November 2015

NEWSLETTER

SINCE 1950

Four Corners Geological Society

*November Meeting:*

# Colorado's Newest Mass Extinction: Weird Facies and Cool Fossils from the End-Devonian Dyer Formation

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| **SPEAKER:** | **James Hagadorn,** Denver Museum of Nature and Science |
| **DATE / TIME:** | Thursday, November 12th, Social hour starts at **6:15pm**, dinner at **6:45pm**, talk at **7:30pm**. ***** STARTS 45MIN LATER THAN USUAL ***** |
| **LOCATION:** | Fort Lewis College, Student Union Building, Ballroom (next to Colorado Room). |
| **COST:** | $20.00/person, $2.00/person talk only, Students free. You can RSVP & pay online at: http://www.fourcornersgeologicalsociety.org/Events/events.asp |
| **RSVP:** | By Monday, November 9th, to Rebecca Helms, rhelms@rwpc.us or 970-563-5356. (*Students, please RSVP by email as the online PayPal system doesn't work for free admission*). |

**ABSTRACT:** The Dyer Formation of west-central Colorado is spectacularly exposed in the Glenwood Canyon area and is of interest because it spans one of the most enigmatic mass extinctions in earth history – the end-Devonian event. Whereas the Dyer is known among fossil collectors for its diverse invertebrate and vertebrate assemblages, its geochronology and facies are poorly constrained.

Recent chemostratigraphic analyses of the Dyer reveals a regionally extensive six per mil positive excursion in the carbonate delta carbon thirteen values in the upper member of the unit. This excursion is interpreted to represent the Hangenberg isotopic excursion, thought to be the predominant signature element of the end-Fammenian extinction. New biostratigraphic work in the Dyer Formation, based largely on conodonts preserved in fish fecal pellets, supports this interpretation, and moreover demonstrates that the upper part of the Dyer, as well as the conformably overlying Gilman Sandstone, were deposited during the Early Carboniferous.

Concordant with these observations, the extinction interval in the Dyer is immediately underlain by a firmground-like facies which bears abundant rugose corals. Elsewhere in the globe, such fossils have been interpreted to represent Lazarus taxa that return after near decimation at the end-Frasnian extinction. Most of the lower Dyer in the Glenwood area exhibits sedimentologic, paleontologic, and diagenetic features consistent with deposition in a shallow wave-influenced stenohaline tropical platform whereas the upper portion of the unit exhibits features more consistent with deposition in a protected mud-dominated euryhaline setting. In contrast, the Dyer's extinction interval facies are characterized by microbialites and bedded cherts – features consistent with a short-term perturbation in environmental conditions at or prior to the Hangenberg Event.

**** Dr. Hagadorn will also give a quick synopsis of current revisions to Colorado's stratigraphic chart.*

**2nd TALK:** *Dr. Hagadorn will also address the FLC student chapter of AAPG on, "Surfing Cambrian Coasts: First Animals to Land". Thursday, November 12th, 12:00pm. Room 380 Bernt Hall (Dept Geosciences), Fort Lewis College. No admission fee. Reservations not required.*



Inside this issue:

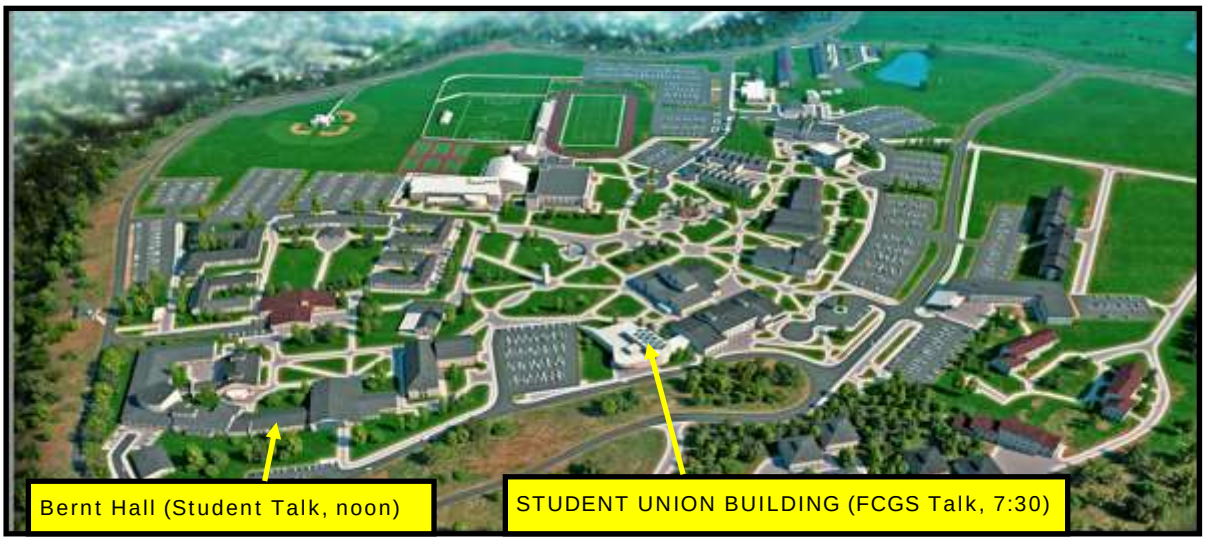
## SPEAKER'S BIOGRAPHY: JAMES HAGADORN

Denver Museum of Nature and Science

James Hagadorn is currently the Tim and Kathryn Ryan Curator of Geology at the Denver Museum of Nature & Science. Everything about "deep time" fascinates him, and he has spent the last twenty years studying modern and ancient environments all over the world. Much of his research has focused on Neoproterozoic and Cambrian strata, but since moving here he's become distracted by Colorado's youthful and marvelously exposed stratigraphy – with recent ventures taking him all the way to the Cretaceous.

Through fieldwork, labwork, and collaboration with academic and citizen scientists, Hagadorn has studied ancient sedimentary environments, large volcanic deposits, weird minerals, extinct creatures, and a variety of enigmatic 'whatsits'. Although this work contributes to improving our understanding of ancient earth systems, Hagadorn is cognizant of the need to leverage our understanding of ancient earth to better understand future earths, and our responsibility to convey science and scientific thinking to the public. To this end, he writes a monthly Colorado-focused science newspaper column, regularly co-hosts a Colorado mineral show, and is helping colleagues to bring Colorado stratigraphy more into the public eye.

