

The University of Arizona
Department of Geosciences

PRESENTS

GEODAZE 2009

Program & Abstracts

The 37th Annual Geosciences Symposium
April 2-4, 2009 - Tucson, Az



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Cover Photo (by Dr. Antoine Vernon): Polygonal salt flat in the Salar Grande, northern Chile.

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Co-Chairs' Welcome

We are delighted to welcome you to GeoDaze 2009, the 37th annual Geosciences Symposium at the University of Arizona! GeoDaze is run by the graduate students in the Department of Geosciences and is funded by the generosity of private and institutional donors. GeoDaze provides students with an excellent opportunity to share their research with a broad audience and receive feedback from faculty and their peers, as well as industry and government representatives.

This year's symposium features over 70 presentations showcasing the diverse research interests of the graduate and undergraduate students at the University of Arizona. We are proud that this year's program includes participants from Hydrology and Water Resources, Physics, the Laboratory of Tree Ring Research, Mining and Geological Engineering, Arid Lands Resource Sciences, Anthropology and Planetary Sciences, as well as Geosciences! Student presentations cover a wide range of topics, from geophysics and economic geology to environmental science. This year, two poster sessions complement nine oral sessions.

We would like to extend a warm welcome to Dr. John Smol, this year's keynote speaker. Dr. Smol is a professor in the Department of Biology at Queen's University in Kingston, Ontario, who uses paleolimnology to study links between aquatic and terrestrial systems, in the context of environmental and climate change. Don't miss Dr. Smol's talk, *From Controversy to Consensus: Making the Case for Recent Climatic Change in the Arctic Using Lake Sediments*, at 3:15 PM on Friday, April 3rd.

Following Dr. Smol's talk, we will announce the student awards and, of course, view the (in)famous annual GeoDaze slide show. Please plan to attend the GeoDaze party, at 7:00 PM on Friday evening at the Tucson Botanical Gardens. On Saturday morning, join Dr. Jon Pelletier for a field trip exploring the geomorphology of the Tucson basin and Santa Catalina forerange.

GeoDaze is an important tradition for our department. We've made some changes this year, which we hope will allow the conference to remain vital and sustainable. This has required more effort, and we would like to thank everyone who has contributed to making it a success. GeoDaze would not be possible without the hard work and dedication of Geosciences students, faculty and staff. Generous financial support from alumni, friends, and corporate sponsors, especially in light of the current economic climate, has made this symposium possible. We are honored to be part of a wonderful community of people who engage in and support geoscience research. Thanks so much for attending this year's GeoDaze symposium. We hope to see you in the years to come!

Christian Manthei & Stephanie McAfee
Co-Chairs, 2009 GeoDaze Symposium

Schedule of Events

Thursday April 2, 2009

8:00 Refreshments

8:15 Welcoming remarks

Karl Flessa

Session I: Geophysics and Geodesy

8:30 Eastern Extent of Pacific-North America Plate Boundary Deformation in the Southwestern U.S. Observed by GPS

A. Holland

8:45 Seismic Interpretation and Structural Analysis Along a Transect from the Baboquivari Mountains to the Transition Zone of the Colorado Plateau

M.S. Arca

9:00 Detecting the Limit of Slab Break-Off in Central Turkey: New High-Resolution Pn Tomography Results

C.R. Gans

9:15 Seismic Evidence for Foundering Lithosphere Beneath the Central Sierra Nevada

A. Frassetto

9:30 Parabolic Dune Reactivation and Migration at Napeague, NY, U.S.A.: Insights from Aerial and GPR Imagery

J.D. Girardi

9:45 Modeling Surface Displacement Caused by Sub-Crustal Loading

K. Gressett

10:00 BREAK

Session II: Planetary Geology

10:15 Modeling of Titan's Surface Processes Constrained by Shoreline Fractal Analysis

P. Sharma

10:30 ¹⁴C Terrestrial Ages of Meteorites from the Atacama Desert, Chile

M. Leclerc

10:45 Volatile Element Composition of Minerals in Meteorites

K. Jackson

11:00 BREAK

Session III: Mineralogy

11:15 Raman Spectra Analysis of Gem Minerals
R. Jasinevicius

11:30 Determining Chemical Composition of the Silicate Garnets Using Raman Spectroscopy
R.R. Henderson

11:45 The Adsorption of Aspartic Acid onto Rutile: Implications for Biochirality
C.F. Estrada

12:00 Announcements and Field Trip Information Session

12:15 LUNCH

1:15 - 2:30 Session IV: Environmental Science, Surface Processes and Geoscience Education Posters

Spreading Roots: The Goals and Challenges of Establishing a Self-Sustaining Diversity Program in Southern Arizona
P.J. Stokes

Roots in the Rock: An Application of Herbchronology Above Treeline at Barney Rock Glacier, Sierra Nevada, California, U.S.A.
R.S. Franklin

Variable Oceanic Teleconnections to Western North American Drought over the Last 1200 Years
J.L. Conroy

The Changing Character of Phenology, Drought, and the Seasons in the Southwestern U.S.A.
J.L. Weiss

Fractional Snow Cover Estimation in Complex Alpine-Forested Environments Using Ikonos/QuickBird, Landsat and MODIS
E.H. Czyzowska

Concentration Changes of Nutrients, Trace Metals, and Labile Organic Matter Due to Pleistocene Recharge and Dilution of Illinois Basin Brines
M.E. Schlegel

A Multi-Tracer Approach to Determine the Impacts of Agricultural Irrigation Recharge on Groundwater Sustainability in the Saddle Mountains Basalt Aquifer, Central Washington, U.S.A.

K. Brown

Interpreting Molluscan Marine Reservoir Ages in a Variable Upwelling Environment

K.B. Jones

Ecological Indicators of Climate Change in the Pantanal Region of Western Brazil

C.M. Landowski

Correlations and Chronology of High Arctic Lakes Based on Magnetic Properties

E. Mortazavi

Aspects of Modern Lacustrine Sedimentation in the Central Andean Foreland:
Preliminary Results

M.M. McGlue

South American Pluvial Lakes: Implications for Quaternary Climate Change

A. Cartwright

Expansion and Contraction of Pleistocene and Holocene Lakes in the Southern Basin and Range Province, U.S.A.: Paleoclimatic Implications

A. Kowler

Palominas Arroyo: An 11.1 kBP Alluvial Record from the San Pedro River, Southeastern Arizona

J.A.M. Ballenger

Geomorphic Evolution of an Earth Fissure: The Roger's Fissure, West-Central Arizona

M. Leclerc

The Exploration of Alluvial Fan Exposures and Recent Fire-Related Geomorphic Responses in Bariloche, Argentina

E. Bigio

Session V: Paleoclimate

2:30 Temperature Estimate for an Early Pliocene Polar Forest, Ellesmere Island, Canada, from $\delta^{18}\text{O}$ Ratios of Freshwater Mollusks and Aquatic Moss

A.Z. Csank

2:45 Vegetation and Climate of Lake Malawi, Southeast Africa During the Last Deglaciation

S. Ivory

3:00 Fingerprinting Southwestern Climate Dynamics During Medieval Time
C. Routson

3:15 Coral Mn/Ca Data from Tarawa Atoll Suggest a Strengthening of the Tropical Pacific Zonal Winds over the 20th Century
D. Thompson

3:30 BREAK

Session VI: Economic Geology

3:45 Jurassic Igneous-Related Metallogeny in the Cordillera of Southwestern North America: Implications for Iron Oxide Deposits
J.D. Girardi

4:00 Hydrothermal Alteration and Mineralization Zoning in Iron-Oxide(-Cu-Au) (IOCG) Vein Deposits near Copiapó, Chile
D.C. Kreiner

4:15 Mineralization Controls at Chailhauagon-Perol Porphyry (Au±Cu) Systems – Minas Conga District – Cajamarca Province, Peru
N. Mendoza Inca

4:30 Characterization and Reconstruction of the North Butte Dike Swarm and Tea Cup Porphyry System, Pinal County, Arizona
P. Nickerson

4:45 Mining Stability and Earthquake Precursor Detection
K.B. Jones II

5:00 Closing Remarks

Association of Environmental and Engineering Geologists Student Night

University of Arizona Student Union Memorial Center,
Catalina and Tucson Meeting Rooms

- 5:30 – 7:00 Career Fair and Mingling
- 7:00 – 7:45 Dinner (RSVP required)
- 7:45 – 8:45 Student Presentations
- 8:45 – 9:00 Award Presentations

Association of Environmental and Engineering Geologists, Arizona Section
& Arizona Hydrological Society, Phoenix and Tucson Chapters

Friday April 3, 2009

8:00 Refreshments

8:15 Welcome and Announcements

Session VII: Climate

8:30 Regionalization of Tibetan Plateau Precipitation

J.L. Conroy

8:45 Mountain Simulation and Winter Precipitation Errors in IPCC AR4 Models

S.A. McAfee

9:00 A Continuum of Drought: Linking Late Holocene Megadroughts to 20th Century Variability

T.R. Ault

9:15 Seasonal Effects of Warming Temperatures During Drought in the Southwestern U.S.A.

J.L. Weiss

9:30 BREAK

Session VIII: Environmental Science

9:45 Alpine Shrub-Chronology: A Tool for High-Elevation Ecological Monitoring

R.S. Franklin

10:00 Quantifying the Effect of Hydrologic Variability on Sediment Transport in Alluvial Rivers

T. Engelder

10:15 The Progression of Precipitation: A Model of Oxygen Isotope Variability in Caves of the Southwest

S.A. Truebe

10:30 BREAK

Session IX: Geochronology

10:45 Using Detrital Zircon Geochronology to Constrain the Ages of Hominid Fossils from Gona, Ethiopia

L. Molofsky

11:00 U-Pb LAM-ICP-MS Zircon Geochronology from Permo-Triassic S-Type Plutons and High-Grade Metamorphic Rocks of the Northern Colombian Andes: Collisional vs. Accretionary Orogenesis in the Proto-Andean Margin

M. Ibanez-Mejia

11:15 Determining the Origin of Enigmatic Bedrock Structures Using (U-Th)/He Thermochronology: Alabama and Poverty Hills, Owens Valley, California

G. Ali

11:30 Cenozoic Exhumation of the Western Antarctic Peninsula: Thermochronologic Results from Northern and Southern Graham Land

W.R. Guenther

11:45 LUNCH

12:45 - 2:00 Session X: Geochemistry, Geochronology, Geophysics, Structure and Tectonics Posters

The Structure Determination of the High-Pressure Analog of Behoite, $\text{Be}(\text{OH})_2$

M.C. Barkley

The Determination and Categorization of Hydrogen Environments in Nominally Hydrous Minerals

M.C. Barkley

Sedimentology, Detrital Zircon Geochronology, and Stable Isotope Palealtimetry of the Early Eocene Wind River Basin, Central Wyoming

M. Fan

U-Pb Ages from Zircons in Sandstones from the Grand Canyon to Determine Source Provinces

R. Koons

U-Pb Geochronology from Santander Massif, Northern Colombia

M. McMillan

Low-Temperature Thermochronology of the Rocky Mountains, Wyoming and Montana

S.L. Peyton

Seismic Investigation of Higley Basin, Central Arizona

M. Warren

Investigation of the San Andreas Fault: GPS Monitoring from San Gorgonio Peak and San Jacinto Peak

A. McCallister

Naf Experiment: Seismic Anisotropy Beneath Northern Anatolia from Shear-Wave Splitting

C.B. Biryol

Crustal Deformation in the Tucson Area Using GPS

J. Ninneman

A Geomorphic Map of Hale Crater, Mars

A.J. Philippoff

Present-Day Loading Rate of Southern San Andreas and Eastern California Shear Zone Faults from GPS

J. Spinler

Slip Rate Estimates for the Garlock Fault Based on Geodetic Surveys

C. King

Metamorphic Rocks in Central Tibet: Lateral Variations and Implications for Crustal Structure

A. Pullen

Cretaceous-Tertiary Geology of Central Tibet and Implications for Plateau Formation: A Synthesis

J. Volkmer

Cordilleran Fold-Thrust Belt and Foreland Basin System of Northwestern Montana

F. Fuentes

Crustal Anisotropy in Southern California: Evidence for Tectonic Underplating?

