the biostratigraphic age based on the dinosaur fossils. We thus question the accuracy of this radioisotopic age, and of other Campanian ages in the 74-76 Ma range on tuffs in the Jose Creek Member. It seems likely that the McRae Formation is mostly of late Maastrichtian age, though its maximum and minimum ages remain undetermined based on present data.

The Cretaceous Section at Placitas, Sandoval County, New Mexico

Spencer G. Lucas[1] and John B. Rogers[2]

[1]New Mexico Museum of Natural History, 1801 Mountain Road N.W., Albuquerque, NM, 87104, spencer.lucas@state.nm.us
[2]Central New Mexico Community College, 525 Buena Vista SE, Albuquerque, NM, 87106

In the vicinity of Placitas, on the northern end of the Sandia uplift in Sandoval County, a much faulted Cretaceous section can be pieced together from outcrops on three fault blocks. However, many of the shale-dominated units in this section have been tectonically thinned, so only their minimum thicknesses can be estimated. The base of the section is the Oak Canyon Member of the Dakota Sandstone disconformably overlying the Upper Jurassic Jackpile Member of the Morrison Formation. The overlying sandstone-dominated Cubero Member of the Dakota completes an ~26 m thick Dakota section. The overlying shale-dominated Graneros-Carlile interval is at least 52 m thick and includes a 2-m-thick Greenhorn Limestone ~7 m above its base. The overlying Juana Lopez Member is ~ 2 m of bioclastic calcarenite, overlain by a D-Cross equivalent shale interval at least 27 m thick. The overlying silty El Vado Member is at least 76 m thick and overlain by the merged Dalton-Hosta Sandstone, which is up to 72 m thick. The overlying sandy shale-dominated Satan Member is at least 107 m thick. Map data suggest a total Mancos Formation thickness as at least 345 m. The overlying Point Lookout Sandstone is 28 m thick and is overlain by the Menefee Formation, which is at least 150 m thick and caps the Cretaceous section. The Menefee encompasses two coal-bearing intervals split by a sandstone interval ~30 m thick. The Cretaceous section at Placitas is very similar to the Cretaceous sections in the Tijeras syncline on the eastern side of the Sandia uplift and in the Hagan basin north of Placitas. These sections document the continuity of Upper Cretaceous lithosomes across the Rio Grande rift and do not support concepts of 50-150 km of right slip along the rift after Cretaceous deposition.

THE PALEOZOIC SECTION AT BELL HILL, SOCORRO COUNTY, NEW MEXICO

Spencer G. Lucas[1], Bruce Allen[2], Karl Krainer[3] and James E. Barrick[4]

[1]New Mexico Museum of Natural History, 1801 Mountain Road N.W., Albuquerque, NM, 87104, spencer.lucas@state.nm.us
[2]New Mexico Bureau of Geology and Mineral Resources, 801 Leroy Place, Socorro, NM, 87801
[3]Institute of Geology, University of Innsbruck, Innsbruck, A-6020, Austria
[4]Department of Geosciences, Texas Tech University, Box 41053, Lubbock, TX, 41053

The Pennsylvanian section at Bell Hill in the southern San Mateo Mountains of southern Socorro County, New Mexico (sec. 16, T8S, R4W and vicinity), has long been considered the thickest Pennsylvanian section (~800 m thick) in south-central New Mexico and the focal point of a late Paleozoic San Mateo depositional basin. Kottlowski (1960) first described the Paleozoic section at Bell Hill (his Eaton Ranch section) as 808 m of Pennsylvanian strata on Proterozoic basement and overlain by the lower Permian Abo Formation. Furlow (1965; Kelley and Furlow, 1965), however, interpreted the section differently, as ~91 m of Cambro-Ordovician strata resting on the basement, overlain by ~732 m of Pennsylvanian strata beneath the Abo Formation. We restudied the Pennsylvanian section at Bell Hill and determined that the Pennsylvanian section is thinner than previously reported, only 495 m thick. At Bell Hill, the Pennsylvanian strata overlie a thin (~70 m thick) lower Paleozoic section that consists of the Cambro-Ordovician Bliss Formation and the Ordovician El Paso Group (Sierrite Member of the Hitt Canyon Formation) and Montoya Formation (Cable Canyon and Upham members). The Middle Pennsylvanian Red House Formation unconformably overlies the Montoya Formation, and is at least 31 m thick (structural complications prevent a certain estimate). It is overlain by the Gray Mesa Formation, which is 158 m thick and divisible into the Elephant Butte (at least 18 m thick), Whiskey Canyon (53 m thick) and Garcia (87 m thick) members. The overlying Bar B Formation is 306 m thick, substantially thicker than to the south, and accounts for most of the relatively great thickness of the Bell Hill Pennsylvanian section. The Bar B Formation is overlain by the Bursum Formation, ~18 m thick, which is overlain by the Abo Formation. Fusulinid and conodont biostratigraphy indicate that at Bell Hill the Red House Formation is Atokan, the Gray Mesa Formation is Desmoinesian and the Bar B Formation is Desmoinesian-Virgilian. The new estimate of the thickness of the Pennsylvanian section at Bell Hill requires redrawing the late Paleozoic San Mateo basin as an east-west-oriented trough instead of a single, localized depocenter.

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THE EVOLUTION OF URANIUM MINERALIZATION IN NEW MEXICO

Virgil W. Lueth[1] and Kelsey McNamara[1]

[1]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, New Mexico, 87801, Virgil.Lueth@nmt.edu

Hazen et al. (2008) identified 10 stages of planetary "mineral evolution" based on observations and geochemical principals. The Earth formed from a relatively homogeneous material and has differentiated over 4.5 billion years of time. Mineral evolution is a consequence of changing temperature, pressure, and composition during this differentiation process that is unique to tectonically active planets. Hazen et al. (2009) noted that the geochemistry of uranium is highly sensitive to some of these "evolutionary stages" and the resulting uranium mineralogy can be used to define four phases of uranium mineralization that have operated within the 10 stages of mineral evolution. Six of the first 10 stages of U mineral evolution occurred prior to the formation of crust that eventually formed New Mexico ca 1.8 Ga. Accordingly, two of the four uranium mineral evolution phases occurred prior to the formation of the oldest rocks in the state. Vestiges of the first two stages may be recognizable in some New Mexico rocks as detrital uraninite or thorite grains or as mineral inclusions in zircons which demonstrate partial U-Th solid solution compositions. The assembly of New Mexico produced the state's first home-grown uranium minerals that were formed in ore deposits associated with late stage magmatic activity. A relatively simple assemblage of uranium-bearing oxides and silicates were deposited, mainly in pegmatites and some copper veins, with some secondary uranium minerals formed via less conventional processes of auto-oxidation. The formation of New Mexico is also coincident with the "Great Oxidation Event" which gave rise to abundant formation of the uranyl ion (U^{6+}) and an explosion of secondary U minerals, estimated at over 200 (Hazen et al., 2009). Since 2 Ga, U^{6+} geochemistry dominates the mobility and mineralogy of the element in both the formation and natural destruction of U ore deposits. Complexation and crystal chemistry results in intricate paragenetic mineralization sequences that are often reversible. Mineralogical change in single ore specimens have been documented over very short time periods (e.g. dehydration of tyuyamunite to metatyamunite) in addition to crystallization of new phases upon extraction from their natural environment (e.g. crystallization of liebigite on mine rock surfaces). Current mineralogy at any deposit (or waste/tailings pile) does not necessarily reflect the dominant geochemical processes that operated over the longest period of time. The additional consideration of biological influences on U mobility further complicates forensic types of research as well as imparting geochemical ambiguities in environmental considerations. Microbes have been documented to either oxidize or reduce uranyl ions in near-surface environments thus influencing uranium mobility irrespective of inorganic chemical controls.

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PHYLLIC ALTERATION IN THE COPPER FLAT PORPHYRY COPPER DEPOSIT, SIERRA COUNTY, NEW MEXICO

Kierran Maher[1] and Chaneil Wallace[1]

[1]New Mexico Institute of Mining and Technology, 801 Leroy Place, Socorro, NM, 87801, kierran.maher@nmt.edu