## MEETING LOCATION: FORT LEWIS COLLEGE




## SUPPORT GEOSCIENCE RESEARCH at FORT LEWIS COLLEGE

By Gary Gianniny, Chair, Department of Geosciences, Fort Lewis College

Every year the FCGS membership gets to see a subset of the research done by Fort Lewis College students and faculty in the April newsletter and meeting. This month we've decided to highlight some of the current research presentations at GSA, AGU, and AAPG as well as publications by FLC faculty (pp 6-8). In almost every case this is research that has been conducted with our students or has lead to richer content in our courses. Fort Lewis students benefit greatly from our close partnership with the FCGS; many members serve as mentors, some support scholarships, others provide guest lectures, or provide stimulating and friendly conversations at meetings. Our students help our members as research interns, employees, and even occasional moving help.

If you would like to contribute to our new Geology, Physics, and Engineering building, a scholarship, or towards our general fund which supports student research and field experience, we welcome and appreciate your support. You can donate online at the Fort Lewis College Foundation by clicking on the "Give Now" button on the www. fortlewis.edu website. To donate to the new building use the GP&E campaign link, or just specify "Geology" on the donation form.

Or you can mail checks to: Fort Lewis College Foundation, 1000 Rim Drive, Durango, CO 81301. (note "Geology or GP&E building in your subject line)

Thanks for your support!

*(Continued on page 6)*

## **"PREZ SEZ"** by John Youle

As if being hit by a freak flood or tornado, large swaths of our membership have been devastated. 200,000 jobs have been lost worldwide in the oil and gas industry (Swift Resources estimate) since WTI prices collapsed from $107/bbl June 20, 2014 to $43.78/bbl presently (Oct 26). 1130 rigs have stopped drilling in the US since October 2014 representing a 60% drop in activity (Baker Hughes), and in the San Juan basin, we're down to only five drilling rigs and 40 well service rigs. Many of our members and their families are suffering the consequences of adverse market conditions beyond their control. These are as tough as times can get for many members.

The FCGS needs to do what it can to help get our fellow members get back on their feet. Consequently, the Newsletter is offering free 1/16th page ads (business card size) for all members feeling the sting of events beyond their control. Please send your ad or business card to our Secretary and Newsletter editor Kim Gerhardt to be included in future Newsletters for the remainder of the 2015-/16 season. And if you're one of the lucky ones not affected by current market conditions, please consider hiring or using someone from our membership when a need arises; I'm confident they would do the same for you.

Stay Compassionate,

John

### Build Up Your Personal Geology Library!

Pat Blair, in cleaning out Rob's collections, is offering the following publications to any member interested in them. Please contact her directly at prblair@bresnan.net.

| | |
|---|---|
| Journal of Research, USGS | January 1973 - November 1978 |
| Earth | September 1986 – May 2012 |
| Journal Geological Education | January 1971 – November 2003 |
| Environmental and Engineering Geoscience | Spring 1995 – August 2006 |
| AAPG Bulletin | June 1944 – October 2009 |
| GSA Bulletin | January 1952 – May 2012 |
| Geology | September 1973 – June 2012 |
| Monographs of different states / areas / basins | 1901 to Present |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# EVENTS, MEETINGS & COURSES *(by date)*

GEOLOGICAL SOCIETY OF AMERICA ANNUAL MEETING, Baltimore, Maryland, November 1-4. For more information and to register go to: http://www.geosociety.org/meetings/ .

ROCKY MT ASSOC. OF GEOLOGISTS NOVEMBER LUNCHEON: Denver CO, Nov. 4th., Maggiano's Little Italy - 500 16th Street Mall #150, 11:30am. Speaker: Ranie M. Lynds and Christopher J. Carroll, Wyoming State Geological Survey, "The case for another look at the Paleocene Fort Union Formation in the eastern Greater Green River Basin, Wyoming". To register go to: https://www.rmag.org/i4a/ams/amsstore/category.cfm?category_id=3.

REMEDIATION AND RESTORATION OF HYDROCARBON AND BRINE CONTAMINATED SOILS: Denver, CO., Nov. 16th. To enroll call Sublette Consulting, Inc. at (918) 691-0639 or email Kerry Sublette at kerry-sublette@utulsa.edu or ksublette@microbe.com

PTTC (Petroleum Technology Transfer Council) WORKSHOP: Golden, CO, November 16th . "Petroleum Geology for Non-Geologists". Instructors Kelly Foley and Laura Wray. For information and to register: https://www.eventbrite.com/e/petroleum-geology-for-non-geologists-tickets-18370409389.

PTTC (Petroleum Technology Transfer Council) WORKSHOP: Golden, CO, November 17th . "Petroleum Engineering for Non-Engineers". Instructor Dr. Jennifer Miskimins, Baree & Assoc. For information and to register: https://www.eventbrite.com/e/petroleum-engineering-for-non-engineers-tickets-18218335532.

22nd INTERNATIONAL PETROLEUM ENVIRONMENTAL CONFERENCE: Denver, CO, November 17-19th. Envionmental issues and solutions in exploration, production, refining and distribution of petroleum. Early registration deadline October 9th. For more information and to register: http://www.cese.utulsa.edu/conferences.php.

ANNUAL COLORADO GROUNDWATER CONFERENCE: Denver, CO, Dec. 4th. Registration is open at (http://www.agwt.org/civicrm/event/info?reset=1&id=193).

COLORADO SCHOOL OF MINES, VAN TUYL LECTURE SERIES:
Schedule posted at: http://geology.mines.edu/GE_Lecture-Series. Lectures are given each Thursday from 4:00-5:00 pm in Berthoud Hall Room 241.

- October 29. Daniel Jarvie, Worldwide Geochemistry. "Utilizing Geochemical Properties to Assess Unconventional and Conventional Petroleum Reserves."
- November 5. Speaker / topic TBA
- November 12. Jerome V. DeGraff, U.S. Forest Service (Retired). "Fire, Earth & Rain: Emergency Response for Wildfire-Induced Landslide Hazards".
- November 19. Vitor Abreu, Exxon-Mobile. "A Simplified Guide for Sequence Stratigraphy: Nomenclature, Definitions and Method.
- December 3. Peter Scholle, "Fifty-One Shades of Gray: The Deposition and Diagenesis of North Sea Chalks".