R. Porter

Lithospheric Structure of the Central North Anatolia from S-Wave Receiver Function Analysis

H.E. Tok

Structure of the South End of the Crawford Thrust, Sevier Thrust Belt, Utah

S.L. Peyton

Timing of Uplift Along the Western Edge of the Central Andes, Northern Chile

K. Umlauf

Session XI: Geochemistry and Volcanology

- 2:00 Tracing Turquoise from Site to Source Using Radiogenic Isotopes
A.M. Thibodeau
- 2:15 Recent Transition in Regional Mantle Chemistry Beneath the Western Canadian Cordillera
C.D. Manthei
- 2:30 ¹²⁹I and Sr Isotopes as Tracers of Large-Scale Fluid Migration in the Northern Appalachian Basin
S.G. Osborn
- 2:45 GIS Applied to Flow Direction and Source Area of the 22.0 Ma Harmony Hills Tuff, Southwestern Utah, Southeastern Nevada
A.M. Hudson
- 3:00 BREAK
- 3:15 **Keynote Speaker: Dr. John Smol, Queen's University**
From Controversy to Consensus: Making the Case for Recent Climatic Change in the Arctic Using Lake Sediments
- 4:15 Awards
- 4:45 Slideshow
- 5:00 Closing Remarks
- 7:00 Party at the Tucson Botanical Gardens

Saturday, April 4, 2009

GeoDaze Field Trip

Geomorphology of the Tucson Basin and Santa Catalina Forerange

- 7:45am Meet at Gould-Simpson loading dock
- 8:00am Vans leave from loading dock
- 4:30pm Vans return to loading dock

Field Trip Guide

Sponsored by a generous donation from ConocoPhillips

Title: Geomorphology of the Tucson Basin and Santa Catalina Forerange

Leader: Professor Jon Pelletier

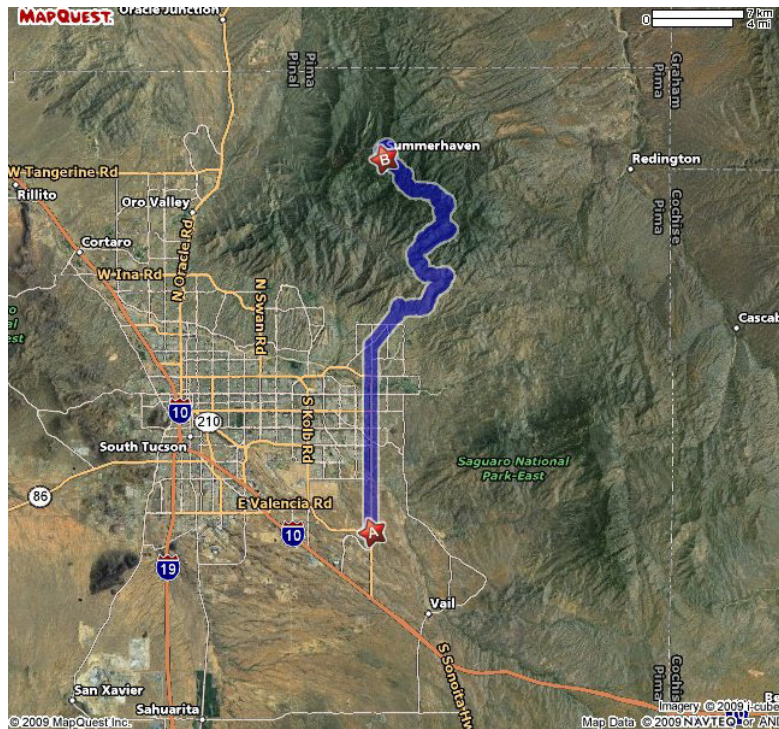
Pre-trip Info Session: 12:00PM Thursday, April 2

Registration Deadline: 5:00PM Thursday, April 2!!

Field Trip: 8:00AM – 4:30PM, Saturday, April 4. Leaving from the Gould-Simpson loading dock. Meet at 7:45AM. Box lunch provided. Participants should bring ample sunscreen and water.

Description: This trip will be a geomorphic transect from the floor of the Tucson Basin to the upper elevations of the Catalina Mountains. We will examine discontinuous ephemeral streams on the basin floor, fill terraces, debris-flow hazards, and pediments along the Catalina Mountain front, structurally-controlled knickpoints in the bedrock channels of the Catalina Mountains, and the effects of fire on hillslope processes near Summerhaven.

Access: One stop will require sliding under a barbwire fence, but all other outcrops are easily accessible with walking distance less than a quarter mile.



EASTERN EXTENT OF PACIFIC-NORTH AMERICA PLATE BOUNDARY DEFORMATION IN THE
SOUTHWESTERN U.S. OBSERVED BY GPS

Austin Holland and Richard Bennett

Department of Geosciences, University of Arizona

We determined a regional strain field for the Colorado Plateau and surrounding region from GPS velocities. There is a distinct extensional strain component concentrated along the western and southern boundary of the plateau. While the number of continuous GPS stations in Arizona and surrounding regions are growing the station spacing is generally quite large, and many of these sites have short observation histories. In order to compensate for these problems, we conducted campaign measurements of benchmarks in Arizona that had been previously measured by the National Geodetic Survey (NGS). The previous GPS measurements conducted by the NGS were part of the Federal Base Network (FBN) and consist of several separate observations in 1998 and 1999. These observations generally consisted of four to five hour observation periods. Some of these FBN benchmarks were re-observed in 2008 with longer observation periods. The data were analyzed using GAMIT/GLOBK version 10.3 to obtain velocities for these and the continuous sites operating in the region. The strain field obtained from GPS velocities indicates that there is primarily east-west oriented extension. The strain field in the Southwestern U.S. clearly demonstrates an influence from both the Pacific-North America plate boundary and the high potential energy areas within the region.

SEISMIC INTERPRETATION AND STRUCTURAL ANALYSIS ALONG A TRANSECT FROM THE
BABOQUIVARI MOUNTAINS TO THE TRANSITION ZONE OF THE COLORADO PLATEAU

M. Serkan Arca

Department of Geosciences, University of Arizona

Reprocessing and interpretation of a regional suite of industry 2-D seismic reflection profiles along a transect from SW to NE across highly extended terranes in southeastern Arizona illuminate subsurface structures related to Cenozoic crustal extension. From southwest to northeast, major tectonic/structural elements crossed by the transect include the Baboquivari Mountains, Altar Valley, Tucson Mountains, Tucson basin, Catalina core complex, San Pedro trough, Galiuro Mountains, Sulphur-Springs Valley, Pinaleno Mountains, and the Safford Basin. Crustal thickness along the transect revealed through earthquake receiver-function analyses and from seismic reflection profiles varies between ~27 and 31 km implying that the Moho in the region is relatively flat.

A new digital compilation of geological data along the transect, coupled with discontinuous reflection profiles and well control, indicate that the Altar Valley fault, Catalina detachment fault, the bounding normal faults of the Galiuro Mountains, and the detachment fault beneath the Safford basin, probably merge with a broad zone of mid-crustal deformation, and represent related aspects of regional extensional events in the middle-Tertiary. These faults were responsible, in part, for core complex exhumation.

A major thrust of this analysis is to test a possible alternative kinematic model for mid-Tertiary extension as compared to “traditional” models of core complex development. Geological and seismological data indicate that viable alternative models explain observations at least as well as the traditional models. Our model suggests that the southwest and northeast dipping normal fault system on the flanks of Galiuro Mountains may not be the breakaway faults for the Catalina and Pinaleno detachment systems; in fact, the breakaway zones for these systems likely have been eroded. Moreover, our kinematic model suggests that major shear zones from the southwestern and northeastern parts of the core-complexes apparently dive beneath the Galiuro Mountains. Since relatively little upper crustal extension is evident at the surface in the Galiuro Mountains, extension beneath the Galiuro Mountains may be accommodated by a middle crustal shear zone with differential movement above and below.

DETECTING THE LIMIT OF SLAB BREAK-OFF IN CENTRAL TURKEY:
NEW HIGH-RESOLUTION *Pn* TOMOGRAPHY RESULTS

Christine R. Gans¹, Susan L. Beck¹, George Zandt¹, C. Berk Biryol¹, and A. Arda Ozacar²

¹ *Department of Geosciences, University of Arizona*

² *Department of Geological Engineering, Middle East Technical University, Ankara, Turkey*

Inversion of *Pn* travel time residuals from a 39-station broadband array provides a high-resolution image of the velocity structure in the uppermost mantle beneath central Turkey. Individually picked *Pn* phase arrivals from events recorded by the North Anatolian Fault Passive Seismic Experiment and the Kandilli Observatory were combined with additional events associated with the Eastern Turkey Seismic Experiment. Tomography results show no change in *Pn* velocity across the North Anatolian Fault, although longitudinal variations are evident. This surprising lack of across-strike variation implies a possible decoupling of the crust from the mantle. Also, a region of very low *Pn* velocities (<7.8 km/s) is imaged east of the Central Anatolian Fault Zone (CAFZ), with a transition to faster velocities (>8.1 km/s) west of the fault. The sharp transition along the CAFZ, which follows the paleotectonic Inner Tauride Suture, may represent the location of the slab rupture edge, where the oceanic slab broke off around 11 Ma.

SEISMIC EVIDENCE FOR FOUNDERING LITHOSPHERE
BENEATH THE CENTRAL SIERRA NEVADA

Andy Frassetto¹, Hersh Gilbert², George Zandt¹, Tom Owens³, and Craig Jones⁴

¹Department of Geosciences, University of Arizona

²Department of Earth and Atmospheric Sciences, Purdue University

³Department of Geological Sciences, University of South Carolina

⁴Department of Geological Sciences, University of Colorado

Recent geophysical studies of the Southern Sierra Nevada suggest that the removal of a gravitationally unstable, eclogitic residue links to recent volcanism, extension, and uplift in the Eastern Sierra. The Sierra Nevada EarthScope Project (SNEP) investigates the extent of this process beneath Central and Northern Sierra Nevada. We present receiver functions, which provide estimates of crustal thickness and Vp/Vs and image the response of the crust and upper mantle to lithospheric removal. For completeness this study combines data from the 2005-2007 SNEP broadband experiment, EarthScope's BigFoot Array, regional backbone stations, and earlier PASSCAL deployments.