Recent work by Wallace (2016) and earlier work by Dunn (1982) recognized widespread, albeit relatively weak, phyllic alteration in the Copper Flat porphyry copper system of the Hillsboro district, Sierra County, New Mexico. We report shortwave infrared (SWIR) spectral absorption features of the phyllic alteration obtained using a probe mask in order to significantly reduce the area sampled by the spectrometer probe. This allows the detection of IR absorption anomalies on a much smaller spatial scale than previously possible. Analytical transects across individual samples of the early phyllic alteration that is widely distributed in the Copper Flat system generally show limited sample-specific wavelength variations for the main Al:OH bond absorption feature in the infrared spectrum. Detailed analyses utilizing the probe mask indicates that sericite in the altered mafic sites has slightly longer wavelength absorption by about 3-4 nanometers (nm) relative to sericite replacing adjacent plagioclase. This supports the conclusion of Wallace (2016) based on microprobe analysis that the sericite in this setting inherited a composition partly from its precursor silicate mineral, rather than being compositionally controlled by the fluid. On average, the early sericite has its main Al:OH absorption feature at around 2210nm, which is produced by mica of celadonitic composition. Analytical transects over samples showing multi-stage phyllic alteration have up to a 9nm wavelength variation in this absorption feature. Later stage phyllic alteration is characterized by well-developed sericite halos to thin quartz ±sulfide veinlets affecting all precursor minerals, but has limited representation in the system. The IR absorption features of this sericite have both longer (to 2214nm) and shorter wavelengths (2205nm) relative to the background sericite. The late sericite of longer-wavelength absorption tends to be a gray color and that of shorter wavelength is white. Based on the location of the Al:OH absorption feature, the late sericite ranges between muscovite and celadonite compositions (2205nm to 2214nm), and overlaps with the background sericite. No sericite of shorter wavelength has been found in the Copper Flat system. The Copper Flat hydrothermal system differs from other copper porphyry systems in a number of ways but the characteristics of the phyllic alteration are particularly noteworthy. As in other porphyry systems, the widespread background carbonate-bearing phyllic alteration likely evolved from earlier potassic alteration fluids, but these were much more restricted in volume, less oxidized and sulfur-poor at Copper Flat. Due to the fact that the host rock rock strongly buffered the phyllic fluid, the resulting alteration was weak and targeted specific minerals with the general preservation of the texture of the rock and the dominance of celadonitic sericite compositions. In other porphyry systems, greater stability of shorter-wavelength sericite (i.e., <2205nm), such as muscovite and paragonite, may result from various processes (absent at Copper Flat) that result in a reduction of the host rock's capacity to buffer the hydrothermal fluid.

Keywords:

hydrothermal alteration, Copper Flat, phyllic, SWIR, porphyry

The Demise of the Cuatrociénegas Gypsum Dune Field, and What It Means for the White Sands National Monument

Ethan A. Mamer[1] and B. Talon Newton[1]

[1]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801, ethan.mamer@nmt.edu

White Sands National Monument and its sister park, the Área de Protección de Flora y Fauna Cuatrociénegas, are linked by their unique gypsum dune fields. Gypsum is a common mineral, but it is extremely rare in the form of sand dunes. While gypsum dune fields unite the parks, at present, there are stark morphological differences between the two dune fields. The White Sands dune field is considered to be a "wet" system due to a very shallow water table that helps anchor the dunes, providing a degree of cohesion between the fine grains that prevents the sand from blowing away. A significant decline in the water table would likely have a profound effect on the overall morphology of the dune field. Where White Sands is considered an active system, dominated by tall dunes that migrate across its dune field, the Cuatrociénegas dune field is dominated by lithified blocks of gypsum. Preserved in these cemented blocks are bedding planes, which indicate that large dunes once dominated the area. At present, there is not a shallow water table found beneath the Cuatrociénegas dune field. Concerned for the long term preservation of its gypsum dune field, the National Park Service sought to determine the cause of the apparent change in morphology of the Cuatrociénegas dune field, and whether a similar fate awaits the White Sands dune field. To understand what lead to the deflation of the Cuatrociénegas dune field a hydrologic investigation of the basin was conducted by the New Mexico Bureau of Geology. This study developed a conceptual model for the Cuatrociénegas dune system to understand the processes that formed and maintained the gypsum dune field in the past. The conceptual model helps our understanding of the effects that anthropogenic activities and natural processes had on the Cuatrociénegas dune field. This insight may help us to predict how similar activities, such as large groundwater diversions, may affect the White Sands dune field. Geochemical and stable isotope analysis was performed on spring pool samples. From our analysis of recently collected data, as well as reanalysis of previously published data, there is a significant body of evidence that suggests a large regional flow system supports the groundwater flow to the basin. PHREEQC saturation modeling of water samples collected from the Cuatrociénegas Basin was performed to understand when the water sources become saturated with respect to gypsum. Remote sensing techniques were used to measure the decline of water bodies in the basin. Microprobe analysis of gypsum samples was preformed to determine if the dune field had previously supported a shallow water table. While it is difficult to determine when the balance was tipped, it is likely that the shift started within the past 100 years, as the water resources in the basin began to be exploited. Possible impacts to the dunes include gypsum mining, draining of the wetlands and the decline of Laguna Grande, high-capacity agricultural water extraction, and long-term drought.

Keywords:

Cuatrociénegas, gypsum, dunes, hydrogeology, White Sands

A POSSIBLE NEW SPECIES OF *DIMETRODON* (EUPELYCOSAURIA: SPHENACODONTIDAE) FROM THE LOWER PERMIAN ABO FORMATION, SOCORRO COUNTY, NEW MEXICO

Kenneth L. McKeighen[1], Kendra R. McKeighen[1], Henry W. McKeighen[1] and Spencer G. Lucas[1]

[1]New Mexico Museum of Natural History and Science, 1801 Mountain Rd NW, Albuquerque, NM, 87104, KENTHEARTIST1@MSN.COM

We add to the growing record of *Dimetrodon* fossils from the Lower Permian Abo Formation in New Mexico with the addition of a potential new species from the Gallina Well locality in Socorro County that previously yielded other material of *Dimetrodon* in 2010. During a visit to the site in 2014, one of us (KLM Jr.) collected a large vertebra and associated fragments including a 15 cm long neural spine. The neural spine morphology of this specimen is of the more primitive round cross section, most similar to *Dimetrodon milleri*, the oldest known *Dimetrodon* from Texas. A significant difference is larger size being at least 50% larger than *D. milleri*. We also see a temporal difference with the Gallina Well *Dimetrodon* being late Asselian or early Sakmarian in age and *D. milleri* being younger in the Sakmarian. The Discovery of this specimen raises several important questions. The first relates to size of early *Dimetrodon* species. Until the discovery of this specimen all known early *Dimetrodon* were small. Indeed, all early species, cf. *D. milleri* from the middle Asselian of New Mexico, *D. occidentalis* from the upper Asselian of New Mexico, and *D. milleri* from the Sakmarian of Texas, are all small species. This was thought advantageous to life in an inland and upland habitat, and that larger size arose to take advantage of deltaic habitats. The new species from Gallina Well demonstrates that larger size arose much earlier than previous thought. The diversity of *Dimetrodon* is also in question with regard to how many species were there in New Mexico deposits. The new Gallina Well *Dimetrodon* suggest the presence of two contemporaneous species in the Abo Formation. Research since 2009 has revealed *Dimetrodon* to be a more common, though not the dominant predator, on the Abo floodplains of Permian New Mexico. Much more research is needed to fully understand *Dimetrodon* from the Lower Permian of New Mexico.

Keywords:

Dimetrodon, Lower Permian Abo Formation

URANIUM RESOURCES IN NEW MEXICO IN 2017

Virginia T. McLemore

New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801,
virginia.mclemore@nmt.edu

During a period of nearly three decades (1951–1980), the Grants uranium district in northwestern New Mexico yielded more uranium than any other district in the United States, thereby making New Mexico a major producer of uranium. Today, uranium is used primarily in nuclear reactors to produce electricity via nuclear fission. Although no producing operations exist in New Mexico today, numerous companies have acquired uranium properties within the Grants, Hook Ranch-Riley, and Red Basin-Pietown districts and plan to explore and develop deposits in the future. The Grants district is a large area in the San Juan Basin, extending from east of Laguna to west of Gallup, and includes eight subdistricts. The Grants district is probably 7th in total world uranium production behind East Germany, Athabasca Basin in Canada, Australia, South Africa, Russia, and Kazakhstan. Other areas in New Mexico have potential for uranium. The most important deposits in the state are within the sandstones of the Jurassic Morrison Formation in the Grants district. More than 340 million pounds of U_3O_8 have been produced from Morrison Formation deposits from 1948–2002, accounting for 97% of the total production in New Mexico and more than 30% of the total production in the U.S. An estimated additional 406 million pounds of U_3O_8 remain in historic reserves in unmined deposits. Three types of uranium deposits are in the Westwater Canyon Member of the Morrison Formation: (1) primary, tabular (trend or blanket), (2) redistributed (roll-type or stack), and (3) remnant-primary sandstone. A fourth type, tabular sandstone uranium-vanadium deposits, is found in the Salt Wash and Recapture Members of the Morrison Formation in the western San Juan Basin. Other types of uranium deposits are found in New Mexico, but have not been major producers. Several companies are planning to mine these deposits by in situ recovery or conventional mining and milling methods. Other areas outside of the Grants district in New Mexico have been examined for uranium potential and some of these areas yielded minor production and have future potential. Exploration has occurred during the last decade in the Hook Ranch-Riley and Red Basin-Pietown districts, and at least one deposit has reported potential resources. Other basins in New Mexico, such as the Las Vegas, Sabinoso, Nacimiento, Chama, and Hagan-La Bajada basins and at Mesa Portales should be evaluated for sandstone uranium deposits. Although worldwide, other types of uranium deposits are higher in grade and larger in tonnage, the Grants district has been a significant source of uranium and has the potential to become an important future source, as low-cost technologies, such as in situ recovery techniques improve, and as demand for uranium increases, thereby increasing the price of uranium. Molybdenum, selenium, and vanadium were produced as by-products at the mill and could be recovered by conventional milling in the future.