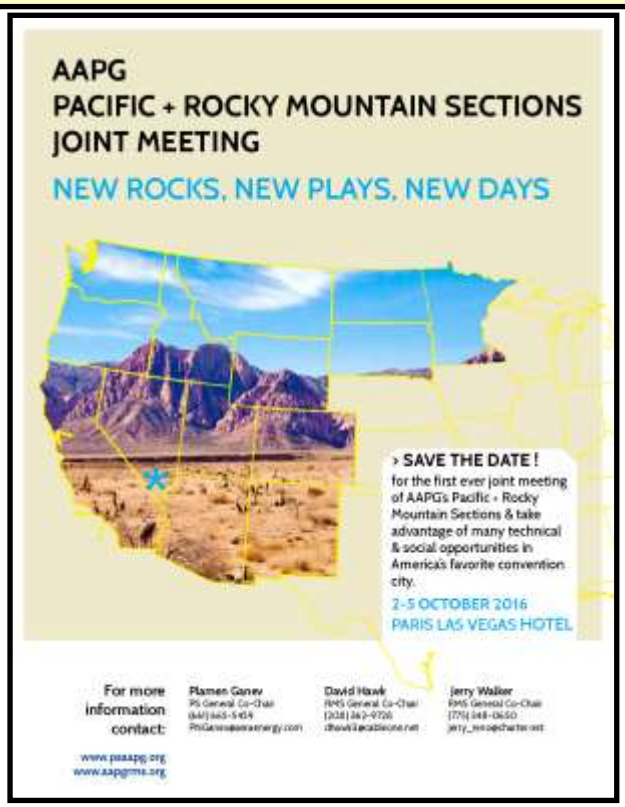
COLORADO STATE UNIVERSITY, DEPARTMENT OF GEOSCIENCES SEMINAR SCHEDULE:
Schedule posted at: http://warnercnr.colostate.edu/geo-news-and-events/department-seminars . Seminars are located in Room 320, Warner College of Natural Resources (NR) Building on Thursday afternoons, and will begin at 12:30 p.m. Questions? Please call (970) 491-5661.

- October 29. Leah Morgan, USGS-Denver. "Variability in Stable Potassium Isotopes (41K/39K) in Geological and Biological Systems."
- November 11. Jerry DeGraff, Cal State – Fresno. "fire, Earth and Rain".
- November 19. Devin Castendyk, SUNY. Topic TBA.
- December 3. Fan-Chi Lin, Univ. of Utah. "Seismic Interferometry and Tomography Across USArray – Imaging Interior Earth Structure from Upper Crust to Inner Core".

UNIVERSITY OF COLORADO BENSON EARTH SCIENCES COLLOQUIUM SCHEDULE
Schedule posted at: http://www.colorado.edu/geolsci/colloquium.htm . All talks are held in the Benson Earth Sciences Auditorium (180) every Wednesday at 4:00 pm unless otherwise noted. Refreshments are served at 3:30 on the 3rd floor.

October 28 – December 9th are all Geobiology lectures or break.

FRIENDS OF THE COLORADO SCHOOL OF MINES GEOLOGY MUSEUM: Monthly informal lecture series on the first Thursday evening of each month. All talks will be held in the conference room (201) directly across from the Geology Museum at 1310 Maple Street, Golden, CO 80401. For more information : 303-273-3815, geomuseum@mines.edu,



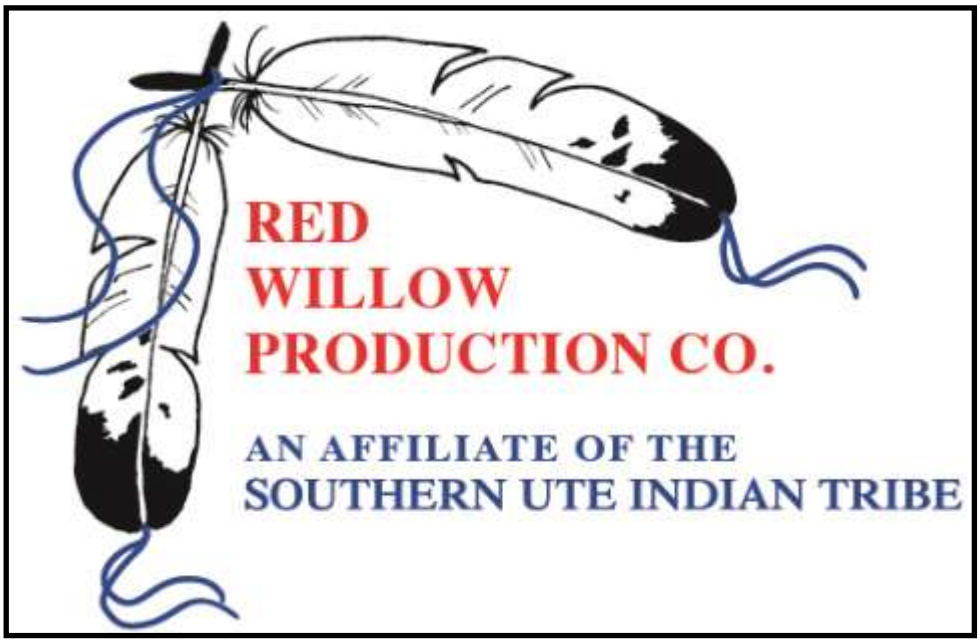


*MISSING SOMEONE?*

Help us find members we've lost touch with since our transfer into the digital age. Give us the names of people you haven't seen in a while and we'll try to find them.

LOST MEMBER CONTACT:
Tom Ann Casey
tcasey@rwpc.us

THANKS!



*(Continued from page 2)*

*To be presented at the GSA National Meeting in Baltimore, Md., Nov. 1-4, 2015:*

**A sequence stratigraphic model for the Redwall Limestone in the Grand Canyon, Arizona,** Gary L. Gianniny, Department of Geosciences, Fort Lewis College, Geological Society of America Abstracts with Programs, v. 47, n. 7,.

The Redwall Limestone exposed in the Eastern and Central Grand Canyon of Arizona has similar facies and a similar sequence stratigraphic organization as the Leadville Limestone in Southwestern Colorado. The similarities in facies have been noted by previous workers (e.g. McKee and Gutschick, 1969; Kent and Rawson 1983), but here I offer an alternative sequence stratigraphic model.

The Grand Canyon Mississippian carbonates initiated slightly earlier (the Kinderhookian Whitmore Wash Member) than in Southwestern Colorado; both units are marked by basal conglomerates and are dominated by shallow water to supratidal facies. In southwestern Colorado, the Osagian Leadville Limestone thickens from highstand grain-dominated updip facies in the San Juan Mountains to westward prograding crinoidal shoal complexes which built out over deeper water, brozoan-rich cherty dolomitic wackestone and mudstone documented in core from the McElmo Dome Field, near Cortez Colorado. This progradation is indicated by an increase in bed and parasequence thickness and a progressive shift to more grain-supported lithologies (Klink et al., 2014). If this interpretation is applied to the facies of the Redwall Limestone in the Grand Canyon region, it suggest a similar progradational relationship for the crinoidal grain to packstone facies of the Mooney Falls member over the cherty bryozoan-rich deeper water facies of the Thunder Springs Member. Similar to the McElmo Dome cores in SW Colorado, exposures of this transition in the central Grand Canyon contain parasequences defined by alternations of these two facies which also appear to thicken, and contain more ooids up section. This progradational interpretation differs significantly from previous workers who view these two members as parts of two separate transgressive units. As the Redwall Limestone depositional system overfilled the margin, thinner, discontinuous shallow water parasequences of the Horseshoe Mesa Member where deposited. The final incised valley-filling Chesterian sequence of the Surprise Canyon Formation has not been --recognized in Southwestern Colorado.