We analyze transects of teleseismic receiver functions generated using a common-conversion-point stacking algorithm. These identify a narrow, "bright" conversion from the Moho at depths of ~30-35 km along the crest of the Eastern Sierra and adjacent Basin and Range northward to the Cascade Arc. Trade-off analysis using the primary conversion and reverberations shows a high Vp/Vs (~1.8) throughout the Eastern Sierra, which may relate to partial melt present in the lower crust. To the west the crust-mantle boundary vanishes beneath the western foothills. However, low frequency receiver functions do image the crust-mantle boundary exceeding 50 km depth along the foothills to the west and south of Yosemite National Park. Unusually deep, intraplate earthquakes occur in the center of this region. The frequency dependence of the Moho conversion implies a gradational increase from crust to mantle wavespeeds over a significant depth interval. The transition from a sharp to gradational Moho probably relates to the change from a delaminated granitic crust to crust with an intact, dense, eclogitic residue. The spatial correlation and focal mechanisms of the deep earthquakes suggest that a segment of this still intact residue is currently delaminating.

PARABOLIC DUNE REACTIVATION AND MIGRATION AT NAPEAGUE, NY, U.S.A.:
INSIGHTS FROM AERIAL AND GPR IMAGERY

James D. Girardi

Department of Geosciences, University of Arizona

Observations from mapping since the 19th century and aerial imagery since 1930 have been used to study changes in the aeolian geomorphology of coastal parabolic dunes over the last ~160 years in the Walking Dune Field, Napeague, NY. The five large parabolic dunes of the Walking Dune Field have all migrated across, or are presently interacting with, a variably forested area that has affected their migration, stabilization and morphology. This study has concentrated on a dune with a particularly complex history of stabilization, reactivation, and migration. We have correlated that dune's surface evolution as revealed by aerial imagery with its internal structures imaged using 200 MHz and 500 MHz Ground Penetrating Radar (GPR) surveys. Both 2D (transect) and high resolution 3D GPR imagery image downwind dipping bedding planes which can be grouped by apparent dip angle into several discrete packages of beds that reflect distinct decadal-scale episodes of dune reactivation and growth.

From aerial and high resolution GPR imagery, a unique mode of reactivation and migration linked to upwind dune formation and parabolic dune interactions with forest trees is documented. This study reveals how blowout deposition can alternate on a decadal scale between opposite sides of a parabolic dune during reactivation and migration. The pattern of recent parabolic dune reactivation and migration in the Walking Dune Field appears to be somewhat more complex, and perhaps more sensitive to subtle environmental pressures, than an idealized growth model with uniform deposition and purely on-axis migration. This pattern, believed to be prevalent among other parabolic dunes in the Walking Dune Field, may occur also in many other places where such observational constraints are unavailable.

MODELING SURFACE DISPLACEMENT CAUSED BY SUB-CRUSTAL LOADING

Katrina Gressett^{1,2} and Rick Bennett¹

¹*Department of Geosciences, University of Arizona*

²*Global Oscillation Network Group, National Solar Observatory*

Topographic subsidence associated with mantle convection has been discussed widely in geodynamics and tectonics (Saleeby, 2004; Morgan, 1965; Zandt, 2004). Convection can be broken into two categories: large scale tectonics and small scale Rayleigh-Taylor instabilities (Saleeby, 2004). Rayleigh-Taylor instabilities are formed when a localized density and temperature contrast form in the mantle (Saleeby, 2004; Zandt, 2004). The higher density of the instability causes it to sink through the mantle until the density contrast is resolved. This viscous movement creates a bottom load on the lithosphere above it causing surface deformation in the form of plate flexure (Morgan, 1965; Saleeby, 2004). While plate flexure has long been a subject of study, most focus on the total displacement caused by flexure and not the rate at which it takes place. New geodetic techniques make it possible to measure the rate of deformation caused by crustal loading. We have developed models to determine the deformation rate of a free surface above a mantle drip. We compare these models to the vertical GPS rates measured over the Isabella Seismic Anomaly in the Central Valley and southern Sierra Nevada regions of California. Our comparison clearly shows that vertical rate GPS is a viable means to resolve the effects of sub-crustal loads.

MODELING OF TITAN'S SURFACE PROCESSES CONSTRAINED BY
SHORELINE FRACTAL ANALYSIS

Priyanka Sharma and Shane Byrne

Department of Planetary Sciences, University of Arizona

The Radio Detection and Ranging (RADAR) instrument onboard NASA's Cassini spacecraft recently discovered hydrocarbon lakes at the North Pole of Saturn's largest moon, Titan.

A statistical analysis of these lakes' shorelines at the North Pole can be used to characterize Titan's topography, as the complexity of a shoreline can be related to the complexity of the surface in which it is embedded through fractal theory. The topographic information thus gleaned can be used to constrain landscape evolution modeling to infer the dominant surface processes that sculpt the landscape of Titan.

We are utilizing Cassini synthetic aperture RADAR observations for this study. Our preliminary results indicate Titan's coastlines do exhibit fractal properties with fractal dimensions comparable to published estimates of the terrestrial coastlines of Britain and Germany at length scales of (1-10) km. Such high values of this roughness parameter show that Titanian coastlines are intricate by terrestrial standards, which implies a rugged landscape. We found some of the lakes' coastlines to exhibit multi-fractal behavior, (different fractal dimensions at different scales) which we interpret to signify a transition from one dominant surface process to another. A steady increase in the fractal dimension with increasing latitude is also observed. We have also examined the data for evidence of anisotropic topography; however, we have found no such evidence to date.

¹⁴C TERRESTRIAL AGES OF METEORITES FROM THE ATACAMA DESERT, CHILE

Marlene Leclerc¹, E. Millarca Valenzuela², and A. Timothy Jull¹

¹*Department of Geosciences and NSF-AMS Laboratory, University of Arizona*

²*Departamiento de Geología, Universidad de Chile*

The terrestrial age of a meteorite is the time elapsed since the meteorite fell on Earth. It is an important parameter in understanding the current degree of weathering and compositional changes in a desert meteorite. Substantial numbers of meteorites are found in arid environments and can survive for at least 50,000 yr. A few meteorites of much older age have been reported from Arabia and there are some meteorites over 250,000 yr old from these locations. We will discuss how the terrestrial ages using ¹⁴C dating are measured at the NSF-AMS Laboratory.

The Atacama is a hyperarid area located in Chile between the Andes and the Pacific Ocean, and has the lowest rainfall records, some as little as 1mm/yr. We have applied ¹⁴C measurements to the terrestrial-age distribution of Atacama Desert meteorites. The terrestrial ages measured span a range from recent falls to >35kyr. The age distribution for the Atacama Desert appears to define a modified simple exponential decay process, as has been discussed earlier. We will compare the age distributions with those of other sites such as Arabia, Western Australia and North American deserts. We will also discuss how measurements from a large Chilean meteorite, Vaca Muerta, and from observed meteorites fall enable to study the rates of ¹⁴C production in Space.

VOLATILE ELEMENT COMPOSITIONS OF MINERALS IN METEORITES

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In the primordial soup of our solar nebula, all the elements that created our solar system existed. As the material cooled, it condensed and accreted into asteroids and planets. Large bodies underwent differentiation, but many asteroids and meteors have remained relatively pristine. When parts of these rocks are delivered to our planet's surface, we jump at the chance to analyze them and explore these remnants of the early solar system. One intriguing aspect of these meteorites is the volatile element distribution among various mineral phases. Elements are considered volatile when they have low condensation temperatures. Rocks that formed in the lower temperature region of the solar system have higher abundances of volatile elements. For example, CI chondrites are the meteorite types with the highest abundance of volatile elements and are thought to have formed in the cooler, outer portion of the solar nebula. Studying the volatile element composition of different types of meteorites helps planetary scientists understand the formation processes of the solar system.

Previous studies have analyzed volatile element composition of bulk meteorites. Our research is designed to look at the distribution of volatile elements (such as selenium, thallium, and germanium) within various components of meteoritic materials. We start by analyzing the composition of specific metal and sulfide minerals within samples of different meteorite types. This is achieved by coupling a laser ablation unit with an inductively coupled plasma mass spectrometer (LA-ICPMS). The laser offers a great advantage of sampling spots as small as 10-20 microns, while the high sensitivity of ICPMS allows for measurement of extremely small concentrations of elements. We are currently working on the lengthy preparation process: mounting and polishing the samples and standards, mapping detailed images of the samples, defining the target spots for laser ablation analysis, and analyzing major element composition of those spots with an electron microprobe. This work will help reveal the conditions under which the different minerals and the meteorites themselves were formed and possibly what sort of processing they later experienced.

RAMAN SPECTRA ANALYSIS OF GEM MINERALS

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Raman spectroscopy, a non-destructive technique used to interpret quantum vibrations, has become a popular tool for the rapid identification of materials. With the advent of numerous gem treatments and a variety of methods available for mineral synthesis, Raman spectroscopy is particularly useful in identifying and characterizing gemstones. Micro-inclusions in minerals can be analyzed using Raman spectroscopy providing evidence of mineral genesis or geologic origin. More recently, fluorescence features attributed to chromophoric ions and trace elements have been observed in Raman spectra, revealing important information about crystal chemistry. Analysis and interpretation of these features may help distinguish between natural, treated, and synthesized materials. Advances in optical technologies have brought hand-held Raman spectrometers to the forefront of materials research. As new instruments are developed, with both increases in portability and decreases in production costs, hand-held Raman units will likely be fundamental to laboratory and field-based Geoscience research in the future. Therefore, the development of databases and interpretation of spectra in anticipation of the new instrumentation is required. We present Raman spectra and associated interpretation of spectral features for the important gemstones.

DETERMINING CHEMICAL COMPOSITION OF THE SILICATE GARNETS
USING RAMAN SPECTROSCOPY

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and Carla Eichler

RRUFF Project, Department of Geoscience, University of Arizona

The silicate garnets are a group of minerals with diverse chemical compositions and multifaceted impacts on the geological sciences. The determination of a silicate garnet's chemical composition is typically done using electron microprobe or mass spectrometry. Both of which are expensive and destructive. Raman spectroscopy has been used in the past century to identify crystalline materials by observing the vibrational modes of atoms.

This project created a technique which correlates the Raman modes of a silicate garnet and its chemical composition. This study utilizes a wide variety of silicate garnets, taken from RRUFF project samples, whose chemistry was determined by electron microprobe, and whose Raman spectra were measured using a Thermo Nicolet Almega microRaman system or an open access custom built Raman spectroscopy unit. Then a correlation matrix was created to compare the shifts of Raman peak position and correlated changes in chemical composition. This approach can characterize silicate garnet samples which fifteen chemical compositional variations using five asymmetric stretching modes. The accuracy of this method can be found to which in 5% of the electron microprobe reported values, and correctly names all varieties of silicate garnet. This will allow scientists in the future to determine chemical composition without destructive methods. Thus advancing the utility of Raman spectroscopy, and making the determination of chemical composition in the silicate garnet group much faster and easier.