Keywords:

uranium, Grants district, molybdenum, in situ recovery

URANIUM RESOURCE POTENTIAL IN NEW MEXICO

Virginia T. McLemore[1] and John Asafo-Akowuah[2]

[1]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801, virginia.mclemore@nmt.edu
[2]Mineral Engineering Department, New Mexico Tech, Socorro, NM, 87801

Mineral resources are the naturally occurring concentrations of materials (solids, gas, or liquid) in or on the earth's crust that can be extracted economically under current or future economic conditions. The *mineral-resource potential* of an area is the probability or likelihood that a mineral will occur in sufficient quantities so that it can be extracted economically under current or future conditions, including the occurrence of undiscovered concentrations of metals, nonmetals, industrial materials, and energy resources. The mineral-resource potential is not a measure of the quantities of the mineral resources, but is a measure of the *potential* of occurrence. Factors that could preclude development of the resource, such as the feasibility of extraction, land ownership, accessibility of the minerals, or the cost of exploration, development, production, processing, or marketing, are not considered in assessing the mineral-resource potential. Mineral-resource potential is a qualitative judgement of the probability of the existence of a commodity and is classified as very high, high, moderate, low, or no potential according to the availability of geologic data and relative probability of occurrence. Although no producing operations exist in New Mexico today, numerous companies have acquired uranium properties within the Grants, Hook Ranch-Riley, and Red Basin-Pietown districts and plan to explore and develop deposits in the future. The mineral-resource potential for uranium is very high (VH) with a high level of certainty (D) in portions of the Morrison and Dakota Formations in the Grants uranium district and high (H) with a high level of certainty (D) in portions of the Morrison Formation elsewhere in the San Juan Basin and in the Todilto Formation in the Grants district. The mineral-resource potential for uranium is moderate (M) with a moderate level of certainty (C) in the Morrison Formation elsewhere in the San Juan Basin and in 19 districts in New Mexico and moderate (M) with a moderate to low level of certainty (B-C) in the Ogallala Formation in southeastern New Mexico. The mineral-resource potential for uranium is low (L) with a low level of certainty (B) in 20 districts throughout New Mexico and in the Morrison Formation in northeastern New Mexico. Exploration has occurred during the last decade in the Hook Ranch-Riley and Red Basin-Pietown districts, and at least one deposit has reported potential resources. Other basins in New Mexico, such as the Las Vegas, Sabinoso, Nacimiento, Chama, and Hagan-La Bajada basins and at Mesa Portales should be evaluated for sandstone uranium deposits. Although worldwide, other types of uranium deposits are higher in grade and larger in tonnage, the Grants district has been a significant source of uranium and has the potential to become an important future source, as low-cost technologies, such as in situ recovery techniques improve, and as demand for uranium increases, thereby increasing the price of uranium.

Keywords:

mineral-resource potential, uranium, Grants district, molybdenum, selenium, vanadium

A HYDROGEOCHEMICAL ANALYSIS AND RECHARGE EVALUATION OF CIENEGA SPRING LOCATED IN THE SANDIA MOUNTAINS, NEW MEXICO

Alexandra J. Minitrez[1], Laura J. Crossey[1] and Christopher McGibbon[1]

[1]University of New Mexico, Albuquerque, NM, 87131, alexmini@unm.edu

In the southwestern United States, water resources are increasingly depleted due to multiple demands including anthropogenic use and climate change. Springs are particularly sensitive to change, and also serve as an important habitat. In an effort to assist water managers, we report on the status of springs in the Sandia Mountains, New Mexico. We focus on Cienega Spring, located in the East Mountain area, as it serves as a water source to over 50 surrounding homes. The spring is tapped by pipes using gravity, and overflow supplies a stream and wetlands. Total discharge rates are unknown, as is any seasonal change in discharge. In order to examine potential hydrologic flowpaths, we perform a hydrogeochemical analysis on the spring and compare with regional groundwater. We have also installed continuous sensors to examine seasonal fluctuations in recharge and use. Performing a hydrogeochemical analysis and recharge evaluation will allow for a conclusion regarding Cienega Spring and provide further insight on spring flow sustainability.

Keywords:

Sandia, Springs, Hydrogeochemical, Flow Sustainability

Sequential Chemical Extraction as a Method to Determine Uranium Mineral Leachability and Speciation

Alexandra Rose Pearce[1], Ingar F. Walder[1], Bonnie Frey[2] and Virgil W. Lueth[2]

[1]New Mexico Institute of Mining and Technology, EES Department, 801 Leroy Place, Socorro, NM, 87801, alexandra.pearce@student.nmt.edu
[2]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801

Improved exploitation of the remaining uranium in the Grants Mineral District, New Mexico, hinges on the development of a mineral-element speciation determination method. Understanding the mobility and leachability of uranium in mine wastes and ores has importance in both industrial and environmental applications. To this end, we are evaluating the applicability of a previously established sequential chemical extraction method (where a sample is exposed to a series of increasingly aggressive reagents) for copper mine waste on three uranium minerals common to New Mexico: the primary ore mineral uraninite (uranium oxide) and the secondary ore minerals meta-autunite (hydrated calcium uranyl phosphate) and meta-tyuyamunite (calcium uranyl vanadate). We evaluated changes to mineral structure and composition via X-ray powder diffractometry and analysis of the leachate via ICP-MS. Sequential exposures to deionized water, 1 M NH_4-acetate, 0.2 M NH_4-oxalate, heated 0.2 M NH_4-oxalate, and 35% H_2O_2 resulted in appreciable changes to mineral composition and abundance and yielded detectable amounts of uranium, molybdenum, vanadium, selenium, and calcium in the leachate as a result of mineral dissolution and/or desorption. With further refinement (i.e., testing on ore samples of mixed mineralogical composition), this method may be of use in evaluating the leachability and mineralogical makeup of uraniferous material (e.g., ore, waste rocks, tailings).

The Raton-Clayton Volcanic Field: Evaluating Open-System Processes in Magmas Derived Beneath the Great Plains

Sid Pinkerton[1], Frank C. Ramos[1] and Matthew Zimmerer[2]

[1]New Mexico State University, 1780 E University Ave, Las Cruces, NM, 88003, sidpinkerton@yahoo.com
[2]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801

The Raton-Clayton Volcanic Field (RCVF) is located along the western edge of the Great Plains province in northeastern New Mexico at the eastern tip of the Jemez Lineament. The Jemez Lineament is a zone of structural weakness formed by accretion of Precambrian Yavapaii and Mazatzal island arc terrains. Raton-Clayton volcanism is the eastern-most extent of Cenozoic volcanism until the Mid-Atlantic Ridge. The RCVF offers an opportunity to understand how open-system processes have affected basalts that ascended through the crust of the Great Plains and to evaluate un-modified melts that are generated from mantle underlying this region of the western United States. The youngest phase of volcanism in the RCVF is the Capulin-phase which ranges from ~1.5 Ma to 0.03 Ma. The youngest (~50 ka - ~30 ka) Capulin-phase basalts were analyzed for this study. Whole-rock and olivine-hosted melt inclusion major element, trace element, and isotope data are used to evaluate the effects of open-system processes in Capulin-phase basalts. Variations in $^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$, $^{208}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{206}Pb/^{204}Pb$ indicate that fractionation alone cannot explain the evolution of Capulin-phase basalts. Trace element, $^{87}Sr/^{86}Sr$, $^{208}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{206}Pb/^{204}Pb$ trends are consistent with open-system processes having contributed to the petrogenesis of Capulin-phase basalts.

LATE TRIASSIC METOPOSAURID AMPHIBIAN SKULL ALLOMETRY: COMPARISON OF THE LAMY, NEW MEXICO, POPULATION TO FOUR OTHER POPULATIONS

Larry F. Rinehart[1] and Spencer G. Lucas[1]

[1]New Mexico Museum of Natural History and Science, 1801 Mountain Rd NW, Albuquerque, NM, 87104,
larry.rinehart@earthlink.net

Metoposaurs (Temnospondyli: Metoposauridae) were large, ubiquitous amphibians of the Late Triassic. They were important members of the Upper Triassic Chinle Group fauna of New Mexico and are found in these strata across the state. One of the most important metoposaur bonebeds in the world occurs in the Adamanian (upper Carnian) Garita Creek Formation near Lamy, NM, where the fossils of hundreds of individuals were hydraulically concentrated on a Late Triassic floodplain. In nearly all metoposaur populations, worldwide, many skull features show shape change throughout ontogenetic growth (allometry). Some workers have believed these allometric growth trajectories to be of taxonomic value. Here, using the largest populations available (for maximum statistical sample size), we investigate the taxonomic utility of these shape changes. Skull allometry in three populations of the metoposaur *Koskinonodon perfectum* (Lamy, NM; Rotten Hill, TX; Popo Agie Formation of WY) was compared to establish intra-specific variation. Then, three populations representing different genera (*Dutuitosaurus ouazzoui* from northern Africa; *Koskinonodon perfectum* from western North America; *Metoposaurus diagnosticus* from eastern Europe) were compared to show variation at the generic level. Anteroposterior movement of the orbits and relative skull width at three positions (snout tip at the anterior nares, basal snout at the anterior orbits, greatest width across the quadratojugals) with respect to midline length throughout ontogeny were determined. Relative orbit position moved anteriorly in *D. ouazzoui* and *K. perfectum* (Rotten Hill), posteriorly in *K. perfectum* (Lamy) and *K. perfectum* (WY), and remained approximately fixed in *M. diagnosticus*. Skull width allometries were of mixed values, but with rare exceptions, the snout grew wider with respect to length throughout ontogeny, whereas the posterior skull became relatively narrower. Thus, the skulls of juveniles were somewhat triangular, and they grew to be more parallel-sided with a wider, blunter snout in adults. Comparison of the calculated allometric constants from the various populations yielded a surprising result: intra-specific variation in growth patterns was as great as or greater than inter-generic variation. The three *K. perfectum* populations, including the Lamy metoposaurs, were not significantly more similar to each other than they were to different genera. The salient point of this preliminary work is that allometric skull growth trajectories in metoposaurs probably have little or no taxonomic value, and metoposaur taxa should probably not be erected based solely on variations in growth patterns.