**Development of penetrative thinking skills in a sophomore field course and Structural Geology,** Kimberly A. Hannula, Department of Geosciences, Fort Lewis College, Geological Society of America Abstracts with Programs, v. 47, n. 7, p. 403.

Spatial thinking skills are a fundamental part of the competencies expected from geology majors, and field experiences are thought to play a critical role in developing those skills. This study examines the development of penetrative thinking in two courses: a sophomore-level field course, and a junior-level structural geology course.

Two sections of a sophomore field course (33 students) and one section of structural geology (27 students) were given the Geologic Block Cross-sectioning Test (GBCT; Ormand et al., 2014) as pre- and post-tests during Fall 2014. The sophomore course was the first time that the students engaged in geologic mapping, and is a pre-requisite for structural geology. Results of the GBCT showed improvement in both courses. The sophomore field class improved from a pre-test mean of 34% to a post-test mean of 45%; median improvement was 3 out of 16 points. Structural geology students also improved, from a pre-test mean of 47% to a post-test mean of 63%; median improvement was 3 out of 16 points.

Analysis of incorrect answers provides insight into the kinds of difficulties students had with penetrative thinking. The most common incorrect answer on both pre- and post-tests (post-test median 4/16 for sophomores; 3/16 for structure) implied that students were not seeing the blocks as a 3-D object. Although students in both classes improved their overall scores, median selection of the most problematic answers only decreased by 1 out of 16 in both courses. Furthermore, a few students (4 sophomores; 7 structure) selected more problematic answers in the post-test than in the pre-test; the sophomores who got no correct answers also had the largest number of problem responses (up to 94%).

Improvement in the GBCT was nearly equal in the field course and in structural geology. Furthermore, the post-test scores for the sophomore course were statistically similar to the pre-test scores for structural geology (p=0.73). This suggests that the students' penetrative thinking skills improved in steps through the sequence of courses. On the other hand, some students, particularly in the field course, did not improve their penetrative thinking skills. Early mapping experience appears useful in development of penetrative thinking skills for most students, but some students may need other interventions.

*To be presented at the AGU National Meeting in San Francisco, CA, Dec 14-18, 2015:*

**Active Deformation in the Greater Himalayan Zone in Western Nepal from Inversion of New (U-Th)/He Cooling Ages, Jonathan E. Harvey**, Department of Geosciences, Fort Lewis College

Much of the central Himalaya features an abrupt rise in mean elevation from ~1.5 km in the Lesser Himalaya to ~4-5 km Greater Himalaya and Tibetan Plateau. This physiographic transition is known as PT2, and is often interpreted as the surface expression of transport over a ramp in the Main Himalayan Thrust (MHT). In western Nepal, however, the same rise in elevation occurs over two distinct topographic steps (PT2-N and PT2-S). In previous work, Harvey et al. (2015) argue that this anomalous topography is the result of recent southward-migration of mid-crustal deformation along the MHT. Due to the seismogenic potential of the MHT it is important to constrain its geometry in the western Nepal seismic gap, which has not had a large earthquake in over 600 years. To test the above hypothesis, we perform [U-Th]/He dating on 39 apatite and 47 zircon samples collected along seven relief transects throughout western Nepal. We constrain exhumation histories by inverting these new cooling ages with the 3-D thermo-kinematic model Pecube. Five transects collected from the Greater Himalaya north of PT2-N are best fit by relatively rapid exhumation rates (~1-2 km/Myr) since ~4 Ma. The other two, collected from farther south near PT2-S, require rapid (~1-2 km/Myr) exhumation until around 8-11 Ma, followed by much slower (~0.1-0.2 km/Myr) exhumation until at least the late Pliocene. Assuming that exhumation rates reflect uplift rates, the rapid Plio-Pleistocene exhumation in the Greater Himalaya north of PT2-N suggest that this physiographic transition is similar to that at the foot of the Greater Himalaya in central Nepal. It follows that active deformation is occurring along a NW-trend as much as 100 km farther north than would be expected if simply projecting PT2 across western Nepal. This finding is consistent with transport over a more northerly MHT ramp or perhaps oblique slip along the recently identified, surface-breaking WNFZ. Although the geomorphology and microseismicity along PT2-S hints at rejuvenated uplift in this zone, late Miocene cooling ages require very slow rock uplift for much of its post-Miocene history. This does not rule out the hypothesized young mid-crustal duplex, but it limits the magnitude of associated uplift and exhumation.

*Recent publications:*

**New U/Pb zircon and 40Ar/39Ar age constraints of the Cenozoic plutonic record, southwestern Colorado: implications for regional magmatic-tectonic evolution**. Gonzales, D.A., 2015, *The Mountain Geologist*, v. 52, no. 2, p. 5-42.

New U-Pb zircon and 40Ar/39Ar crystallization ages for latest Mesozoic to Cenozoic plutonic rocks in the west-ern San Juan Mountains provide insight into the timing and interplay of mantle and crustal magmatism over the past 80 Ma. Subduction-driven magmatism in the Laramide (75-60 Ma) generated alkalic intermediate to mafic magmas. These were emplaced as laccoliths and stocks along northeast trends that were likely controlled by crust-al-scale zones of weakness with Proterozoic ancestry. The transition from Laramide subduction to slab rollback and delamination was marked by incipient regional extension and widespread emplacement of plutons. Oligocene plu-tons of gabbro to granite were mostly peripheral to 29-27 Ma caldera complexes that formed over a regional sub-volcanic batholith. Alkaline mantle magmas that accompanied the semi-continuous intrusion of shallow felsic to intermediate plutons from 25 to 4 Ma produced diatreme-dike complexes and dike swarms across the northern San Juan Basin. Emplacement of plutons from 75-4 Ma caused localized uplift that had a major influence on landscape evolution, and often were linked to zones of mineralization.

Late Mesozoic to Cenozoic plutonic events in the western San Juan Mountains record a long -term shift to more bimodal magmatism. Injection of mantle melts from 25 to 4 Ma during incipient crustal extension accompanied elevated thermal gradients over the region, as evidenced by resetting of cooling ages in some Laramide intrusive rocks. The preservation of xenocrystic zircons in 75-4 Ma plutonic rocks provides evidence for variable magmatic conditions with an overall increase in the thermal state of Oligocene melts proximal to caldera systems and all plu-tons emplaced after 18 Ma. High geothermal gradients caused by the long duration of magmatism and increased mantle contributions may have permitted more prolonged assembly and slower cooling in some plutons.