THE ADSORPTION OF ASPARTIC ACID ONTO RUTILE: IMPLICATIONS FOR BIOCHIRALITY

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Mineral surfaces may have facilitated the concentration and polymerization of simple biomolecules into macromolecules while promoting the development of biochirality. In this study, rutile and aspartic acid (Asp) were investigated as a possible system in this scenario. Batch adsorption experiments were performed to examine the adsorption of Asp as a function of total concentration and pH. A constant background electrolyte of 0.1 M NaCl was applied to the system, and all solutions were purged with argon gas to eliminate carbon dioxide contamination. Asp adsorbs onto rutile to the highest extent over the pH range 3-5.5 suggesting that an acidic environment is required for the adsorption between Asp and rutile to occur in significant amounts. This pH range of maximum adsorption is constrained between the isoelectric point of Asp and the point of zero charge of rutile, which indicates that electrostatic effects are influencing Asp adsorption. Both the L- and D- enantiomers of Asp were individually adsorbed onto the rutile surface to determine the potential of the system for chiral selection. Preliminary results indicate that D-Asp may possibly adsorb in greater amounts than L-Asp at higher Asp total concentrations. This trend is unexpected as the growth planes dominating the rutile are achiral, and a more thorough study is required to validate this difference in adsorption. Nevertheless, this result may provide insight on the emergence of chiral selection in macromolecules within what might be a predominantly achiral prebiotic system.

SPREADING ROOTS: THE GOALS AND CHALLENGES OF ESTABLISHING A SELF-SUSTAINING DIVERSITY PROGRAM IN SOUTHERN ARIZONA

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Statewide, less than 8% of geosciences undergraduate degrees are awarded to Arizona students from traditionally underrepresented groups. This figure is disproportionate when compared to the ratio of these groups in the state population (approx. 35%). On a related but often overlooked issue, many public colleges and universities struggle to recruit local students from within their surrounding communities. An ideal solution to this conceptually broad issue would incorporate elements from a range of previously funded diversity programs. These successful projects have included broad bases of program participants, networks of support faculty and staff, unique outreach activities, research experiences for participants, and both quantitative and qualitative self-assessment. In order to serve underrepresented groups for the long term, a model program would be organized to self-sustain beyond the lifetime of the initial grant. The proposed project, Southern Arizona Geosciences Union for Academics, Research and Outreach (SAGUARO) would fulfill these goals at the University of Arizona. The challenges of designing such a program will be discussed and constructive feedback will be welcomed.

**ROOTS IN THE ROCKS: AN APPLICATION OF HERBCHRONOLOGY ABOVE TREELINE AT
BARNEY ROCK GLACIER, SIERRA NEVADA, CALIFORNIA, U.S.A.**

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Herbchronology, a technique adapted from dendrochronology, is the study of the annual growth rings in roots of certain perennial dicotyledonous plants. The presence of annual growth increments in plants in alpine and above-treeline environments is significant as it highlights the importance of herbchronology for climatic, ecological and geomorphologic applications in alpine and above-treeline ecology. I am presenting the results from a herbchronology analysis of the plants colonizing Barney Rock Glacier. This site, at 3200 meters elevation on the northeast side of the valley wall, is located below Duck Lake Pass in the eastern Sierra Nevada mountain range. Upon analysis of the secondary root xylem of the shrub *Leptodactylon pungens* (Polemoniaceae), a member of a circumboreal genus, I discovered the presence of annual growth rings that appear to be reflecting a common signal. I am presenting preliminary herb-chronologies for this species based on site aspect around the Barney Lake Rock Glacier. These herb-chronologies are also compared with a *Pinus albicaulis* chronology from the same site and with PRISM climate data from this region. Comparison can potentially determine whether or not annual growth in the root rings of these plants is controlled by regional climate, microclimate, aspect, snow pack or perhaps other factors.

VARIABLE OCEANIC TELECONNECTIONS TO WESTERN NORTH AMERICAN DROUGHT OVER
THE LAST 1200 YEARS

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Cool La Niña conditions in the tropical Pacific often bring drought to western North America on interannual timescales. Recent syntheses of available paleoclimate records suggest that past intervals of persistent, widespread ‘megadrought’ may also result from a cool tropical Pacific, but the strength of such conclusions have been limited by a dearth of appropriate sea surface temperature (SST) records. Here we use a new, continuous record of eastern equatorial Pacific (EEP) SST to explore the context of past megadroughts in western North America. Our results indicate that major episodes of drought occurred when EEP SST was below its 20th century mean, but multidecadal variability in the EEP SST record does not correspond with multidecadal variability in the drought record. In particular, droughts from 850-1050 AD and 1350-1400 AD occurred during periods of relatively warm EEP SST. Reconstructions of North Atlantic SST demonstrate that these droughts co-occurred with North Atlantic warmth, highlighting the potential diversity of controls on drought in western North America.

THE CHANGING CHARACTER OF PHENOLOGY, DROUGHT, AND THE SEASONS IN THE SOUTHWESTERN U.S.A.

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The growing importance of phenological monitoring and modeling in the face of climate change is manifest in ongoing implementation of a U.S.A.-National Phenology Network (NPN) with regional branches. Subtropical and semi-arid regions like the Southwestern U.S.A. (Southwest), where phenophases may be triggered by both temperature and precipitation, arguably present some of the biggest challenges. Not only is the Southwest characterized by high spatiotemporal variability of plant phenology due to a highly seasonal climate and complex terrain, but it is also projected to be a hotspot of future change in climate means and variability. Climate limits on plant phenology are anticipated to change both seasonally and topographically. We examine this hypothesis by comparing seasonal phenological limits based on observed surface climates during the pronounced Southwest droughts of the 1950s and 2000s.

Compared to the 1950s drought, plant phenology during the 2000s drought in the Southwest was: (i) less limited by minimum temperatures in mid-winter at lower elevations, and from mid-spring through mid-autumn at higher elevations throughout much of the region; (ii) more limited by evapotranspirational demand from mid-spring through late summer at lower elevations, particularly across Arizona and Utah; (iii) less limited by overall growing season conditions at higher elevations and, in contrast, more limited at lower elevations from mid-spring through late summer, and less limited in mid-to late autumn and mid-winter at lower elevations.

Results thus support the hypothesis in that during the 2000s drought, the Southwest had seen significant changes in seasonal phenological limits corresponding to warmer winters, longer and hotter growing seasons, and topography. As the terrain strongly influences the distribution of biotic communities in the Southwest, elevational changes in climatic limits on plant phenology may have consequences for regional biogeography, including areas of high diversity at middle elevations.

FRACTIONAL SNOW COVER ESTIMATION IN COMPLEX ALPINE-FORESTED ENVIRONMENTS
USING IKONOS/QUICKBIRD, LANDSAT AND MODIS

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There is an undisputed need to increase the accuracy of fractional snow cover (FSC) estimation in regions of complex terrain, especially in areas dependent on winter snow accumulation for a substantial portion of their water supply, as in western United States. Observed snow cover extent (SCE) in alpine/forested environments exhibits high sensitivity to variations in climate and water cycle changes. The aim of this research is to develop FSC using a fusion methodology between remotely sensed data at the highest available temporal resolution (daily images; MODIS) and the highest available spatial resolutions (30, 4 and 1 m; Landsat, Ikonos/QuickBird). An Artificial Neural Network (ANN) is used to capture the multi-scaled information structure of the data by means of the ANN training process.

**CONCENTRATION CHANGES OF NUTRIENTS, TRACE METALS, AND LABILE ORGANIC MATTER
DUE TO PLEISTOCENE RECHARGE AND DILUTION OF ILLINOIS BASIN BRINES**

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Economic accumulations of biogenic gas in the deep subsurface have recently been recognized as an unconventional semi-renewable energy source. Methane is generated as microbes reduce carbon dioxide and ferment organic acids (primarily acetate) sourced from organic-rich substrates, such as the Upper Devonian New Albany Shale (~1500m deep) and Pennsylvanian coalbeds (~100m deep) in the Illinois Basin. The occurrence of biogenic methane seems to be associated with a plume of anomalously low-salinity water that corresponds to the axis of the Michigan lobe of the Laurentide ice-sheet, suggesting that the dilute water is glacial in origin. We hypothesize that Pleistocene glaciation enhanced freshwater recharge into fractured shales and coalbeds, which significantly diluted formation water salinity to levels non-inhibitory for methanogenesis, and may have enhanced release of nutrients, trace metals, and labile organic matter, further stimulating biogenic methane production. To test our hypotheses we will use PHREEQC modeling to simulate initial basinal brine conditions followed by multiple percentages of fresh water mixing and subsequent microbial metabolism. Model results will be coupled with carbon-14, stable isotope, ion, trace metal, and acetate analyses to determine the groundwater age of the dilute plume and evaluate our understanding of interactions between the aquifer matrix, solute chemistry, and microbial processes in the subsurface.

**A MULTI-TRACER APPROACH TO DETERMINE THE IMPACTS OF
AGRICULTURAL IRRIGATION RECHARGE ON GROUNDWATER SUSTAINABILITY
IN THE SADDLE MOUNTAINS BASALT AQUIFER, CENTRAL WASHINGTON, U.S.A.**

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Irrigation in semi-arid agricultural regions has profound effects on the recharge rates and water quality of shallow groundwater. In the case of oxic groundwater systems, such as the Flood Basalt aquifers of the western U.S., high nitrates from fertilizers persist for long time periods due to the absence of denitrification. Stable isotopes (²H, ¹⁸O) were used in conjunction with age-tracers (³H, CFCs, ¹⁴C), ⁸⁷Sr/⁸⁶Sr, and elemental chemistry to determine the residence times, sources, and flowpaths of shallow groundwaters in the Saddle Mountains Basalt Aquifer. The results demonstrate the presence of two distinct groups of waters: 1) contaminated irrigation waters with high NO₃⁻ (11-116 mg/l), detectable tritium (2.8-13.4 TU), CFC ages between 20 to 50 yrs b.p., high δ¹⁸O values (-13.5‰ to -16.1‰), and ~100 percent modern carbon (pmc); and 2) pristine groundwaters at depth with low NO₃⁻ (1-5 mg/l), no tritium, low δ¹⁸O values (-17.3‰ to -18.9‰) and < 15 pmc. Nitrogen and oxygen isotopes of NO₃⁻, in conjunction with high dissolved oxygen values, confirm that denitrification is not an important process in the organic-poor basalt aquifers resulting in the transport of high NO₃⁻ irrigation waters to depths greater than 40 m in less than 30 years.

INTERPRETING MOLLUSCAN MARINE RESERVOIR AGES
IN A VARIABLE UPWELLING ENVIRONMENT

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Changes in marine upwelling can affect marine radiocarbon reservoir age (the radiocarbon content of seawater), and these radiocarbon variations are recorded in mollusk shell carbonate. Changes in molluscan growth rate from both fluctuating environmental conditions and time-averaging of radiocarbon assays due to homogenization of days or weeks of precipitated carbonate during sampling bias shell-based marine reservoir age estimates. We modeled the growth and radiocarbon sampling of two Peruvian mollusks, *Argopecten purpuratus* and *Mesodesma donacium*, to investigate these biases. *A. purpuratus* grows steadily year-round, but *M. donacium* is cold-loving and its growth rate decreases in summer. Given an annual reservoir age variation of 530 ¹⁴C yr, our model shows that samples of *A. purpuratus* shell carbonate can capture the whole range of annual marine radiocarbon variation; the median average-radiocarbon-age of a suite of *A. purpuratus* samples is within 30 ¹⁴C yr of the actual marine mean. Suites of *M. donacium* samples, however, typically reveal less than 75% of the annual marine radiocarbon variation, and the mean radiocarbon age of sample suites may be biased about 140 ¹⁴C yr older than the actual marine mean. If growth tolerances and parameters of mollusks used for radiocarbon reservoir analyses are known, it may be possible to correct for these biases and improve the accuracy of marine radiocarbon chronometry.