Keywords:

Lamy metoposaur, Koskinonodon skull, allometry

LEGACY MOLYBDENUM MINE TAILINGS IN THE CONTEXT OF THE QUESTA CALDERA: CHALLENGES IN DISTINGUISHING ANTHROPOGENIC FROM BACKGROUND WATER TYPES

Kylian Nathiel Robinson

New Mexico Tech, 1704 SE Columbia, Albuquerque, NM, 87196, Kylian.Robinson@student.nmt.edu

Questa, New Mexico is located near the confluence of the Rio Grande and Red River in north central New Mexico. Domestic supply wells in the area access waters collected and transmitted by the watershed in the adjoining Questa caldera, which also hosts an inactive molybdenum mine. Most wells are located in an overlying alluvial basin fill aquifer, while a considerable subset monitors groundwater around a mine tailings facility. Other wells access the volcanic aquifer. Constituents of concern at the Questa mine tailings facility superfund site include molybdenum, uranium, and sulfate. Although the mine is inactive and the facility no longer receives tailings, it continues to receive water from mine dewatering. Significant volumes of water infiltrate into the aquifer system beneath the mine tailings surface pond (NMED, Arcadis). We have evaluated three sets of data: (1) from NMBGMR sampling during 2015 in which $p > n$ (or the number of parameters sampled exceeded the number of sample sites), (2) current tailings facility monitoring from the New Mexico Environment Department (NMED), and (3) 2005 USGS mountain block aquifer sample data. With regard to water chemistry, across the region, sulfate is highly correlated with TDS. Wells completed in the mountain block have mineralized weathering products with elevated concentrations of various trace metals. Wells completed in the alluvial aquifer up gradient of the tailings facility generally have low TDS, but may have elevated levels of some metals including uranium, complicating separation and mixing analysis in relation to contaminant loading. We hypothesize that there is preferential flow through highly heterogeneous rift- fill alluvial deposits that are well connected with mountain block aquifer fluxes. Data analysis is challenging because of sample size decay at each grouping hypothesis (not enough sample sites within the remaining group) and parameters chosen for testing. Traditional water source evaluation methods in conjunction with grouped regression led to identification of important chemical tracers for local hydrogeological processes. A map based on End Member Mixing Analysis (EMMA) retains significant uncertainties. Incorporating stable isotopes and additional dissolved constituents uniformly at all sample sites would be helpful to increase the number of covariance groups available for analysis.

^{40}Ar/^{39}Ar Geochronology of Magmatism and Alteration in the Gallinas Mountains With Implications for Rare Earth Mineralization

Alanna Robison[1], William McIntosh[2] and Virgil W. Lueth[2]

[1]Dept. of Earth and Environmental Sciences, New Mexico Tech, Socorro, NM, 87801, alanna.robison@student.nmt.edu
[2]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801

The five alkaline laccolithic intrusions of Gallinas Mountains, along the border of Lincoln and Torrance Counties, New Mexico, have only one age date that was established using the K-Ar dating method (29.9 Ma). This single age is not sufficient to establish the relative timing of all magmatic and the associated alteration events. The geologic contacts between intrusive units are indefinite and few cross-cutting relationships were noted by previous mappers. This project dated four the of five intrusions and associated alteration events using the ^{40}Ar/^{39}Ar dating method. These age determinations are used to relate the age of magmatism to rare earth mineralization that occurs in the area. The oldest and smallest intrusion is porphyritic andesite, which has an age of 38.74 ± 0.058 Ma. It is more similar in age and appearance to the Chupadera dikes to the west. The porphyritic latite of Cougar Mountain has an age of 28.178 ± 0.040 Ma. A porphyritic trachyte, which produced an age range from 27.66 ± 0.18 to 29.232 ± 0.097 Ma, is the largest intrusion and hosts some of the rare earth element (REE) mineralization. An equigranular syenite phase is found as dispersed lenses within the trachyte and produced the range of ages from 26.51 ± 0.15 to 29.77 ± 0.16 Ma. It is mineralogically similar but texturally different than the more abundant porphyritic trachyte. The porphyritic rhyolite that comprises Gallina Peak has no apparent cross-cutting relationship with the other intrusions. It contains fluorite porphyroclasts, variable degrees of vesiculation from top to bottom, but could not be dated because of severe alteration. Based on mineralogy, geochemistry, and the ages of the other intrusions, the rhyolite body is speculated to be the youngest magmatic intrusion. The most intriguing feature of the Gallinas is the large-scale fenitization. This alteration is most abundant at the northern boundries of the trachyte. Dating three different fenite occurrences units has revealed that fenitization may span a period of time (~27 Ma to ~30 Ma). Stair-stepping spectra with integrated ages around 29 Ma suggest a period of hydrothermal alteration after emplacement and/or the potential for excess argon in the analysis. Adularia veins cross-cut the trachyte and the iron replacement skarnwhich was related to the onset of the trachyte magmatism by previous workers. The adularia has a stair-stepping spectra and age range similar to the fenites. REE-fluorite breccias cross-cut both the trachyte and Permian sedimentary host rocks. One breccia pipe contained clasts that resemble the iron skarn, suggesting that the skarn mineralization occurred prior to the REE breccias. The similarity of ages between the fenites, adularia veining, and trachyte alteration suggests that most of the alteration in the area probably occurred during or shortly after the emplacement of the trachyte. The undated fluorite-bearing rhyolite unit may have some genetic relationship to the breccia pipes.

LOWER CRETACEOUS (UPPER ALBIAN) NAUTILOIDS FROM CERRO DE CRISTO REY, DOÑA ANA COUNTY, NEW MEXICO

Paul L. Sealey[1], Spencer G. Lucas[1] and Kevin Durney[2]

[1]New Mexico Museum of Natural History, 1801 Mountain Road, NW, Albuquerque, NM, 87104, ammonoidea@comcast.net
[2] 3701 Trailhead Court, Cedar Park, TX, 78613

At Cerro de Cristo Rey in Doña Ana County, southern New Mexico, an ~ 350 m thick section of Cretaceous strata ranges in age from late Albian to middle Cenomanian. Nautiloids are rare in these strata and were collected from the upper Albian Smeltertown and Muleros formations. Five nautiloids, all assigned to *Cymatoceras* cf. *C. loeblichi*, are in the collections of the New Mexico Museum of Natural History (NMMNH). NMMNH P-50940 (179 mm in diameter), from the Smeltertown Formation, is a complete, somewhat dorso-ventrally crushed adult mold that has a large and broadly rounded conch with prominent ribs that are slightly sigmoidal on the flanks and that form fairly deep ventral sinuses, as in *Cymatoceras* (Miller and Harris, 1945, p. 3). The ribs bifurcate on the flanks and are low, flattened, closely-spaced and separated by narrow interspaces. The ventral sinus is almost V-shaped. The shell is wider than high and involute. The suture is simple and has a shallow lateral lobe. *Cymatoceras hilli* (Shattuck) and *Paracymatoceras texanum* (Shumard), both of which occur in association with *C. loeblichi*, have more strongly sinuous sutures and narrower conchs (Miller and Harris, 1945, p. 7). P-50973 (136 mm in diameter), from the Muleros Formation, is a mold of an uncrushed, adult phragmocone that has features similar to P-50940, but the conch is not as broad. P-50974, also from the Muleros Formation, encompasses three moderately-preserved specimens. The smallest (56 mm in diameter), which is an inner whorl, has the narrowest conch. The largest (119 mm in diameter), which is a laterally crushed whorl, exhibits some of the above features, including some preserved ribbing. The third specimen (79 mm in diameter), a juvenile whorl, has the broadest conch. The NMMNH specimens are tentatively assigned to *Cymatoceras loeblichi* on the basis of their relatively broad conchs and only slightly sinuous sutures. Miller and Harris (1945, p. 6) state that the ornamentation on the type specimens is not too well preserved, "but the sinuous transverse ribs do not seem to be increased in number by bifurcation or implantation." However, they further mention that *C. loeblichi* rather closely resembles *C. neohispanicum* (Burckhardt), from the middle Aptian of Mexico and lower Albian of New Mexico, in size, shape and ornamentation of conch (Miller and Harris, 1945, p. 7). *C. neohispanicum* and two of the Cristo Rey specimens of *C.* cf. *C. loeblichi* that preserve sufficient ribbing, demonstrate bifurcating ribs. The nautiloid from the Smeltertown is in the *Mortoniceras equidistans* Zone and the nautiloids from the Muleros are in the *Drakeoceras lasswitzi* Zone. Both zones are late Albian in age. The type specimens of *Cymatoceras loeblichi* came from the Albian-Cenomanian Washita Group of north-central Texas. This is the first report of the rare nautiloid *C. loeblichi* from New Mexico.