**A cool time in the Early Jurassic: first continental palaeoclimate estimates from oxygen and hydrogen isotope ratios in chert from Navajo Sandstone carbonate lenses, Utah (USA),** Kenny, Ray, 2015, in: Carbonates and Evaporites, Springer Verlag.

Cool continental palaeoclimate estimates ranging from ~9 to 18°C were inferred from oxygen and hydrogen isotope composition of chert precipitated contemporaneously with algal carbonate in interdune, freshwater lakes of the Early Jurassic Navajo Sandstone (USA). The oxygen and hydrogen isotope composition also indicate that meteoric waters were involved in the crystallization history of the chert. These results are consistent with previous studies that suggest that the interdune carbonate lenses in the Navajo Sandstone are freshwater carbonates precipitated in a wet-climate, pluvial episode. Approximate palaeotemperature estimates from oxygen and hydrogen isotope composition of silicified wood samples adjacent to a carbonate lens yield palaeotemperature estimates of ~33 to 43°C. These data are consistent with burial diagenetic temperatures and support the interpretation that the algal chert precipitated contemporaneously with the algal carbonate. The results of this study demonstrate that the potential for obtaining quantitative, continental palaeoclimate estimates from freshwater chert found throughout the geologic record.

**Along-strike changes in Himalayan thrust geometry: Topographic and tectonic discontinuities in western Nepal,** Jonathan E. Harvey, Douglas W. Burbank, and Bodo Bookhagen, 2015, LITHOSPHERE; v. 7; no. 5; p. 511–518; doi:10.1130/L444.1

Geodetic and seismologic studies support a tectonic model for the central Himalaya wherein ~2 cm/yr of Indo-Asian convergence is accommodated along the primary décollement under the range, the Main Himalayan thrust. A steeper midcrustal ramp in the Main Himalayan thrust is commonly invoked as driving rapid rock uplift along a range-parallel band in the Greater Himalaya. This tectonic model, developed primarily from studies in central Nepal, is commonly assumed to project along strike with little lateral variation in Main Himalayan thrust geometry or associated rock uplift patterns. Here, we synthesize multiple lines of evidence for a major discontinuity in the Main Himalayan thrust in western Nepal. Analysis of topography and seismicity indicates that west of ~82.5°E, the single band of steep topography and seismicity along the Main Himalayan thrust ramp in central Nepal bifurcates around a high-elevation, low-relief landscape, resulting in a two-step topographic front along an ~150 km segment of the central Himalaya. Although multiple models could explain this bifurcation, the full suite of data appears to be most consistent with a northward bend to the Main Himalayan thrust ramp and activation of a young duplex horse to the south. This poorly documented segmentation of the Main Himalayan thrust has important implications for the seismogenic potential of the western Nepal seismic gap and for models of the ongoing evolution of the orogen.

**Petrographic and Geochemical Constraints on the Provenance of Sanidine-Bearing Temper in Ceramic Potsherds, Four Corners Region, Southwest USA.** David A. Gonzales,1,* Fumi Arakawa,2 and Alan Koenig3, 2014, Geoarchaeology: An International Journal **30** (2015) 59–73.

Previous researchers proposed that trachybasalt temper with "poikolitic" sanadine, found in pottery from the Mesa Verde region of the American Southwest, was procured along the eastern Chuska Mountains. This served as one line of evidence that Chaco Canyon was a regional trade center linked to the Chuska Mountains in the ninth to thirteenth centuries. Recent geologic studies, however, revealed other potential sources for the trachybastalt temper. A comparison of petrographic features and geochemical signatures of poikilitic sanidine in rock samples and potsherds shows no definitive correlation of temper materials and a specific geologic source. Several outcrops of trachybasalt are identified as less viable prospects, but the results do not support the idea that the sanidine-rich temper was exclusively gathered in the Chuska Mountains. This conclusion opens up the possibility that raw materials were gathered from local sources that were more accessible, reducing the dependence on a regional trade center.

*Presented at May, 2015 GSA –Rocky Mountain Section Meeting:*

**Application of AR-HE-NE isotopes at McElmo Dome – Doe Canyon to investigate $CO^2$ souce and system characterization.** Joshua G. Adams and David A. Gonzales, Department of Geosciences, Fort Lewis College, 1000 Rim Drive, Durango, CO 81301

The McElmo Dome-Doe Canyon field (MDO) is one of the largest subsurface $CO_2$ reservoirs in the Four Corners region. In prior studies, hypotheses favored $CO_2$ generation by thermal in situ decomposition of carbonate-sulfate assemblages in the Leadville Limestone or from magmatic degassing of Laramide plutons. The source of the $CO_2$ gas, however, was not fully evaluated. In this investigation, noble gas isotope signatures (Ne, Ar, He) were used to fingerprint the $CO_2$ gas produced in the field and test competing hypotheses on its origin.

Analyses of noble gas isotopes and major gas composition data across the MDO reveals signatures that are consistent with a mixture of crustal, magmatic, and atmospheric contributions, dominated by elevated radiogenic and nucleogenic isotopes ($^4$He, $^{21}$Ne, $^{40}$Ar). A comparison of $CO_2/^3$He to $CO_2$ volume shows our helium concentrations are consistent with magmatic $^3$He sources, but other isotopic in gas signatures reveal a dominant crustal or lithospheric mantle signature.

Our preliminary data shows mixed signatures of crustal and mantle input, possibly reflecting different sources of $CO_2$ and noble gases. We argue that the $CO_2$ gas was sourced from 30-4 Ma magmas that degassed and filled stratigraphic traps in the Leadville Formation. Oligocene mantle melts are the favored candidate for a mantle magmatic source. Magmatic events in the area span from 75-5 Ma and involved melting of Proterozoic lithospheric mantle, which was a key source of carbonate-rich mantle melts. Oligocene mafic rocks generated from these melts have elevated K, U, Th and F, and provide a possible explanation of exceptionally high nucleogenic ($^{21}$Ne, $^{22}$Ne) and radiogenic ($^4$He, $^{40}$Ar) noble gases concentrations observed in the MDO.

**Testing models on the relationship of clay alteration and mineralization: Bulldog Mountain vein system, Creede, Colorado.** Nathan Spencer, David A. Gonzales and Cassady Harraden, Department of Geosciences, Fort Lewis College, 1000 Rim Drive, Durango, CO 81301

The Bulldog Mountain vein system is one of the four major epithermal deposits in the Creede mining district. Exploration drill core from within the Bulldog Mountain system reveal alteration haloes that contain secondary micas formed during volcanic and hydrothermal events. In this research we tested the hypothesis that Short Wave Infrared (SWIR) spectroscopy could delineate the proportions of clay species and that these data could be used to predict silver concentrations within the Bulldog Mountain system.