**ECOLOGICAL INDICATORS OF CLIMATE CHANGE IN THE
PANTANAL REGION OF WESTERN BRAZIL**

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With a surface area greater than 150,000 km², the Pantanal (western Brazil) is the world's largest neotropical wetland and a hotspot of South American biodiversity. Owing to its unique mixture of lush aquatic and cerrado flora, the Pantanal is ecologically sensitive to environmental perturbations, especially those that impact the seasonal flooding cycle of the Paraguay River. This study utilizes short sediment cores and radioisotopic dating to detect recent environmental change in the Serras do Amolar, along the western floodplain of Paraguay River.

Biostratigraphic analyses of five cores from two lakes in the Pantanal region of Brazil suggest that the past several thousand years in this tropical wetland can be characterized by shallow, productive lakes surrounded by fire-prone lowland. Screen wash data are dominated by alternating horizons of organic- and terrigenous-rich sediment with sandy, charcoal-laden loam. Intermittent sequences of vivianitization and pyritization of terrigenous material in the cores indicates that the lakes have been episodically highly eutrophic, resulting in anoxia at the sediment-water interface.

**CORRELATIONS AND CHRONOLOGY OF HIGH ARCTIC LAKES BASED ON
MAGNETIC PROPERTIES**

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Located at 78°N the island of Spitsbergen is covered by small glacial lakes. Linnévatnet and Kongressvatnet are two such lakes and are separated by about five kilometers along the western coast. These lakes have been part of an ongoing study to better understand the present and past climate changes. Many cores have been recovered from the lakes, but a correlation between cores from the different lakes has yet to be determined. By correlating the cores a greater understanding of the changes in the high arctic. Furthermore, chronology is especially hard to establish. Linnévatnet has sediment provenance from Tertiary coal beds. Kongressvatnet and Linnévatnet both have large carbonate groups feeding into them. Large amounts of detrital coal as well as the depletion of ¹⁴C due to carbonate dissolution make ¹⁴C-dating methods unreliable. In areas proximal to the inlets of Linnévatnet sufficient amounts of terrestrial plant macrofossils allow for radiocarbon dating, but this leaves the question of dating for the distal to the inlet areas as well as in Kongressvatnet.

During the summer of 2008 three cores were recovered from Linnévatnet with lengths of 32cm, 35cm and 65cm, in addition to one core from Kongressvatnet with a length of 67cm. These were u-channel sampled and paleomagnetic data in a cryogenic magnetometer. Using historical data of polar wander a chronology was established. Correlations between the cores within Linnévatnet was successful using inclination, but the Kongressvatnet paleomagnetic record provide to be inconclusive, but environmental magnetism data may bring more information of records these cores.

ASPECTS OF MODERN LACUSTRINE SEDIMENTATION IN THE
CENTRAL ANDEAN FORELAND: PRELIMINARY RESULTS

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Lake deposits housed within foreland basins are important components of the ancient rock record. Such deposits are well known for their hydrocarbon resources and for their potential as archives of continental environmental change. Yet despite their importance, accurate interpretations of ancient lacustrine beds in foreland basins remain a challenge, due in large part to a dearth of fully developed modern analogs. In order to address this knowledge and data gap, we studied modern lakes that span pronounced tectonic and climate gradients in the Central Andean Foreland, the world's archetypical retro-arc foreland basin. Suites of lake bottom sediments were collected from several lake systems in Argentina and Brazil, and analyzed for aspects of physical sedimentology and organic geochemistry. Modern facies models are developed for each lake, and the results highlight the linkages between tectonic, climatic and biotic processes and their collective influence on sedimentology and recent stratigraphy.

SOUTH AMERICAN PLUVIAL LAKES: IMPLICATIONS FOR QUATERNARY CLIMATE CHANGE

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Pluvial lakes in Argentina provide a unique record of climate change during the Late Quaternary. Two lake systems were studied as part of an effort to understand major climatic changes during the Last Glacial Maximum (LGM: 24-18 ka) and the following deglaciation (18-13 ka). Today, both of the studied regions are arid, and the lake basins contain much smaller lakes than in the past. Laguna Cari-Laufquen is located at 41°S and the modern basin is occupied by two lakes: Cari-Laufquen Grande and Chica. Preserved shorelines and sediments show these two lakes rose and merged multiple times during the Late Quaternary. Initial radiocarbon and U-series dates show the lake was the highest during the LGM, with several smaller, more recent lake oscillations. The second lake system in this study is Laguna Bebedero, located at 33°S in western Argentina. Previous studies show the highest shorelines date to 23-16,000 yrs BP. Our new radiocarbon dates help constrain the timing of the highstands, allowing the differentiation between the LGM-age lake, and lakes created during the following deglaciation. Our lake highstand evidence provides a unique opportunity to reconstruct shifts in Atlantic (easterly)- or Pacific (westerly)-driven moisture. The age of deep lakes at Laguna Cari-Laufquen and Bebedero suggest a more northerly position of the westerlies during the LGM. The late-glacial age of the high shorelines at Bebedero points to a shift in the easterlies to a more southerly position. The late-glacial intensification and expansion of the sub-tropical easterlies is visible in many other South American lake records, and is probably linked to a colder eastern Pacific and North Atlantic at that time.

EXPANSION AND CONTRACTION OF PLEISTOCENE AND HOLOCENE LAKES IN THE SOUTHERN
BASIN AND RANGE PROVINCE, U.S.A.: PALEOCLIMATIC INTERPRETATIONS

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Climatic conditions in the Southwest during the Holocene epoch were strongly contrasting to late Pleistocene conditions. Based on paleoenvironmental reconstructions for the region, the late Pleistocene can be characterized by cooler annual temperatures and predominate influence of winter precipitation, while the Holocene can be described as summer precipitation-dominated with significantly increased winter and summer temperatures. Corresponding differences in effective precipitation should be evident in the shoreline records in closed basins of the southern Basin and Range province, since lake surface area is controlled primarily by the P-E balance (ratio of precipitation to evaporation). However, stranded shorelines spanning the Holocene in age, in three hydrologically independent basins, are remarkably close in elevation, and thus reconstructed lake surface area, to their late Pleistocene counterparts. The paleoclimatic implication of this is that, during brief intervals throughout the Holocene, the P-E balance nearly equaled those inferred for the LGM and terminal Pleistocene. We present preliminary radiocarbon data from southern Arizona and New Mexico which corroborate these findings and warrant further investigation into the timing and causes of these anomalously moist periods during the Holocene epoch.

**PALOMINAS ARROYO: AN 11.1 k B.P. ALLUVIAL RECORD FROM THE SAN PEDRO RIVER,
SOUTHEASTERN ARIZONA**

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Stratigraphic evidence of arroyo cutting and filling is readily evident in the tributaries of the San Pedro Valley. At Curry Draw and Lehner Ranch Arroyo, alluvial stratigraphy and radiocarbon dating indicate that spring-fed streams incised their channels between 6.7 – 8 k B.P. (hiatus) in response to warm, dry Altithermal conditions. Pollen from the Lehner Clovis site indicate a transition from a cienega environment to more xeric vegetation between 9.6 – 8 k B.P. Episodic arroyo cutting and filling became more frequent around 4 k B.P., coinciding with increased El Niño (ENSO) activity.

Previous research in the San Pedro Valley has documented the erosional evidence for stream incision (paleochannels); the mouth of Palominas Arroyo preserves the downstream aggradation associated with arroyo formation. Three cores taken from the mouth of the arroyo reveal a 12 m sequence of reddish arroyo sediments and soils. The top of the lowest buried soil occurs at 8 mbs and is radiocarbon dated ~6.5 k B.P., signaling the first pedological evidence of 11 Holocene-age entrenchment episodes in the actual mouth of the arroyo. Coarse alluvium fans across the bottom of the arroyo fill (12 mbs) above a dark, organic-rich sapropel capped by black peaty sediments. The top of the sapropel occurs at precisely the same elevation as the present channel of the San Pedro River, indicating that it was deposited in a backwater swamp environment when the river was near its present elevation. Interbedded layers of coarse-to-fine alluvium occur below the sapropel from ~12.6-13.2 mbs, signifying a slowly aggrading stream between 10.1 – 11.1 k B.P. One core encountered a probable paleochannel that extends 14.4 mbs and dates before 10.68 k B.P. Incipient Holocene erosion and arroyo formation is tightly bracketed approximately 400 yrs (¹⁴C) earlier than previously documented. The bottom of the reddish arroyo alluvium produced a ¹⁴C date of 8.4 k B.P. The top of the black peat is radiocarbon dated to 8.48 k B.P.

**GEOMORPHIC EVOLUTION OF AN EARTH FISSURE:
THE ROGER'S FISSURE, WEST-CENTRAL ARIZONA**

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Earth fissures are kilometers-long cracks. Groundwater level withdrawal and presence of clay bodies or bedrock “steps” cause the differential compaction of the sedimentary column, and therefore are the origin for earth fissures within basins containing poorly consolidated sediments. We studied the Roger’s Fissure, located in the Harquahala Basin in West-Central Arizona, which formed in 1997. The groundwater level of the Harquahala Basin decreased drastically, due to water pumping for anthropic activities between 1950 and today. We showed that the fissure formed between a steady area and an area with approximately 1 cm/yr of subsidence from 1992 to 1999.

The fissure also modified the preexisting drainage, causing a base level decrease. As a consequence, the fissure rims eroded and gullies formed on the southwestern rim where the major drainage from the Eagletail Mountains flows into the fissure. Measurement on the field show that the gully depths follow a normal distribution with an average of 1.5m, the gully widths follow an exponential law and there is no correlation between the gully depths and the fissure depths. Furthermore, we used a set of ground photographs taken between 1997 and 2002 to characterize the periods of aggradation and erosion in the fissure and the gullies. We compared these results with rainfall data and we shown that aggradation and erosion occur during heavy rainstorms events, in particular when rainfall is greater than 3 cm/month.

THE EXPLORATION OF ALLUVIAL FAN EXPOSURES AND RECENT FIRE-RELATED GEOMORPHIC RESPONSES IN BARILOCHE, ARGENTINA.

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The region of northwestern Patagonia was explored for the potential of using alluvial fan sediments for fire history research. The stratigraphy of alluvial fan sediments may be used as a proxy method for historical fire events, where the deposit characteristics are used to interpret the severity of historical fires, and radiocarbon dating of charcoal pieces determines the age of fire events. On the east side of the Andes, the landscape surrounding Bariloche, Argentina is characterized by glacially-carved valleys, with low-order tributary basins feeding into higher-order streams and lakes. Fire history has been extensively studied using tree-ring and lake/bog sediments in the region, though alluvial fan exposures have not yet been documented in northwestern Patagonia. The development of this proxy method will serve to broaden the understanding of historical fire regimes beyond the extent of the tree-ring record (~ 300 years).

Alluvial fans were identified in aerial imagery, and field work identified several exposures of the fan sediments. Two alluvial fan sampling sites were located within recently burned areas. The first site had several locations with up to three meters of exposure, and indicated that fan material is primarily composed of debris flow deposits. The deposits were composed of glacially-derived boulders supported by a matrix material of volcanic ash. Scattered charcoal deposited within the finer grained lenses within the stratigraphy indicated a possible fire-related origin for the debris flow events. The stratigraphy is overlaid in places by thick deposits of volcanic ash and pumice. Analysis of rainfall and geomorphic responses determined that prolonged rainfall over several days could initiate landslides and debris flows in both burned and unburned areas, though burned areas may exhibit a greater number of events. Further analysis could identify whether topography, bedrock, surface deposits or burn severity play a greater role in the initiation of debris flows under extreme rainfall conditions.