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PRESCRIBED BURN IMPACTS ON SURFACE WATER QUALITY AND QUANTITY IN THE UPPER SANTA FE MUNICIPAL WATERSHED: BASELINE DATA AHEAD OF BURNS

Zach Shephard[1] and Dan Cadol[1]

[1]New Mexico Tech, Earth and Environment Sciences Department (Hydrology), Soccoro, NM, 87801, zach.shephard@student.nmt.edu

A planned project by the City of Santa Fe and the United States Forest Service to thin a portion of the Pecos Wilderness Area in the upper Santa Fe municipal watershed involves prescribed fire by aerial ignition in the absence of mechanical treatments. These burn treatments are an attempt to decrease fuel loads that could lead to dangerous wildfires and also to increase soil water availability per tree. Careful study and monitoring of the impacts of the prescribed burns on water quality and quantity are planned during the course of the treatments. Watershed-scale response to these relatively new treatment methods are currently understudied. Pyrogenic carbon (PyC), a form of black carbon, is a byproduct of forest fires formed from the incomplete combustion of organic matter. It encompasses the carbonaceous component of fire-derived materials such as char, soot, and ash. PyC is studied due to its effect on contaminant transport, water quality, and the global carbon cycle. PyC has the ability to adsorb heavy metal contaminants, and can alter the transport and sequestration of these contaminants in post fire storms. Fires can also reduce understory vegetation and surface roughness, and may enhance hydrophobicity in burned soils. These short-term effects have the potential to increase water yields and change storm water runoff timing. We are monitoring dissolved and suspended total and organic carbon throughout the project, along with dissolved trace metals in the surface water of the Santa Fe River before, after, and during the upstream burn treatments. Also, we are analyzing the impacts of the treatments on water yield using stream flow gauge records. Current results are an analysis of the first year of baseline data ahead of the prescribed burn. All dissolved analytes were found in low or trace amounts or were not detected. Dissolved elements reflect the basin lithology mineral constituents, and decline in concentration during spring runoff. Dissolved carbon increased during the rising limb of snowmelt as it was first flushed through the system, but then declines through the spring and summer.

GEOCHRONOLOGY AND GEOCHEMISTRY OF THE METASOMATIC PROCESSES RELATED TO EPISYENITES IN CENTRAL NEW MEXICO AND COLORADO

Adam E. Smith[1], Matthew T. Heizler[2], Virginia T. McLemore[2], Kierran C. Maher[1] and Frank C. Ramos[3]

[1]New Mexico Institute of Mining and Technology, Socorro, NM, 87801, adam.smith@student.nmt.edu
[2]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801
[3]New Mexico State University, 1780 E University Ave, Lac Cruces, NM, 88003

Episyenite bodies produced by metasomatism of Precambrian basement rocks occur in the Caballo Mountains and Lobo Hill, NM and at the Amethyst prospect in Fremont County, CO. Many of these episyenites are REE-enriched and are being explored for their economic potential. Previous studies have shown similarities to metasomatism via alkaline intrusive complex derived fluids (fenitization). This hypothesis is reasonable in NM as the late Cambrian-early Ordovician Bliss Formation unconformably overlies these rocks and in CO due to their spatial relationship to known Cambrian magmatism. However, previous $^{40}Ar/^{39}Ar$ geochronology yielded variable age results; perhaps due to post-formation thermal episodes or fluid alteration. The main goal of this study is to determine the timing of alteration that produced these episyenites. Primary and secondary feldspars were characterized using BSE analysis and these individual crystal fragments were analyzed for Ar/Ar geochronology. Rb and Sr isotope analysis and whole rock geochemistry is used to help determine the origin and chemistry of the altering fluids. Secondary feldspar is comprised of fine-grained aggregates of anhedral and unexsolved feldspar that are near Or_{100}, while primary K-feldspar has exsolution textures typical of basement K-feldspar. Secondary K-feldspars from the episyenites yield relatively flat age spectra with integrated ages from 338±3 to 429±10 Ma, and plateau ages from 316-418Ma, with younger ages that coincide with Ancestral Rocky Mountain uplift. Age spectra from episyenites in the Amethyst prospect are also nearly flat with integrated ages from 392 to 416 Ma to gently rising with ages ~450-500 Ma in higher temperature steps. Primary K-feldspar age spectra from both CO and NM have gradients from ~560 to1090 Ma and indicate cooling below ~150°C by late Precambrian. Thus, the young ages for secondary K-feldspar are not consistent with late Cambrian plutonic emplacement followed by cooling through argon closure near 400 Ma. That is, the young secondary K-feldspars ages are not the result of elevated post-Cambrian regional temperatures. It is interesting that these young ages are recorded in both NM and CO episyenites, and that the episyenite ages in the Caballo Mountains coincide with Ancestral Rocky Mountain activity. Whole rock geochemistry from the Caballo Mountains shows an increase in K_2O as well as Fe_2O_{3t} and MgO, and losses of SiO_2 and Na_2O. Most of the trace elements are enriched in episyenites relative to background rocks. Pb, Th, and U show the most enrichment, but increases in Y, Zr, and F are notable. REE also increase with the degree of alteration, with HREE increasing more readily than LREE. These elements can be mobile in peralkaline settings, but lack of strong enrichment for Ba, V, Sc and Sr do not support this idea. The data collected so far suggests that if alteration due to Cambrian alkaline magmatism formed the episyenites, later fluid processes are required to explain younger ages and inconsistencies in trace elements. Overall young ages suggest post-Cambrian low temperature fluid alteration of the episyenites, but it remains puzzling that this additional alteration event did not significantly affect basement Precambrian K-feldspar or overlying sedimentary rocks.

Keywords:

Caballo Mountains, Wet Mountains, episyenite, alkaline rocks, metasomatism

METAL LEACHING FROM THE VHMS SULITJELMA MINING DISTRICT, NORWAY

Franciszka Kay Stopa[1] and Ingar Walder[1]

[1]New Mexico Institute of Mining and Technology, Socorro, NM, 87801, franciszka.stopa@student.nmt.edu

The Sulitjelma mining district, located in Northern Norway, consists of more than twenty deposits that were mined from 1860 to 1991 and produced some 26 million tons of ore. The mining district was closed and partly mitigated in the mid 1990's, based on very little characterization data, by leading adit water into the larger underground mine areas and plugging lower portals. A thin layer of soil was also applied to one of the larger exposed tailings piles. This closure has failed in its intent to reducing the concentration of copper to less than 10 µg/L in the receiving environment. The ore deposits within the district are classified as volcanogenic massive sulfide (VMS) hosted in an ophiolite complex. The long Lake Langvatn divides the district in a north and south section. The sulfide deposits were predominantly mined for sulfur, copper, and zinc. Ore processing and exposed waste rock dumps scattered around the district has resulted in A/NRD and soil contamination. As a consequence of A/NRD, there is heavy metal leaching from waste rock into surrounding streams leading into the Lake. In addition to waste rock contamination contribution, there is discharge from several of the mine adits. Thus, determining the sources of the contamination load on the receiving lake is more complicated than siting a single source. Implications of waste rock weathering and the impact on the surrounding water sources is being examined. Most waste dumps were sampled (solids and seep water when available), while four major mine areas were sampled more extensively during the summer 2016. The focus of this research is on the south side of the Langvatn, but the study also includes one waste dump on the North side. Waste rock and water samples were taken from each site and analyzed. The majority of sites yielded a low soil pH, and high total dissolved solids. Water samples from numerous creeks and drainages were sampled and tested for copper, zinc, iron, and sulfate. The data shows a wide spread of values, with highest copper concentrations (35 mg/L) near a small open pit mine, Furuhagen (the westernmost sampling point). When evaluating overall copper loading on the Lake, an adit on the North side is found to contribute 2.09 mg/L at a rate of 1033 L/sec. Ten waste rock samples selected from the four zones will be used in kinetic column tests to determine mineral reactions and further leaching potential together with mineralogy, acid base accounting, and sequential chemical extraction. This information will be combined with streamflow data to estimate contaminant load to the Langvatn. The Norwegian government has a regulation that the acceptable copper levels leaving Lake Langvatn have to be under 10 µg/L Cu. Upon measuring water at the end of the Lake, the copper level was ten times this, at 112 µg/L Cu. Without this more extensive mineralogical and geochemical characterization of the district any remediation/mitigation of such a large variable mining area is likely to fail.