The relative proportions and identities of clays species were determined in seven samples from four drill using electron microprobe and QEMSCAN analyses. The analyses demonstrated that the clay alteration is mostly illite + sericite in varying proportions along with minor kaolinite. Electron microprobe and QEMSCAN data served as a baseline to compare with SWIR absorption spectra collected using three different methods of sample preparation. The SWIR spectra gave no definitive control on the abundances or identification of the different clay species in the samples despite using several different methods of analysis. Our results also show no correlation between the SWIR spectra and silver concentrations. Further research is required to fully assess the viability of the TerraSpec® 4 Mineral Spectrometer as a tool to use for exploration in the Bulldog Mountain vein system.

**Geochronologic evidence for the timing of precious metals mineralization in the Bessie G Mine, LaPlata Mountains, Colorado.** Sara C. Holden and David A. Gonzales, Department of Geosciences, Fort Lewis College, 1000 Rim Drive, Durango, CO 81301

Precious metals mineralization in the La Plata Mountains is spatially associated with Laramide intrusive rocks emplaced between 75 and 65 Ma. A long-standing assumption was that mineralization was related to Laramide magmatic-hydrothermal processes, but more recently it was proposed that mineralization was linked to regional Oligocene magmatic activity. A lack of geochronologic control on the timing of mineralization made it difficult to test these competing ideas.

Thermochronologic analyses reveal a complex history for the epithermal vein system in the Bessie G mine of the La Plata mining district. $^{40}$Ar/$^{39}$Ar analyses on roscoelite from veins define an early stage of hydrothermal activity marked by cooling below temperatures of 300-400° C at 57.46 ± 0.11 Ma. These data suggest that some of the mineralization was related to the cooling of fluids released by Laramide intrusive rocks. Fission-track analyses on apatite from Laramide intrusive host rocks define a later stage of thermal activity defined by cooling below 130° C at 27.23 ± 0.14 Ma. The cooling ages for roscoelite and apatite thus reveal multiple hydrothermal events at different times and perhaps different peak thermal conditions.

Our data are consistent with rapid heating and cooling in the Bessie G vein system at ~27 Ma which was synchronous with Oligocene magmatic activity throughout the western San Juan Mountains. Late-stage coloradoite + native gold overprint earlier Au-Ag telluride minerals in the Bessie G deposit. The ~57 Ma magmatic-hydrothermal event was related to Au-Ag telluride mineralization which was superceded by the hydrothermal activity at ~27 Ma that likely produced the coloradoite + native gold. Paragenetic and fluid inclusion data from previous studies support this interpretation. These findings offer constraint on the timing of ore deposition and reveal the complex nature of hydrothermal activity and mineralization in the La Plata Mountains.

**Resolution of controversy over the timing of emplacement of the Mt. Sneffels-Stony Mountain stock, Western San Juan Mountains, Colorado.** Kyle A. Lewis and David A. Gonzales, Department of Geosciences, Fort Lewis College, 1000 Rim Drive, Durango, CO 81301

Intermediate to mafic intrusive rocks are exposed in the Mt. Sneffels-Stony Mountain stock in the western San Juan Mountains, Colorado. Debate over the timing of pluton emplacement in previous studies impeded an understanding of how this pluton fit into the regional magmatic history. Detailed field studies revealed that the pluton intruded adjacent Oligocene volcanic rocks of the Southern Rocky Mountain volcanic field. However, a previous K/Ar age of ~32 Ma suggested that the stock was older than the ~28 Ma volcanic rocks. A new U/Pb zircon age determination constrains the emplacement of this stock to ~27 Ma, resolving the previous age contradiction. This U/Pb zircon age indicates that the Mt. Sneffels-Stony Mountain stock is the oldest Oligocene mafic intrusion in the western San Juan Mountains and was emplaced shortly after the formation of multiple calderas from ~28-27 Ma. This temporal and spatial association with major calderas supports the thesis that mantle-derived basaltic magmas were temporally and genetically related to caldera formation.

Isotopic concentrations of $^{87}$Sr/$^{86}$Sr (0.7059) and $\varepsilon_{Nd}$ (-6.2) are consistent with existing data which suggest that the Mt. Sneffels-Stony Mountain stock was derived from lithospheric mantle melts that interacted with the lower crust. This also supports previously proposed tectonic-magmatic models for magma production of the Southern Rocky Mountain volcanic field during the Oligocene. Continued isotopic and geochronological study of intrusive and extrusive rocks of the region will further constrain the origins of voluminous volcanism in this intracontinental setting, a topic of current petrologic debate.

**New insights into the history of the Chicago Basin stock from U/Pb zircon age constraints, Needle Mountains, Southwestern Colorado**. Nora J. Dwer and David A. Gonzales, Department of Geosciences, Fort Lewis College, 1000 Rim Drive, Durango, CO 81301

The Chicago Basin stock (CBS) is a porphyritic granite hosted by Mesoproterozoic granite in the Needle Mountains of southwestern Colorado. Previous studies have interpreted the timing of emplacement as Oligocene or Miocene, and have documented extensive molybdenite mineralization in this stock.

New U/Pb analyses on zircons from a sample at the core of the CBS reveal three zircon populations. Some of the crystals analyzed are ~1.4 Ga xenocrystic zircons contributed by melting and incorporation of the adjacent Eolus Granite. The most abundant fraction of zircons yielded an age 28.09 ± 0.36 Ma, while a smaller population defined an age of 9.1 ± 0.5 Ma. No distinct core to rim variations were determined in any of the zircons. The ~28 Ma emplacement corresponds to widespread regional magmatism and volcanism from 28-27 Ma related to caldera eruptions. The ~9 Ma population of zircons is similar in age to fission-track zircon age previously recorded in the CBS. The Miocene zircons correspond to emplacement of small volume granitic stocks across the western San Juan Mountains some of which are also related to molybdenite mineralization. These data imply that the Chicago Basin stock was a site of at least two different events that either involved multiple generations magma emplacement or an Oligocene pluton overprinted by Miocene veins and hydrothermal alteration.