TEMPERATURE ESTIMATE FOR AN EARLY PLIOCENE POLAR FOREST, ELLESMERE ISLAND,
CANADA, FROM $\delta^{18}\text{O}$ RATIOS OF FRESHWATER MOLLUSKS AND AQUATIC MOSS

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Recent interest in the response of high-latitude ecosystems to climatic change has increased interest in past warm periods. A limited number of studies have been conducted to reconstruct paleotemperatures from Pliocene forest sites primarily based on NLR (nearest living relative) studies of fossil flora and fauna. Two recent studies investigated paleotemperatures from a coeval site using $\delta^{18}\text{O}$ values of wood cellulose, obtaining temperatures of $\sim 5.5^\circ\text{C}$ warmer than today. This study utilizes $\delta^{18}\text{O}_{\text{calcite}}$ values of the freshwater gastropods *Gyraulus albus*, *Lymnacea spp.* and the freshwater clam *Pisidium spp.* collected from within a peat layer from the Pliocene Beaver Pond site, Ellesmere Island, to reconstruct past temperature. Stable isotope values of freshwater molluscs have long been used to reconstruct lake water values to say something about paleoenvironmental conditions, however, their use as a paleotemperature proxy has been hampered by the necessity to know the lake water $\delta^{18}\text{O}_{\text{water}}$ values. Studies have examined the ability of $\delta^{18}\text{O}_{\text{cellulose}}$ values of peat to reproduce $\delta^{18}\text{O}_{\text{water}}$ finding that $\delta^{18}\text{O}_{\text{cellulose}}$ values from peat are a very accurate representation of $\delta^{18}\text{O}_{\text{water}}$. In this study freshwater mollusks recovered from within peat layers affords a unique opportunity to use the $\delta^{18}\text{O}_{\text{cellulose}}$ ratios derived from exceptionally well-preserved Pliocene peat to reconstruct lake water $\delta^{18}\text{O}$ values. Using the reconstructed lake water $\delta^{18}\text{O}$ value paleotemperatures could then be calculated from the $\delta^{18}\text{O}_{\text{calcite}}$ values of freshwater molluscs. A mean annual temperature of -10.2°C was calculated directly from the isotopic ratio of aquatic moss and an average growing season temperature of 13.5°C was derived from isotopic ratios of freshwater mollusks. These temperature estimates both indicate that temperatures were on the order of $9\text{-}10^\circ\text{C}$ warmer than present, much warmer than the previously obtained wood cellulose temperature estimates.

VEGETATION AND CLIMATE OF LAKE MALAWI, SOUTHEAST AFRICA
DURING THE LAST DEGLACIATION

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Pollen analyses from core Mal-2A taken from the northern basin of Lake Malawi (10°01.1'S, 34°11' E; 345m water depth) provides a high-resolution continuous continental record of the influence of the African Monsoon regime on vegetation change in south-east Africa from the end of the LGM to the Pleistocene/Holocene transition (~18-9ka BP) including the Younger Dryas (YD). Recent studies of local vegetation from lowland and high-elevation sites have reported contrasting rainfall signals and abrupt changes in seasonality during the YD. Located just south of the Livingstone Mountains and at the current southernmost limit of the Intertropical Convergence Zone (ITCZ), Lake Malawi is an ideal location to track vegetation changes in a range of habitats and altitudes in response to African Monsoon fluctuations as it incorporates input from a large catchment.

In agreement with studies showing a gradual increase in temperature and humidity at the end of the LGM, the Mal-2A pollen record shows gradual decline of montane vegetation originating in the highlands north of Lake Malawi. Influx of evergreen taxa remains strong until the YD when there is a gradual increase of Zambesian woodland taxa. The establishment of woodland assemblages is coeval with a stepwise decrease in Lake Surface Temperature (LST) and the change to dominance of southeasterly tradewinds resulting in a more pronounced dry season.

FINGERPRINTING SOUTHWESTERN CLIMATE DYNAMICS DURING MEDIEVAL TIME

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The Medieval Climate Anomaly (MCA) is a period from ~900-1400 AD characterized in Scandinavia and some other regions as a period of warm temperatures. In the western United States this period is distinguished by a general shift toward more arid conditions, punctuated by a series of severe droughts. This research focuses toward characterizing southwestern climate dynamics during the MCA by generating the first set of multiproxy, high elevation climate reconstructions for the San Juan Mountains in southern Colorado. Working in conjunction with Dr. Connie Woodhouse and Dr. Jonathan Overpeck, I am using a combination of tree-ring chronologies from high elevation bristlecone pine (*Pinus aristata*) coupled with lake sediment records to generate millennial length climate reconstructions for the San Juan Mountains. Anthropogenic forcing of climate could push southwestern climate toward a system where droughts are more frequent and intense. The MCA could be a potential analog for southwestern climate conditions in a warmer world. Understanding the dynamics of temperature and moisture availability during the MCA is critical for understanding the climate conditions southwestern communities face in the ensuing century.

CORAL Mn/Ca DATA FROM TARAWA ATOLL SUGGEST A STRENGTHENING OF THE TROPICAL PACIFIC ZONAL WINDS OVER THE 20TH CENTURY

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Variability in the tropical Pacific significantly impacts weather throughout much of the world, yet there is still considerable uncertainty in climate model projections of how this system will change. Models with a dynamic ocean but simplified atmosphere suggest that under greenhouse-gas forcing, strong upwelling in the eastern Pacific will counterbalance warming, leading to a strengthening of the Pacific SST gradient. In contrast, models with a dynamic atmosphere, but a slab ocean, suggest that the Walker circulation within the tropical Pacific will weaken, leading to a reduced SST gradient. Coupled GCMs suggest an intermediate response, with a tendency towards a weakened Walker. This response is consistent with sea-level pressure (SLP) trends over the 20th century, with anomalously high SLP in the west and low in the east. However, observational SST products disagree regarding the SST trend, with some datasets suggesting a stronger gradient, while others suggest a weaker gradient. Analysis of observational zonal wind products alone cannot reconcile these differences; reanalysis dataset suggests a weakening of the zonal easterly winds within the Niño3.4 region, while the purely instrumental records suggest a strengthening. Essentially, our ability to discern changes in the tropical Pacific is hampered by a dearth of long, reliable wind records.

Here, we use a coral Mn/Ca record to help reconcile discrepancies in the 20th century zonal wind trend. Situated in the westward facing lagoon of Tarawa Atoll, this record serves as a proxy for the westerly wind bursts that occur during El Niño events. The record displays a trend towards less frequent and intense high Mn anomalies. These results suggest a trend towards less frequent and intense El Niño events, consistent with a strengthening of the Walker circulation. These changes in the tropical Pacific will have a profound impact on teleconnection patterns, including drought in the southwestern US.

JURASSIC IGNEOUS-RELATED METALLOGENY IN THE CORDILLERA OF SOUTHWESTERN NORTH AMERICA: IMPLICATIONS FOR IRON OXIDE DEPOSITS

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Preliminary results from a synthesis of compiled regional geochronologic, geochemical, and isotopic data on Jurassic magmatism and mineral deposits from the Basin and Range of Arizona, eastern California, Nevada, and western Utah, show that to first order, metal contents correlate with magma composition. Patterns of igneous geochemistry and hydrothermal ore deposits suggest that the type(s) of fluid source(s) were also key to mineralization. This association is apparent for iron-oxide-rich hydrothermal systems, and associated sodic(-calcic) alteration, for which the role of circulating evaporitic brines may be crucial to their formation. The availability of brines as sources of fluids yielding widespread sodic(-calcic) alteration during the Jurassic is consistent with its arid paleoclimate, and low elevation, which was ideal for forming evaporites. Thus, during the Jurassic in North America, it is speculated that paleogeography may be a key component to the formation of iron-oxide-rich deposits (cf. Humboldt Mountains, NV), and igneous composition is not necessarily a primary control.

HYDROTHERMAL ALTERATION AND MINERALIZATION ZONING IN IRON-OXIDE(-Cu-Au) (IOCG) VEIN DEPOSITS, NEAR COPIAPÓ, CHILE

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Recent work in the Copiapó region of northern Chile provides insight into vertical and lateral zoning of vein-type Iron-oxide(-Cu-Au) (IOCG) deposits as a function of structural levels. Two vein systems hosted in La Brea diorite phase of the Copiapó batholith were investigated via drill core and surface mapping. Geologic field relations and alteration assemblages indicate that these vein systems represent two different structural levels. Vein systems at Transito are characterized by magnetite-chalcopyrite mineralization and high-T Na(-Ca) alteration dominated by scapolite-actinolite-epidote(-albite) which is consistent with deeper structural levels of the IOCG forming environment. In contrast, at Tigresa moderate to low-T alteration assemblages of chlorite-albite(-potassium feldspar-epidote) and musketovite + chalcopyrite(-specularite) mineralization are consistent with higher structural levels. These data and other geologic evidence indicate that the Tigresa vein formed near the upper contact of the host La Brea diorite, at depths of less than approximately 2 km, while Transito formed at greater depths (approximately 2-4 km).

Few IOCG systems have well documented vertical and lateral zoning. The contrasting, relatively simple vein systems at Transito and Tigresa demonstrate that the economic mineralization can persist over considerable (>500m) vertical intervals and overlaps with multiple styles of hydrothermal alteration. These relationships are broadly comparable to the patterns seen in some larger manto and breccia type IOCG systems where deducing time-space patterns can be far more difficult. Thus, a comparative study of the Transito and Tigresa vein systems indicates vertical zoning pattern in both mineralization and alteration that may be present in the larger more complex systems. It is postulated from this work, that structural level may be a component of distinguishing “well-mineralized” and “barren” IOCG systems.

MINERALIZATION CONTROLS AT CHAILHUAGON - PEROL PORPHYRY (Au±Cu) SYSTEMS -
MINAS CONGA DISTRICT - CAJAMARCA PROVINCE, PERU

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The Minas Conga district contains several clusters of Miocene porphyry copper deposits that are especially gold rich. The Chailhuagon and Perol projects are the two largest deposits in the district, are located in separate but adjacent clusters, and illustrate some of the differences between deposits in the district. The deposits are located 10 km east-northeast of the huge epithermal gold systems of the Yanacocha district, northern Peru. Exploration has been conducted in the Minas Conga district since 1992, first by CEDIMIN and by Yanacocha geologists since 2002. Newmont's combined ore reserves for the two deposits is 8.71 million ounces of contained gold at an average grade of 0.8g/metric tons Au and 1.01 million tons of contained copper at 0.3% Cu.

These two deposits were emplaced along a district-scale north-south structural trend within the northwest trending Miocene Andean arc. These clusters of porphyry systems are a segment of a copper-gold metallogenic belt that starts in the Ancash province of northern Peru and extends into central Ecuador.

The porphyry intrusions associated with ore are felsic stocks: a granodioritic unit at Chailhuagon and quartz-feldspar porphyry (QFP) at Perol (~23 Ma). The predominant wall rock over this area is a Cretaceous clastic and calcareous sequence. The oldest intrusive unit present is the Picota diorite (~43 Ma), and a dacitic volcanic unit occurs near Perol.