The project is funded by Kjeøy Research & Education Center and Norwegian science foundation

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The Onset of Rhyolite Volcanism and Subsequent Collapse in the Schoolhouse Mountain Caldera, Mogollon-Datil Volcanic Field, Southwest New Mexico

Vanessa M. Swenton[1], Jeffrey M. Amato[1], Tara Jonell[2], and William C. McIntosh[3]

[1]New Mexico State University, Las Cruces, NM, 88003, vswenton@nmsu.edu
[2]Louisiana State University, Baton Rouge, LA, 70803
[3]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801

Megabreccia deposits in calderas are diagnostic of a collapse event where hot ash and gasses interact with pre-caldera rocks and basement rocks. The late-Eocene Schoolhouse Mountain caldera (SMC) in the Mogollon-Datil volcanic field (MDVF) of southwest New Mexico is a relatively unstudied caldera, where little is known regarding the caldera stratigraphy and the timespan of magmatism. We undertook field mapping, petrology, and $^{40}Ar/^{39}Ar$ geochronology to develop a model for the evolution of the caldera and its relationship to MDVF volcanism. Volcanism began with the pre-collapse dacite lava flows and dikes of the Saddlerock Canyon sequence, dated at 35.2 ± 0.2 Ma (U-Pb zircon). The top of this lowermost sequence has interlayered dacite flows and rhyolite tuffs overlain by lithic-rich rhyolite tuffs, flows, and breccias at the base of the overlying Kerr Canyon sequence. Tuffs are separated by volcaniclastic sandstone or flow-banded rhyolite. Clasts within breccia include rhyolite with abundant phenocrysts and pumice, Cretaceous sandstone, and sparse Proterozoic granite. Clasts range from up to 15 cm in the lithic breccia, and up to 4 m in the megabreccia. Total thickness of the Kerr Canyon sequence is ~800–2000 m but may be thicker in the central area and tapering to the edges, suggesting infilling of a topographic low. Several clasts in the breccia have apparent injection of rhyolite into the clasts in a wispy, flame-like structure, discolored thermally altered rinds, and vesiculation of the rhyolite near the clasts from degassing. Thus, we suggest this is a collapse breccia associated with an eruption, rather than a lahar deposit consisting of cold, reworked volcanic material. Sanidine crystals from two boulder clasts and the rhyolite matrix were dated using $^{40}Ar/^{39}Ar$ single-crystal laser fusion. The clasts yielded identical ages of 35.34±0.03 Ma and the matrix had ages of 35.17±0.11 Ma and 35.35±0.05 Ma. Some clasts have abundant quartz and sanidine phenocrysts similar to the Kneeling Nun tuff, which is similar in age (McIntosh et al., 1992), raising the possibility that these were derived from this unit. Two tuffs at similar stratigraphic levels in this sequence had $^{40}Ar/^{39}Ar$ biotite dates of 34.71±0.14 Ma and 34.33±0.08 Ma. This may indicate that the Kerr Canyon sequence was erupting at 34.7–34.3 Ma and that the breccia contains clasts with "inherited" sanidine that were not reset during emplacement. The higher units in this system have an uncertain relationship with respect to the history of the SMC. The next highest unit, Mangas Creek, consists of quartz-latitic tuffs and andesite lava flows, volcaniclastic sandstones, and volcanic breccias up to ~2000 m. Overlying this is the McCauley Ranch tuff, with a sanidine $^{40}Ar/^{39}Ar$ date of 33.99±0.04 Ma, and the Cherokee Canyon tuff (600 m), which has a sanidine $^{40}Ar/^{39}Ar$ date of 33.84±0.02 Ma. Thus, the eruptive history of this caldera ranges from at least as old as 34.71 Ma to 33.84 Ma, or approximately 1.1 m.y.

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An Abandoned Uranium Mine Survey of Mine Sites in New Mexico

Annelia Tinklenberg[1] and Robert Sengebush[1]

[1]INTERA, Inc, 6000 Uptown Blvd NE, Suite 220, Albuquerque, NM, 87110, United States, atinklenberg@intera.com

In 2006, the Mining and Minerals Division (MMD) of Energy, Minerals and Natural Resources Department (EMNRD) began developing a uranium mine inventory to detail all past uranium mining sites in New Mexico, including reclamation efforts at these sites. This uranium mine inventory compiled information from multiple sources including a database developed at the New Mexico Bureau of Geology and Mineral Resources, MMD records, and records from other state, federal and tribal agencies. From these sources, MMD developed a list of 260 mine locations that reported production of uranium to state and federal agencies. Of these 260 uranium-producing mine locations, MMD found that 137 mine locations had no record of reclamation overseen by an agency. These 137 mining locations with no record of reclamation became priority locations for a systematic abandoned uranium mine survey of the potential or existing environmental condition at each site. After contacting landowners for access and developing field data packages, INTERA used a GeoXM GPS and Ludlum scintillometer to conduct the abandoned uranium mine survey for 55 of the abandoned uranium mine sites. The greatest obstacle for conducting the abandoned uranium mine surveys was gaining site access permission. Records from the counties and the State Land Office were utilized to determine land owners and find contact information prior to the field visit. Fourteen (14) sites were not surveyed due to landowners denying access or the land ownership status could not be resolved. Each abandoned uranium mine survey consisted of site mapping and description of existing features, identification of current human activity and land use, a radiological survey, description of vegetation and wildlife, identification of the soils, a summary of hydrogeology, and photo documentation. A site assessment report, including maps, and a geodatabase were developed for each abandoned uranium mine surveyed. Completing the abandoned uranium mine surveys provided MMD with the information necessary to prioritize legacy sites for reclamation.

NICKEL LEACHING FROM DUNITIC MINE WASTE

Margaret Tinsley[1], Ingar F. Walder[1], Franciszka Stopa[1], Jenna Donatelli, and Rodrigo Embile[1]

[1]New Mexico Institute of Mining and Technology, 1221 El Camino Real St, Socorro, NM, 87801, margaret.tinsley@student.nmt.edu

The Bruvann nickel-olivine deposit was mined from 1989 to 2002, but now lies abandoned, with large heaps of waste rock that contain both acid producing minerals and silicate minerals that neutralize some of that acid. The resulting pH of water draining from the site is near neutral, so it is not remediated, despite considerable amounts of mobilized metals, especially nickel. This project examines both the natural leaching of nickel rich olivine by water and alternative methods to increase the rate of nickel leaching, making the waste rocks a resource. In July, fieldwork was conducted at the Bruvann deposit in Ballangen, Norway. A stream emerging from a mine adit was traced until it left the area, and sampled wherever additional water entered. Samples were analyzed for pH, conductivity, and metals content. Twenty samples were taken from the waste rock heaps surrounding the mine, and paste pH tests were used to rank their potential for leaching. Ten samples were selected to represent the breadth of leaching potentials and shipped to New Mexico Tech for further testing and analysis. An additional four are undergoing leaching in Norway. Splits of each waste rock sample are undergoing mineralogical analysis. Minerals of interest, such as pentlandite and nickel sulfides, will be separated from the bulk rock and used for thin and polished sections to study the mineralogy. This will require a magnetic separation, as the silicate minerals are too dense to be separated from the other important minerals using common heavy liquids. Small portions of the waste rock will also be used for short-term analyses. Sulfur species tests will determine how much reactive sulfur is in the various samples, as well as how much of that sulfur is stored as sulfides, which are known to be excellent acid producers. Acid generation, neutralization potential, and net acid generation tests will add more information about what pH may be expected, as well as how much neutralization capacity is contributed by the olivine. A test involving the slow addition of acid to the samples will yield similar information which may be compared to the other acid-base accounting tests to confirm the validity of each method. This data will be used to inform new methods to increase the rate of nickel leaching. Kinetic columns have recently been established at New Mexico Tech, with the first rinse on March 16. Each week, 1 L of deionized water will be sprinkled over each column, and the resulting leachate is collected and analyzed. This demonstrates the effects of natural weathering at a laboratory size scale and faster rate. While the columns are not a perfect representation of natural processes, observing them provides more insight into what happens over time than shorter tests. Results will be compared to field water data to see how representative the columns are. Later, columns may be treated with sulfuric acid, nitric acid, or other substances in an attempt to leach more nickel from the waste rock, with initial testing on small batches of waste rock.

Keywords:

nickel, mine waste, leaching

A MODEL FOR SOCORRO MAGMA BODY EMPLACEMENT

Jolante van Wijk[1], Shuoyu Yao[1], and Gary Axen[1]

[1]New Mexico Tech, 801 Leroy Place, Socorro, NM, 87801, jolante.vanwijk@nmt.edu

We propose a new model for emplacement of the Socorro Magma Body (SMB) that is based on numerical models of crustal deformation as a result of sill emplacement, and supported by (geophysical) data. In this model, the SMB was emplaced in the last few hundred years at the brittle-ductile transition, and has been injected with magma in recent decades. The sill is imaged as a liquid body with seismic data, and in order for it to be detectable as liquid, our models predict that it needs to be younger than ~500 years. Thermal expansion as a result of sill emplacement results in a surface uplift pattern that is not compatible with observations; surface uplift is in agreement with inflation as a result of recent magma injection pulses. Sill inflation results in tensional crustal stresses above ~13 km depth that are large enough to cause tectonic earthquakes, in agreement with seismic data. This results in an *apparent* brittle-ductile transition at depths shallower than the sill.