**Climatic paleotemperatures from oxygen and hydrogen isotopes in chert, and petrography of the neoproterozoic Sixtymile Formation: Grand Canyon National Park, AZ.** Ray Kenny, Geosciences Department, Fort Lewis College, Durango, CO 81301,

Twenty-one chert samples from the middle and upper members of the NeoProterozoic Sixtymile Formation (SMF) at Nankoweap Butte in eastern Grand Canyon were analyzed for oxygen and hydrogen isotopic composition. Plotted on a δ18O vs δD diagram, the δ values indicate that chert is non-marine and precipitated at climatic temperatures between 27-33ºC. The δ values are inconsistent with hydrothermal alteration. Hydrothermal isotopic signatures can only occur if hydrothermal fluids later permeate the deposit along fractures; in thin section, silica-filled fractures and veins, interlocking megaquartz (>35µm), and phyllosilicate minerals, are mostly absent. SMF chert contains quartz polymorphs as colloform crusts, detrital grains, glaebular aggregates, and pseudo-brecciated structures displaying great micromorphological complexity. Chert petrography reveals: (1) mosaic, microgranular (<35µm) quartz; (2) minor lath-shaped silicified crystallites; (3) fine polygonal cracks in poorly-ordered silica phases possibly due to dehydration of gel-like deposits; (4) an irregular but repetitive succession of wavy laminae; and, (5) radial and fibrous length-slow (quartzine) and length-fast (chalcedony). The affinity of quartzine to evaporite precursors is well-documented, but definitive evidence of early evaporite progenitors was not found. Alternating chert laminae suggest temperature and geochemical fluctuations typical of shallow continental lakes. Collectively, the micromorphological features and silica mineralogy suggest that SMF chert likely precipitated as inorganic, poorly-ordered silica in response to fluctuating pH and cation concentrations induced by periodic influx of meteoric water. The absence of phyllosilicates suggest that silica might have been introduced by groundwater and/or with some contribution from ash or dust.

The upper member of the post 742Ma SMF has been correlated with the diamictite beds of

the Kingston Peak Formation (CA) placing the SMF in the Sturtian Ice Age (~750-700Ma). In outcrop, no striated clasts or features suggestive of glacial deposition were observed in the breccias of the upper member. The field data along with the new climatic temperatures suggest that chert from the middle member of SMF precipitated in a warm, shallow pan/ lacustrine environment.

**Stable isotopes and speleothem chronology from a high alpine cave, southern San Juan Mountains, CO: Evidence for deglaciation as early as 13.5KA.** Ray Kenny, Geosciences Department, Fort Lewis College, Durango, CO 81301,

An ~11cm tall stalagmite from a shallow, speleothem-poor, high elevation (10,636 ft; 3242 m) cave (near Molas Pass) in the southern San Juan Mountains (SSJM) was sampled for oxygen (O) and carbon (C) isotopes, and U-series dating. Long transects along continuous growth bands were sampled and used to constrain the age of the stalagmite at 13,446±170years. Speleothem growth bands provide irrefutable evidence of liquid water and non-freezing conditions in the shallow subsurface, indicating that the surface above the cave was ice-free at ~13.5ka. Previous studies suggest that the SSJM deglaciated at a rate of ~15m/year, becoming ice-free by ~12.3±1ka. New data from this study suggests that deglaciation likely occurred at an average rate of ~25m/year.

The bulk of the stalagmite (~86%) crystallized between 13,446±170 to 13,284±180, followed by a ~10k year growth hiatus; precipitation resumed ~2.7ka. Mean annual air temperature (MAT) correlates closely with air temperature in shallow caves; studies have shown that shallow caves respond within decades to major atmospheric temperature changes. O isotope variations in drip water are temperature dependent and reflect MAT. No significant variation in average δ18O values was observed between modern and 13.5ka growth bands (-10.0±0.1‰ vs -10.26±0.1‰ VPDB, respectively) suggesting that MATs were similar to modern MATs between 13.25 and 13.5ka. C isotope values principally reflect the C isotopic composition of soil CO2 derived from oxidation of local organic matter and the isotopic composition of the bedrock. δ13C values in the growth bands are notably depleted relative to δ13C values in the host (Hermosa Group) carbonate, hence the δ13C values largely reflect soil CO2 values and not bedrock values. δ13C values in the more recent growth bands are depleted by only ~1.5 ‰ relative to 13.5ka growth bands, suggesting that at least some alpine plant cover and soil cover must have been established at this location and elevation by ~13.5ka. The proxy δ values support the argument that the surface above the cave was ice-free.

The U-series and isotopic data from this study suggest that: (1) the area near Molas Pass was ice-free by ~13.5ka; (2) at least some alpine plant and soil cover had established by ~13.5ka; and, (3) deglaciation rate in the SSJM may have been as rapid as 25m/year.

**OSL dating of fluvial and lacustrine sediment north of Durango, Colorado: A record of an asynchronous glacial advance at 5.5KA?** P.I., Anderson and Ray Kenny, Geosciences Department, Fort Lewis College, 1000 Rim Drive, Durango, CO 81301

New optically stimulated luminescence (OSL) ages were obtained from fine-grained fluvial sediment exposed in a well-preserved outcrop at the southern end of the San Juan Mountains, Durango, Colorado (Z13, 249144mE, 4132617mN; 2098 m). The sedimentary sequence exposed in the ~4 meter high outcrop consists of multiple and repetitive sets of mm-size rhythmite couplets, climbing ripples, planar laminae, and minor, small-scale water escape structures, overlain by a diamicton; the outcrop was previously interpreted as a remnant of the glacial landscape formed during a Bull Lake glacial advance (MIS 5d - 6). Three samples collected along a vertical transect (~0.8 meters apart) yielded preliminary ages of ~50±10ka, 51.61±8.07 ka, and ~65±13ka (MIS 4, early Wisconsin Glaciation, ~55ka). The OSL ages are asynchronous with northern hemisphere glacial maximums. No previous studies have reported significant asynchronous glacial advances as far south as the study area (~37°17' N latitude). Alternative explanations were sought to explain the seemingly anomalous ages, including: (1) OSL bleaching; (2) abandoned meander sequences in the adjacent glacial valley (Animas River); and, (3) deposition from a stream that presently occupies an incised channel and flows ~parallel to the outcrop (Spring Creek).

Sediment deposited in glacial environments is often inadequately bleached, but OSL has been successfully used on glaciofluvial deposits. Insufficient bleaching would yield older ages, which suggests that the sedimentary sequence in this study is not correlative with older Bull Lake glacial deposits. Similarly, a lack of trough cross-bedded sands, mud drapes, lateral accretion surfaces, and fining upward sequences argue against a meander sequence. It is also difficult to explain the process linkage that would yield the change of stream flow direction required for sediment to have been deposited by an entrenched stream that, at present, drains away from the outcrop.

Field evidence from the isolated outcrop was insufficient to definitely determine sediment provenance and glacial origin. Consequently, we remain open to the prospect that this outcrop may represent the first quantitative ages of a significant asynchronous glacial advance in the southern San Juan Mountains.