At Chailhuagon, the highest grade of Au±Cu mineralization is associated with an early phase of quartz veinlets associated with potassic alteration. The best grades at Perol are related to phyllic and intermediate argillic alteration; lower grades are observed at depth associated with potassic alteration. The sulfide assemblages are chalcopyrite-bornite and pyrite. Microscopic studies reveal fine inclusions of native gold, mainly inside or bordering chalcopyrite and bornite. In addition, gold is observed with pyrite associated with phyllic alteration at Perol.

CHARACTERIZATION AND RECONSTRUCTION OF THE NORTH BUTTE DIKE SWARM AND TEA CUP PORPHYRY SYSTEM, PINAL COUNTY, ARIZONA.

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Porphyry deposits in the Laramide province of southwestern North America currently are reasonably well described at the scale of the individual ore bodies; however, alteration products formed on the distal flanks and roots of the systems have only recently been identified, so a system-scale understanding of their evolution remains to be developed. One complexity that has hindered a system-scale understanding is the complex normal faulting that dismembered most Laramide porphyry systems after their emplacement. This study, building on earlier work, synthesizes results of mapping rock type, structure, and alteration and U-Pb dating of zircons in the northern Tortilla Mountains of central Arizona. The study focuses on North Butte dike swarm but extends eastward to the Kelvin-Riverside district associated with the composite Tea Cup pluton. The North Butte dike swarm and its associated porphyry copper occurrence, known as the Red Hills prospect, have been enigmatic since their discovery due to their seemingly distant relationship to any known pluton.

Results show that the both areas have been rotated $\sim 90^\circ$ to the east along five sets of normal faults that initiated at high angles ($\sim 60^\circ$ - 70°). Members of the North Butte dike swarm contain phenocryst phases and proportions similar to dikes near the Tea Cup pluton, including the unusual, primary muscovite-bearing porphyry dike that crops out in both areas. Distinctive types of hydrothermal alteration assemblages, including some with abundant specular hematite, also are present in both areas. Palinspastic reconstruction of a 30-km cross section from the Tea Cup pluton to the North Butte dike swarm appears to show that the dike swarm is a second porphyry center sourced from the Tea Cup pluton. Rotation caused by normal faulting provides a unique cross-sectional view at the present surface of the porphyry system, from its distal flanks, to paleodepths >10 km.

MINING STABILITY AND EARTHQUAKE PRECURSOR DETECTION

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With the ever increasing global population, mining has become more demanding to satisfy the world's mineral resource needs. These needs have increased global mining activities requiring assurances concerning mine safety with regards to mine stability of pillars, drifts, and walls to large excavations of stopes and open pit mines. However, the most important precaution needing increased attention is the attenuation of earthquake hazards associated with mine development. Earthquakes occur with virtually no warning, despite best guess efforts and computer modeling. For many years, the mining safety organization, NIOSH, has required microseismic sensors with every production-related excavation, but the warning times are still far too short for any adequate evacuation time. With research reaching further into the field of acoustic, electric, and infrared emission with special emphasis with regard to electromagnetics, corollaries are being attained with various minerals and rock types influenced by mechanically induced stresses. When rock is stressed, on the order of hundreds of megapascals of force, interesting rock characteristics are produced. It is these characteristics when amplified that may serve as an early warning system to alert miners, and possibly trend towards a warning system for the general population.

REGIONALIZATION OF TIBETAN PLATEAU PRECIPITATION

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Many paleoclimate records from the Tibetan Plateau link past changes in local precipitation to Southwest and East Asian Monsoon variability. However, few of these records are correlated with instrumental records of Southwest or East Asian Monsoon variability. Although the majority of annual Tibetan rainfall occurs during the summer months, a dearth of rain gauge data, particularly from the western part of the plateau, makes it difficult to comprehensively identify regions of Southwest and East Asian Monsoon influence. To properly interpret proxy climate records, we require a more quantitative understanding of Asian monsoon influences across the Tibetan Plateau. With this goal in mind, we investigated precipitation variability across the Tibetan Plateau using three monthly merged satellite-gauge precipitation products. Rotated empirical orthogonal function analysis indicates three main precipitation regions within the Tibetan Plateau. The eastern region (89-105°E 27-40°N) has the most annual precipitation, with 83% of annual precipitation occurring from May to September. Mean summer precipitation in the eastern region is significantly correlated with precipitation south of the Tibetan Plateau down to the Bay of Bengal as well as Bay of Bengal sea surface temperatures. Eastern region summer precipitation is not correlated with any Asian Monsoon indices. The summer wet season in the southwestern region (75-89°E 27-36°N) occurs from June to September and accounts for 74% of annual precipitation. Summer rainfall in the southwestern region is correlated with Southwest Asian Monsoon indices, as well as precipitation across northern India, 850mb winds in the western Arabian Sea, and latent heat flux in the southern Indian Ocean. The northwestern region (75-91°E 36-40°N) is the driest of the three regions, and receives the majority of its rainfall from May to September. Increased precipitation in this region coincides with an increase in latent heat flux and an anomalous 200 mb cyclone to the northwest of the region.

MOUNTAIN SIMULATION AND WINTER PRECIPITATION ERRORS IN IPCC AR4 MODELS

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In a suite of 18 general circulation models (GCMs) used by the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4), all overestimated winter (November to April) precipitation over all or part of western North America. Errors varied in magnitude spatially and between models but frequently approached 300% of observed precipitation in the West. There are two primary reasons why the attenuated orography used in the models induces errors in winter precipitation. Low mountain volume over the Rocky Mountain region is associated with higher zonal wind speeds aloft over the Pacific Ocean between 20° and 40°N. Increased zonal wind speeds are associated with greater precipitation south of about 40°N and west of the Mississippi in both observations and models. There are a number of reasons why faster and southwardly displaced winds over the eastern Pacific Ocean might increase precipitation over the West. Storms developing over warmer water tend to be wetter. Stronger wind speeds tend to increase the activity of the storm track, producing more frequent and/or stronger storms. Over the Pacific Northwest and western Canada, all models simulate too much precipitation inland, and many simulated too little precipitation along the coast. This is consistent with the fact that the Cascade Mountains and the coastal ranges of British Columbia are not resolved in most models. As a result, the large-scale windward precipitation peak and lee rain shadow characteristic of the region do not develop. Inaccuracies in the size and distribution of mountains explain a significant and consistent error among state-of-the-art GCMs. In addition, these errors make precipitation projections for the West less certain, as locations with the largest and most consistent errors display reasonably strong correlations between model error and projected precipitation change.

**A CONTINUUM OF DROUGHT:
LINKING LATE HOLOCENE MEGADROUGHTS TO 20TH CENTURY VARIABILITY**

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During the last few millennia droughts far worse than those experienced during the 20th century have periodically plagued North America. Yet their causes remain largely unknown. Volcanic eruptions and changes in solar radiation have long been invoked as drivers of multidecadal to multicentury drought. Alternatively, low frequency modulation of moisture variability by the oceans, or by complex land-surface feedbacks, may gradually alter the background state of the hydrologic system on timescales of decades to many centuries. Here, we evaluate these two hypotheses using a variety of proxy records, instrumental data, and climate model simulations.

We use a linear regression-based method to identify appropriate coefficients, or “power-laws,” that relate frequency to variance. During the 20th century, we find that precipitation variability depends only very weakly on timescale. This is not true, however, for drought indices that track soil moisture, suggesting that interactions between the land surface and rainfall dramatically influence the power-law scaling regime. From interannual to century timescales we find that tree-ring reconstructions of drought, precipitation, and river flow all exhibit very similar power-law relationships that are more consistent with precipitation scaling. At century to millennial timescales, tree-ring records exhibit unrealistically low variance due to the removal of long-term growth trends. Lakes, in contrast, may over estimate the frequency-variance slope, but provide a hypothetical upper bound for the energy of drought at very long timescales. Finally, long control runs on climate models do not exhibit any significant relationship between moisture availability and timescales longer than a few years. The large magnitude of uncertainty in estimating an appropriate range of natural variability means that our ability to estimate the severity and duration of future droughts, upon which climate change will be superimposed, is quite limited.

SEASONAL EFFECTS OF WARMER TEMPERATURES DURING
DROUGHT IN THE SOUTHWESTERN U.S.A.

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Climate in the southwestern U.S.A. (Southwest) is highly seasonal, with two distinct and relatively wet periods separated by the hottest and driest part of the year. As the likelihood for warmer temperatures and more arid conditions in the region increases due to anthropogenic climate change, it is anticipated that evapotranspirational demand will become more magnified during the hot-dry and hot-wet seasons. We examine this hypothesis by comparing seasonal observed surface climates during the pronounced Southwest droughts of the 1950s and 2000s, the latter influenced by warmer temperatures now attributed mostly to the buildup of greenhouse gases.

Compared to the 1950s drought, the 2000s drought in the Southwest exhibited warmer maximum temperatures during summer and warmer minimum temperatures from mid-spring through early autumn throughout much of the region. Higher temperatures largely drove greater vapor pressure deficits, a measure of evapotranspirational demand, during the more recent drought from mid-spring through late summer across much of the region. Higher dew point temperatures during the 2000s drought in central New Mexico and southeastern Arizona from mid- to late summer compensated the warmer temperatures enough to maintain evapotranspirational demand in the hot-wet season similar to what it was during the relatively cooler 1950s drought.

Our results thus support the hypothesis in that during the 2000s drought, the Southwest had seen significantly warmer air temperatures that drove higher evapotranspirational demand during the hot-dry season. These conditions continued into the hot-wet season for parts of the region outside of the core North American monsoon area. Further such changes to the character of the hot-dry and hot-wet seasons in the Southwest likely will have disproportionately negative societal impacts and represent the most severe conditions of future regional droughts.

ALPINE SHRUB-CHRONOLOGY: A TOOL FOR HIGH-ELEVATION ECOLOGICAL MONITORING

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Herbchronology, a technique adapted from dendrochronology, is the study of the annual growth rings in roots of certain perennial dicotyledonous plants. The presence of annual growth increments in plants in alpine and above-treeline environments is significant as it highlights the importance of herbchronology for climatic, ecological and geomorphologic applications in alpine and above-treeline ecology. Results from a study of the plants colonizing Barney Rock Glacier at 3200 meters elevation adjacent to Mammoth Pass, Mono County, CA, show these plants have an inverse relation to snowpack than trees but a positive response to summer temperature. Similar woody shrubs colonize GLORIA (Global Observation Research Initiative in Alpine Environments) monitoring sites in the Sierra Nevada. I have sampled these species (*Leptodactylon pungens*, *Phlox diffusa*, *Ribes cereum* and *Ericameria spp.*) on peaks immediately adjacent to the GLORIA sites at Dunderberg Peak and Granite Lakes (initially GLORIA alternate sites). Above-treeline shrub-chronologies (50 – 100 years in length) such as these can shed light on how sensitive alpine ecosystems will respond to changing climate. Here I present the resulting chronologies and discuss how the climate and ecological information gained from this method of study can compliment and add to the monitoring work done at high elevation sites.