The Late Miocene- Early Pliocene Unconformity in the Rio Grande Rift

Jolante van Wijk[1], Gary Axen[1], Dan Koning[2], and David Coblentz[3]

[1]New Mexico Tech, 801 Leroy Place, Socorro, NM, 87801, jolante.vanwijk@nmt.edu
[2]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801
[3]Los Alamos National Laboratory, Los Alamos, NM, 87544

A late Miocene- early Pliocene unconformity has been found along almost the entire length of the Rio Grande rift, from the San Luis Basin in Colorado to the Mesilla Basin in southern New Mexico. The unconformity generally spans from about 8-5 Ma, and has often been described as an angular unconformity. It is most pronounced on the hanging wall sides of the asymmetric grabens. The unconformity was preceded by rapid basin subsidence and sediment infill, and is followed by continued basin subsidence. It is broadly synchronous with uplift of the Ogallala Formation on the western Great Plains. What may have caused this almost rift-wide unconformity? We have calculated geoid-to-elevation ratios that give information on the mechanism of topographic compensation. North of 35°N, these ratios suggest that mantle-driven dynamic uplift has occurred during the late rifting phase. Such dynamic uplift has also been predicted by geodynamic modeling studies (Moucha et al. 2008). We propose therefore that dynamic uplift, focused in the northern rift-region, promoted wide development of the unconformity in the Rio Grande rift, promoting erosion along basin margins and restricting aggradation to basin depocenters. Such dynamic uplift could also explain tilting of the Ogallala formation.

USING A NEW TEMPORARY SEISMIC NETWORK TO DETECT EARTHQUAKES IN THE SOCORRO MAGMA BODY REGION

Rhiannon E. Vieceli[1], Susan L. Bilek[1], Richard C. Aster[2], Lindsay Lowe-Worthington[3], and Brandon Schmandt[3]

[1]New Mexico Institute of Mining and Technology, Socorro, NM, 87801, rhiannon.vieceli@student.nmt.edu
[2]Colorado State University, CO
[3]University of New Mexico, Albuquerque, NM, 87131

The Socorro Magma Body (SMB), a thin tabular shaped body of magma located at a depth of 19 km within the Rio Grande Rift in central New Mexico, is the second largest continental mid-crustal magma body in the world. This feature leads to slow regional uplift on the order of a few mm/yr and has been linked to concentrated seismicity at shallower depth. These small earthquakes have been monitored with a variety of long- and short-term local seismic networks over the past several decades, although with large station spacing, limiting resolution. For two weeks during February 2015, seven broadband and 804 vertical component short period node seismographs were deployed with a station spacing of approximately 300 m in the northern region of the SMB, where uplift is maximum. This temporary installation of instruments has been the largest of its kind in the region. Initial, visual review of the broadband data produced a catalog of 33 small magnitude earthquakes located within the region. Additional events may be recorded in the collected seismic data, but evade visual identification due to lower signal-to-noise ratios (SNRs). Implementing cross-correlation techniques has proven useful in identifying signals even when the SNR is relatively low. Cross correlation is a measure of similarity between two waveforms as a function of a time lag applied to either of the waveforms. Identification of events using cross correlation starts with a high-quality recording of an earthquake signal of interest, known as a template. The template signal is then correlated with the continuous seismic data stream over a time range of interest to detect signals with a similar shape. Here we use the initial earthquake catalog as templates in a cross-correlation scanner to detect additional events recorded on both the broadband and more numerous node seismographs. We also will compare the newly detected events with detections produced by a back-projection technique using the node data. Our newly detected events will be located using a regionally appropriate velocity model for comparison to longer term earthquake catalogs and regional structure of the SMB.

X-RAY AND NEUTRON COMPUTED TOMOGRAPHY OF VERTEBRATE FOSSILS AT THE LOS ALAMOS NEUTRON SCIENCE CENTER, LOS ALAMOS NATIONAL LABORATORY, NEW MEXICO

Thomas E. Williamson[1], Stephen L. Brusatte[2], Michelle A. Espy[3], Cort Gautier[3], James Hunter[3], Adrian S. Losko[3], Ronald O. Nelson[3], Katlin Schroeder[4], and Sven Vogel[3]

[1]New Mexico Museum of Natural History and Science, 1801 Mountain Road, NW, Albuquerque, NM, 87121, thomas.williamson@state.nm.us
[2]School of GeoSciences, University of Edinburgh, Grant Institute, James Hutton Road, Edinburgh, EH9 3FE, United Kingdom
[3]Los Alamos National Laboratory, Los Alamos, NM, 87545
[4]Department of Biology, University of New Mexico, Albuquerque, NM, 87104

3D visualization of x-ray computed tomography (CT) has revolutionized the study of paleontology over the last decade by allowing paleontologists to gain essential insights into the anatomy, development and preservation of important specimens. Neutron computed tomography (NT) is an exciting new frontier in 3D visualization that has only rarely been applied to vertebrate fossils. NT is based on the interaction of neutrons and the nuclei of materials and thus is able to reveal internal detail in fossils impregnated with dense minerals otherwise impervious to traditional CT, and can also be used to distinguish areas of distinct elemental or isotopic composition within fossils. We have applied high resolution CT and NT to two specimens, the skull of the holotype of the Cretaceous tyrannosauroid *Bistahieversor sealeyi* (NMMNH P-27469) and a nearly complete skull of the Paleocene phenacodontid "condylarth" mammal *Tetraclaenodon puercensis* (NMMNH P-69898) using the unique capabilities of the Los Alamos Neutron Science Center (LANSCE) at Los Alamos National Laboratory (LANL), New Mexico. To reduce attenuation of neutrons and x-rays a special carbon fiber composite, rather than plaster, support jacket was constructed to hold the *Bistahieversor* skull. The CT scan of the *Bistahieversor* skull used 10 MeV x-rays at 200 μm resolution. This is the highest resolution CT of an entire large (> 1m long) tyrannosauroid skull ever made. Both specimens were also scanned using high-energy or low-energy (thermal) neutrons. Preliminary NT results reveals details of the internal bone structure of both specimens not readily visible with CT, with no residual increased radiation level following the cool-off period. CT and NT showed that *Bistahieversor* possesses the extensive tympanic sinuses and elongate, tubular endocast that were once thought to diagnose only the largest-bodied, most derived tyrannosaurids like *T. rex*, whereas *Tetraclaenodon* has an endocast that was not as proportionally large, and overall more primitive, than the brains of modern placentals.

Grant Information: Work was undertaken on joint grants from the New Mexico Consortium, National Science Foundation (EAR 0207750 to TEW, EAR 1325544 and DEB-1654952 to TEW and SLB), Bureau of Land Management awarded to TEW and SLB, and led by NNSA programs to further development of advanced technique. LANL and the LANSCE accelerator facilities used in this work are funded under DOE contract DE-AC52-06NA25396.

Keywords:

Bistahieversor, Tetraclaenodon, X-ray, Neutron, Tomography

ASSESSING URANIUM CONCENTRATION IN STREAM SEDIMENT ON THE LAGUNA AND ISLETA PUEBLOS

Brianne Willis

Eastern New Mexico University, 116 S Houston Ave., Portales, NM, 88130, brianne.willis@enmu.edu

As a summer internship through a New Mexico EPSCoR funded STEMAP program. Myself and another intern worked with the uranium team at New Mexico Tech. We collected sediment samples from streams and washes on Laguna and Isleta Pueblo lands. Samples were collected from the Rio Puerco, San Jose, Del Valle, and Paguate washes to analyze the heavy metal content washing down from upstream uranium mines. Knowing the type and quantity of heavy metals washing down these washes, could help with further clean up or reclamation efforts in the area. The samples needed to be dried, sieved, ground into a fine powder, then digesting in acid. Analysis of heavy metals was done using an ICP-MS for heavy metal content. We also performed a mass fraction of grain size on each sample to get a course sand content vs. the finer grain content. Our hypothesis being that uranium particle adheres to the larger surface area by volume of the clay material better than course sand. Uranium concentrations were present on samples we collected from the washes downstream of the main uranium mines. Our data also supported our hypothesis when we correlated the amount of finer grained material a sample had with the concentrations of uranium that was present in that same sample. Sites G,H,I the fine grain fraction of C and the course grain fraction of B held the highest concentration of uranium, which was above the average Earth's background uranium concentration of 3 mg/kg.

http://www.irsn.fr/EN/Research/publications-documentation/radionuclides-sheets/environment/Pages/Natural-uranium-environment.aspx

Keywords:

uranium concentration, ICP-MS

THE CHARACTERIZATION OF URANIUM MOBILITY AT THE JETER MINE, LADRON MOUNTAIN MINE DISTRICT, SOCORRO COUNTY, NEW MEXICO

Ashlynne Winton[1], Ingar Walder[1], and Bonnie Frey[2]

[1]New Mexico Institute of Mining and Technology, Socorro, NM, 87801, Ashlynne.Winton@student.nmt.edu
[2]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801

Mining has played a remarkable role in the economic development of the United States. Despite the closure of many mine features as a way to mitigate physical safety hazards, state and federal agencies are concerned that some of these features could still pose an environmental affect after closure and some of these effects could increase due to natural hazards that occur especially in desert environments, such as wildfires and periods of regional monsoonal flow. The objective of this research is to investigate and identify concentrations of uranium and other heavy metals from the Jeter mine, in the Sierra Ladrones Wilderness Study Area, Ladron Mountains district, Socorro County, New Mexico, which produced 26,563 kg U3O8 between 1954–1958. By utilizing standard flow-through column tests on waste rock material, physical and chemical hazards posed by the Jeter mine site will be evaluated. Preliminary paste pH ~ 6 results suggest this area is non-acid producing; XRD analysis coinfirms that torbernite is precipitating along the fault gouge. Before and after concentrations of uranium will be measured and analyzed using electron microprobe, ICP-MS, sequential chemical extraction (SCE), acid based accounting (ABA), and field leach tests. Further water chemistry analysis will be conducted on the surrounding cattle wells in the district.