**Luminescence chronology of a post-Bull Lake glacial deposit in the southern San Juan Mountains: Implications for revisiting the glacial stratigraphy in the Durango, Colorado area.** Candice D. Passehl and Ray Kenny, Geosciences, Fort Lewis College, 1000 Rim Drive, Durango, CO 81301

Optically stimulated luminescence (OSL) was used to constrain the age of a 2.3 meter high, mixed fluvial/aeolian sedimentary sequence deposited on a glacial moraine in the southern San Juan Mountains, Durango, Colorado (37.298747N, 107.876272W; 2078 m). Three OSL ages on fine-grained fluvial sediment from a stratigraphic section yielded preliminary ages of ~62±12ka, ~60±11ka, and ~82±15ka (uppermost to lowermost horizons, respectively). The OSL ages indicate that the sedimentary sequence was deposited during the interval between the last glacial maximum (~19.4ka; MIS 2) and Bull Lake glaciation (~85 to >130ka; MIS 6). Interpretation of the OSL data is complicated because the sedimentary sequence was deposited on a boulder-rich deposit previously interpreted as a pre-Bull Lake glacial moraine (glacial maximum ~250ka; MIS>6); glacio-chronologic correlation of the moraine was based on elevation, incision rates, and terrace sequences. Hypotheses to explain the processes required to deposit a ~60ka sedimentary sequence on top of a ~250ka moraine perched high above the valley floor, included: (1) insufficient OSL bleaching; (2) flawed OSL dates; and, (3) incorrect correlation of the boulder-rich deposit as a pre-Bull Lake moraine. Insufficient OSL bleaching would yield older ages, but it is unrealistic to suggest inherited dates would yield an OSL age ~four times the observed value. A complimentary field study ~4 km across the Animas River valley (Anderson and Kenny, 2005 GSA RM Section Meeting) yielded three OSL dates around 55ka on probable glaciofluvial sediment deposited at a similar elevation of 2098 m. These dates add credence to the OSL ages from this study. Although extensive work has been done on correlating moraines in the Durango area, it remains a possibility that the boulder-rich deposit is younger than pre-Bull Lake. Pierce (2003) also suggested that few terrace sequences can be tied directly to pre-Bull Lake glacial moraines without adequate age control on one or more terraces. Based on the new, preliminary OSL dates, we tentatively suggest that the boulder-rich deposit stratigraphically beneath the sedimentary sequence of this study may be erroneously ascribed as a pre-Bull Lake moraine. Quantitative data from this study indicates that the glacial stratigraphy of the Durango area should be revisited.

**Preliminary rock varnish exposure ages on pediment boulders from the Henry Mountains, Utah: Implications for pediment formation processes.** Ray Kenny[1], Tanzhuo Liu[2] and, David Canova[1], (1) Geosciences, Fort Lewis College, 1000 Rim Drive, Durango, CO 81301, (2)VML Dating Lab, 560 Riverside 2G, New York, NY 10027

Here we report the first rock varnish exposure ages on boulders from two pediment surfaces adjacent to the Henry Mountains (~38.1° N latitude). Rock varnish is a slowly accreting, Mn - and Fe-rich surface coating precipitated in microstratigraphic layers on subaerially exposed surfaces. Varnish microlamination compositional differences are principally influenced by regional climate conditions. Pediments are gravel-covered, gently-sloping, low-relief planation surfaces incised into bedrock; their processes and formation have been a source of debate for more than a century. In the Henry Mountains region, ten discrete, dissected pediment levels (L0-L9; oldest to youngest) have been previously mapped. Varnish microlamination (VML) dating was conducted on pediment level L6 (northeast of Mt. Hillers; UTM: Z17, -2124969mE, 4640124mN) and pediment level L8 (west of Mt. Ellsworth; UTM: Z17, -2137380mE, 4618798mN). VML exposure ages were derived using the varnish microlamination record for the western USA. An age of ~157 ka was obtained for pediment L6. This date correlates to wet period (WP) 11 in layering unit (LU)-6, which is correlative with MIS-6 (Late Illinoian Stage or Bull Lake Glaciation). An age of ~105 ka was obtained for pediment L8, which corresponds to LU-5 (WP8) and is coeval with MIS-5d (a cooler, wetter MIS-5 interval). Microlamination layers precipitated during periods of wet climate are black on ultra-thin sections under transmitted light microscope and Mn and Ba achieve their highest concentrations in these dark layers. Microlamination stratigraphy and mineralogy indicate that gravel emplacement/pediment formation occurred during periods of cold and wet climate wherein enhanced moisture levels may have promoted gravel transport. The Henry Mountains were not glaciated, but patterned ground and other periglacial features in the highest elevations correspondingly indicate that the region was impacted by episodes of cold and wet climate. Our aim is to contribute a better understanding of pediment formation and determine whether pediments are shaped by brief, high-energy, fluvial flow regimes during wet climatic events. Additional VML ages (forthcoming) are needed to determine whether all pediments in the Henry Mountains region formed in a similar fashion

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**Application of Noble Gas Isotopic Signatures at McElmo Dome-DOE Canyon to Investigate CO2 Source and System Characterization.** J.G. Adams, D. Gonzales and T. Darrah.

The McElmo Dome-DOE Canyon field in the Four Corners region is one of the largest sources of CO2 in the Rocky Mountain region. In prior studies, hypotheses in favor of CO2 generation by thermal in situ decomposition of carbonate-sulfate assemblages in the Leadville Limestone or magmatic-gas release were proposed. The fundamental source of the gases, however, remained poorly understood. In this investigation, noble gas isotope signatures were used in an attempt to fingerprint the source of the CO2 gas and test competing hypotheses on its origin, migration, and evolution. Analyses of noble gas isotopes, stable isotopes, and major gas compositions across the McElmo-DOE field reveal variable and mixed mantle-crust signatures which are dominated by the addition of radiogenic crustal signatures (4He, 21Ne, 40Ar). A comparison of CO2/3He against CO2 concentrations are consistent with a magmatic 3He source that mixed with crustal contributions. The crustal contributions are indicated by helium isotope ratios 3He/4He (where the ratio of RAIR=1) from 0.057 to 0.215 (R/Ra), nucleogenic (following U and Th decay) 20Ne/22Ne (<8.5), 21Ne/22Ne (>0.10), and highly elevated radiogenic Ar with 40Ar/36Ar* >15,000. Our preliminary data suggests that CO2 gas was likely sourced from Cenozoic magmatic activity in the region that filled Leadville Formation traps at the time of magmatism. Magmatic events spanned the period from 75-5 Ma and involved melting of Proterozoic lithospheric mantle which was a key source of carbonated mantle melts in the Oligocene. Mafic rocks generated from these melts have elevated K, U, Th and F, and these magmas could have been a major source of the exceptionally high nucleogenic (21Ne, 22Ne) and radiogenic (4He,40Ar) signatures of noble gases in the McElmo Dome and Doe Canyon CO2 fields.