RELATIONSHIP BETWEEN TREE CANOPY COVER AND DISCHARGE OF UPPER GALLINAS WATERSHED, NEW MEXICO, 1939 – 2015

Behnaz Yekkeh

New Mexico Highlands University, 815 5th Street, Apt. 2, Las Vegas, NM, 87701, b.yekkeh@gmail.com

With the advent of climate change, it is expected that the US Southwest will experience warmer average temperatures in all seasons, longer summers, shorter winters, and reduced snowpack in the higher elevations. In the northeastern part of New Mexico, the city of Las Vegas has been dealing with the threat of water shortage since the beginning of the 21st century. The Gallinas River is a tributary of the Pecos River system in northern New Mexico, yielding an average of 3,100 acre-feet of water annually. The river originates at Elk Mountain and the watershed ranges in elevation, from 4,900 to 11,600 feet. The upper Gallinas watershed is located approximately 20 miles northwest of Las Vegas, and covers approximately 52,500 acres. Land use of the upper watershed has transitioned over the past few decades from agriculture, focusing on timber, livestock, and hay production, to primarily full-time and part-time residential use and summer creation. The purpose of this study is to determine the tree canopy cover change through time and if a correlation exists between tree canopy cover, precipitation, temperature and the Gallinas River discharge from 1939 to 2015. Aerial photography and Geographic Information System (GIS) techniques have been used to determine the percentage of tree canopy cover in Gallinas watershed from 1939 to 2015. The preliminary results suggest an increase in the tree canopy cover from 1939 to 2011, 36.6% and 53.1% respectively, which can be due to reduced logging and grazing, fire suppression, and different land management practices in the area. On the contrary, results indicate a decrease (about 10.86%) from 2011 to 2014, that can be related to the thinning projects have been conducted in the last few years. By assessing changes in canopy cover, precipitation, and discharge over time, we can provide insight into whether canopy cover, precipitation patterns, or both are influencing water discharge in the Gallinas River. Statistical analysis allows us to distinguish the extent of impact each of these factors has on the discharge of the Gallinas River. This information can potentially be used by water and land managers to better inform their decisions for the utilization and management of the watershed.

A MULTI-SCALE VISUALIZATION AND EXPLORATION OF THE MORA WATERSHED, NEW MEXICO

Joseph Zebrowski[1], Patti Dappen[2], and Adrian Sanchez[1]

[1]New Mexico Highlands University, NMHU NRM Dept, Box 9000, Las Vegas, NM, New Mexico, 87701, United States, jpzebrowski@nmhu.edu
[2]New Mexico Forest and Watershed Restoration Institute, Box 9000, Las Vegas, NM, New Mexico, 87701, United States

Beginning in the spring of 2015, a team of New Mexico Highlands University (NMHU) faculty and students began developing a series of curriculum modules to teach various practices for delineating watersheds, collecting field data, and exploring watershed features using desktop and online geographic information systems. This work was funded as part of New Mexico EPSCoR's Western Consortium, Watershed Analysis, Visualization, and Exploration (WC-WAVE), Undergraduate Visualization and Modeling Network (UVMN). In the first phase of the project, curriculum for delineating watersheds from 30-meter, 10-meter, and lidar-derived 0.3-meter resolution digital elevation models was developed. The Environmental Protection Agency's BASINS software is used. A users' guide for field data collection with Avenza's PDF Maps applications was also developed. A suite of camera equipment and accessories was obtained to help enhance field data collection using "gigapan" photography. In the continuation phase of the project, NMHU is developing an Introduction to Geographic Information Systems module. This module is being supported with exercises in using ESRI's ArcGIS Online platform to explore and create web maps, create Story Maps, and collect field data using ESRI's Collector for ArcGIS app. A unique aspect of this project was the establishment of a "co-learning" environment among students and faculty. Students were assigned to develop specific modules and were then expected to teach their faculty mentors what they had learned. Modules from the first phase of the project are already being used in various NMHU courses. Modules from the continuation phase are being piloted at NMHU this spring and will be incorporated in a course being conducted this summer at nearby Rio Mora National Wildlife Refuge by the Community College of Denver. The Denver Zoo at Rio Mora National Wildlife Refuge is also adopting the curriculum for use in various courses and workshops they will offer. All curriculum will be made available on the New Mexico Forest and Watershed Health Clearinghouse, allaboutwatersheds.org.

Keywords:

watershed, geographic information systems, EPSCoR, WC-WAVE, UVMN

Turning Toys Into Tools: Unmanned Aircrafts for the 21st Century Geoscientist

Matthew J. Zimmerer[1] and Jake I. Ross[1]

[1]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801, matthew.zimmerer@nmt.edu

Unmanned aircraft systems (UAS), commonly known as "drones", are an established but rapidly developing technology for scientists, engineers, farmers, artists, and numerous other private and public entities. This presentation will introduce new UAS mapping capabilities at the New Mexico Bureau of Geology. UAS allow geoscientists to make observations and measurements in an important part of the scale spectrum that lies between satellite and ground-based photogrammetry methods. Traditionally, this part of the scale spectrum is accessed by piloted fixed-wing and rotary-wing aircraft. Although useful, these aircrafts are expensive, require extensive training and certification, and have limited availability, all of which inhibits their full potential in the geosciences. In contrast, most UAS are relatively inexpensive, lightweight, and require only minimal to moderate training and certification. All of these features make using UAS an attractive solution to addressing many geologic problems. The New Mexico Bureau of Geology recently acquired two UAS, one turnkey quadcopter for mapping and aerial photography and one custom-built hexacopter for research and development. Freely available open source software is used to process the aerial photos into orthomosiacs, digital elevation models, and 3D models. These models approach the accuracy of traditional photogrammetry methods and in most cases are at a much higher resolution. In addition to aerial photography the UAS are outfitted with a "companion computer" designed at the NM Bureau of Geology. The primary software for this computer is developed in-house offering a large degree of autonomy and flexibility. These lightweight microcomputers are used for collecting georeferenced scientific data, such as temperature, humidity, and UV intensity. Additional payloads including thermal cameras, multi-spectral cameras, and atmospheric or gas monitoring equipment are also possible. The lightweight design and low cost of our UAS make them a particularly attractive tool for geomorphic, hydrologic, and hazard mapping studies, where repeated time-sensitive measurements of a landscape are necessary. In addition to research, UAS imagery and 3D models provide a memorable immersive experience for outreach and educational services, allowing users to virtually explore geologic features in new and exciting ways. This presentation will also focus on some initial case studies of field sites in New Mexico, operating limitations, certification requirements, and legal aspects of using UAS for the geosciences.

Keywords:

UAS, drone, photogrammetry, aerial photography, mapping

ORIGIN AND MINERAL RESOURCE POTENTIAL OF THE ROSEDALE DISTRICT, SOCORRO COUNTY, NEW MEXICO

William Zutah[1] and Virginia T. McLemore[2]

[1]New Mexico Institute of Mining and Technology, 1101 El Camino Real St., Apt 2, Socorro, NM, New Mexico, 87801, United States, william.zutah@student.nmt.edu
[2]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM, 87801-4796

More than 50,000 troy ounces of gold and 5 million troy ounces of silver have been produced from Socorro County, New Mexico between 1863 and 1981. Rosedale district is one of the more important gold producing districts in Socorro County. Gold was discovered in 1882 and, because of the rich Au content of the deposit, it created a rush to the area. An estimated total value of metals (Au and Ag) produced from Rosedale district between 1882 to 1981, amounted to about $500,000 generated from 28,000 oz of gold and 10,000 oz of silver mined from 7 levels underground. However, exploration within the district has shown that there is still potential for volcanic-epithermal gold and silver deposits. Exploration work conducted in 1976 by Perry, Knox and Kaufman, Inc. estimated 1.5 to 2 million tons of 0.3 oz/short ton Au remained in the district. Rosedale lies in a tectonically active and structurally complex area and is part of the Mogollon-Datil volcanic field, which is a late Eocene-Oligocene volcanic province that extends from west-central New Mexico southward into Chihuahua, Mexico. Rosedale lies on the northeastern slope of the San Mateo Mountains, about 25 miles south of Magdalena and about 30 miles north of San Marcial. Main rock types associated with mineralization are brecciated and sheared rhyolite, partly cemented by banded bluish-white quartz. These rocks have been fractured, and recemented with glassy vein quartz. The walls have been silicified, and the outcrop stands out clearly. The vein carries free-milling gold. There is limonite throughout, and manganese oxides occur in stringers and as coatings on the fracture surfaces. Manganese appears to be associated with the higher grades of ore. Sulfide mineralization appears to exist above the water level, which is at 725 ft depth. Some of the quartz in the oxidized ore above water level contains cavities formerly occupied by other minerals. Changes in the primary ore values within the veins have been observed and the origin of this can be established by actual examination of the paragenesis of the veins in the district. Comparatively rich shoots are present, and are probably very irregular in form. These observations indicate the potential of gold mineralization is part of an epithermal vein system.

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New Mexico Bureau of Geology and Mineral Resources
2808 Central SE, Suite 127
Albuquerque, NM 87106-2245
505-366-2530 information
505-366-2559 fax