QUANTIFYING THE EFFECT OF HYDROLOGIC VARIABILITY ON SEDIMENT TRANSPORT IN ALLUVIAL RIVERS

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Existing equations for predicting the long-term bedload sediment flux in alluvial rivers do not explicitly include variations in discharge. In this paper, we develop an analytical equation for the time-averaged sediment flux in an alluvial river that incorporates the instantaneous sediment transport equation and the frequency-size distribution of flood events, taking into account both the mean and coefficient of variation of discharge for a channel with a prescribed geometry and grain size. Three applications of the resulting equation are then considered. First, the equation is used to refine estimates for the effective diffusivity of alluvial channels within the framework of the diffusion model for longitudinal profile evolution. Second, the geomorphic effectiveness of end-member climatic regimes is considered, taking into account the inverse relationship between the mean and coefficient of variation of discharge in alluvial rivers. The results indicate that an alluvial river in a relatively humid climate transports more sediment per unit time than the same river would in an arid climate. Third, the effective discharge and its corresponding return period were calculated using the analytical equation for alluvial rivers in climates that range between arid and humid end-members. Rivers in humid climates have effective discharge return periods of months to decades, while the return periods for extremely arid climates can be up to several hundred years. If channel cross-sections are formed by the effective discharge in arid climates, then alluvial rivers may spend a significant amount of time out of equilibrium.

**THE PROGRESSION OF PRECIPITATION:
A MODEL OF OXYGEN ISOTOPE VARIABILITY IN CAVES OF THE SOUTHWEST**

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Cave speleothems provide superb records of climate variation on long (100,000 yr) timescales and with high temporal resolution. As calcium carbonate formations grow, they record changes in hydrology, vegetation, and temperature through time. However, many factors influence the $\delta^{18}\text{O}$ value of water on its trajectory from cloud moisture to cave formation. These factors include large-scale circulation dynamics to small-scale percolation through soil and rock. Here we develop a model of stalagmite oxygen isotope variability to assess the relative importance of these factors, and we then use this model to guide our interpretation of Holocene speleothem records.

The motion of water through the soil is predicted using a simple “leaky bucket” model and calibrated with nearly 7 years of surface and cave dripwater data from Cave of the Bells, Arizona. To constrain the potential isotopic composition of individual storm events, we use NOAA NCDC International Satellite Cloud Climatology Project archived infrared water vapor imagery for several days preceding the rain events to determine storm trajectories and moisture sources. We use a Monte Carlo approach to simulate a physically plausible range of isotopic values of cave waters and resultant calcite for the modern climate system. Preliminary results suggest that although multidecadal variability in cave records is usually interpreted as long-term variation in drought and monsoon strength, some variability may arise solely from the slow diffusion rate of high-frequency weather events. By modeling how precipitation gets to and enters the cave system, we have provided a metric against which we can judge the range of isotopic values observed in the paleorecord, lending confidence to our interpretation of past climatic change.

USING DETRITAL ZIRCON GEOCHRONOLOGY TO CONSTRAIN THE AGES OF HOMINID FOSSILS
FROM GONA, ETHIOPIA

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The Gona project area of east-central Ethiopia contains one of the longest and most prolific hominid fossil records in East Africa, and thus offers a unique opportunity to better constrain the timing of hominid evolution. Fossils ranging from *Ardipithecus ramidus*, thought to be the earliest upright hominid ancestor, to *archaic Homo sapiens* have been recovered in tuffaceous deposits spanning the last 6.4 million years. Among the many exciting prospects, Gona provides the opportunity to determine the timing of hominid-chimpanzee divergence, thought to occur as late as 5.4 million years ago. Recent discoveries of fossils of *Ardipithecus kedabba*, the earliest known hominid ancestor, from the Adu-Asa formation (6.4 Ma to ca. 5.5 Ma.) potentially pushes human-chimpanzee speciation to a pre 5.4 million time period.

The ages of hominid fossils have traditionally been constrained by $^{40}\text{Ar}/^{39}\text{Ar}$ dating of host deposits. However, most tuffs at Gona do not contain viable phenocrysts for $^{40}\text{Ar}/^{39}\text{Ar}$ dating (i.e. phenocrysts are absent, too small, altered, or lack substantial K). In addition, correlating regional stratigraphy is complicated by extensive faulting and limited tephrostratigraphy. Consequently the dates of roughly 90% of Afar deposits are simply estimated or unknown. Here we describe the application of U-Pb geochronology on detrital zircons using laser-ablation ICP-MS to determine tuff ages. Initial dates of six deposits are within reasonable error of their known $^{40}\text{Ar}/^{39}\text{Ar}$ dates, indicating that detrital zircon geochronology holds substantial promise for constraining the ages of hominid fossils, and the timing of hominid evolution.

U-Pb LAM-ICP-MS ZIRCON GEOCHRONOLOGY FROM PERMO-TRIASSIC S-TYPE PLUTONS AND HIGH-GRADE METAMORPHIC ROCKS OF THE NORTHERN COLOMBIAN ANDES: COLLISIONAL VS. ACCRETIONARY OROGENESIS IN THE PROTO-ANDEAN MARGIN.

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Global tectonic processes during Upper Paleozoic times are characterized by the final closure of the Rheic Ocean along the Variscan-Alleghanian-Ouachita suture, resulting in the final amalgamation of supercontinent Pangea. After the closure of the Iapetus in the Silurian, subduction initiated along both the Laurentian and Gondwanan margins leading to the generation of pre-collisional magmatic arcs surrounding the Rheic. These arcs terminated with the final closure of the oceanic basin by diachronous collisions that began with the Variscan and Alleghanian orogens developed between Baltica and West Africa, followed by the Ouachita orogen between Gondwanan Amazonia and SW Laurentia. Although debate still persists about the timing of final closures, most recent reviews suggest that the Rheic was totally extinct by the late Carboniferous. Orogenic collapse and subsequent Mesozoic rifting between Gondwana and Laurentia led to the generation of several smaller crustal blocks that are now found dispersed in Central America, North America and Europe.

In the Northern Andes, a continuous belt of S-type plutons and high grade metamorphic rocks of proposed Upper Paleozoic age runs along the backbone of the Cordillera, but robust crystallization and metamorphism ages were not yet available. In this short communication new LAM-ICP-MS U-Pb zircon geochronological results of S-type plutons, gneisses and migmatites from the northern Colombian Andes are presented. Our results, along with other data from Ecuador and Peru, suggest a common tectonometamorphic evolution for this segment of the proto-Andean margin during Permo-Triassic times, several millions of years after the proposed closure of the Rheic. Inherited zircon cores in the metasedimentary gneisses and the S-type granites point the protoliths of these rocks to be derived from Meso- Neo-Proterozoic and Lower Paleozoic terranes. Sources like those can be found in the western Amazon Craton and the Eastern Andes of Peru. We suggest that this magmatic-metamorphic belt can also be the result of (1) terrane-accretion processes along the continental margin or (2) stronger plate coupling in the plate boundary after cessation of shortening in the internal collisional orogens of Pangea. If so, they represent the vestige of subduction along the margin in this portion of the proto-Andes, and would be related to the Gondwanide pulse along the Terra-Australis orogen instead of the Ouachita collision *sensu stricto*.

DETERMINING THE ORIGIN OF ENIGMATIC BEDROCK STRUCTURES USING (U-Th)/He THERMOCHRONOLOGY: ALABAMA AND POVERTY HILLS, OWENS VALLEY, CALIFORNIA

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The Alabama and Poverty Hills are enigmatic, topographic highs of crystalline basement surrounded by Neogene sediments in Owens Valley, California. The 150-km long Owens Valley, the westernmost graben of the Basin and Range Province, has experienced ~2-4 km of vertical relief from the Sierra Nevada and White/Inyos crests to the valley floor since 6 Ma. Along the valley, the active right-lateral Owens Valley Fault Zone (OVFZ) accommodates a significant portion of Pacific-North American plate motion, creating an oblique dextral fault zone, with localized transpression along minor left-stepovers.

The Mesozoic rocks of the Alabama Hills are bounded by the OVFZ to the east. Paleozoic rocks of the Poverty Hills are along an apparent 3-km left step-over of the OVFZ. The significance of both structures is not known, but published hypotheses include: 1) OVFZ-related transpressional uplift; 2) down-dropped normal fault blocks; and 3) giant landslides from adjacent ranges.

We measured apatite (U-Th)/He ages on 15 samples from the Alabama and Poverty Hills to understand the history of shallow crustal exhumation of these structures. Apatite He dating typically yields cooling ages corresponding to closure temperatures of ~55-65 °C (depths of ~2-3 km in the crust). The apatite He (AHe) ages from the Alabama Hills are 52-70 Ma, and the Poverty Hills are 39-61 Ma. These data indicate that the Poverty Hills were not exhumed as a transpressional structure from depths greater than ~2-3 km since extension began in Owens Valley. Alabama Hills AHe ages are similar to rocks about 2.5-3 km higher, near Mt. Whitney in the adjacent Sierra Nevada. This suggests that the Alabama Hills have been down-dropped eastward in the hanging wall of the Sierra Nevada frontal fault zone. Structural reconstruction of these AHe age-elevation correlations requires 2.6 km of vertical, and 1.5 km of eastward motion for the Alabama Hills.

**CENOZOIC EXHUMATION HISTORY OF THE WESTERN ANTARCTIC PENINSULA:
THERMOCHRONOLOGIC RESULTS FROM NORTHERN AND SOUTHERN GRAHAM LAND**

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Several major tectonic changes affected the Antarctic Peninsula in the Cenozoic, including cessation of subduction south of the Bransfield strait, Scotia arc tectonism along the peninsula's northernmost reaches, and opening of the Drake Passage in the late Eocene. In order to reconstruct the exhumational history of Graham Land associated with these events, we analyzed fission track and (U-Th)/He ages of apatite and zircon from 14 sites from the northern tip of the peninsula to just north of the Antarctic Circle. Apatite He ages in two regions along the western coast of Graham Land show strongly differing ages, suggesting distinct tectonic domains. South of Anvers Island apatite He ages are relatively young, ranging from 8 to 16 Ma, whereas to the north they range from 24 to 65 Ma, with one exception at 11 Ma. In the southern region, apatite He ages are the oldest at the southernmost site and generally young towards the north, whereas the opposite is seen in the northern region (oldest ages at the northernmost site and younging towards the south). Time-temperature plots for eight sites evenly distributed between the two regions further support the notion that Graham Land is composed of unique domains. The plots from all four northern sites display a late Cretaceous pulse of rapid cooling followed by slow cooling to the present. In contrast, plots from the southern sites display either linear cooling to the present or an initial phase of slow cooling followed by rapid cooling in the mid-Miocene. We argue that each domain underwent differential slab window induced tectonic exhumation. Spatial and temporal correlations between apatite He and sea floor ages along-strike of the Peninsula demonstrate that, south of Anvers Island, progressive northward opening of a slab window led to a similar shift in the locus of exhumation.

THE STRUCTURE DETERMINATION OF THE HIGH-PRESSURE ANALOG OF BEHOITE, $\text{Be}(\text{OH})_2$

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The crystal structure of behoite, with the ideal formula $\text{Be}(\text{OH})_2$, was first determined by Seitz, Rosler, & Schubert (1950) from a synthetic sample. The crystal structure of behoite is analogous to the structure of cristobalite, where the 6 membered tetrahedral rings are occupied by Be and Si respectively. The structure of behoite undergoes a transformation between 1.3 GPa and 1.8 GPa. Previous data from Dr. Ronald Miletich's group suggests that the structure of the high-pressure polymorph of behoite is analogous to the structure of tridymite. While the transformation from cristobalite to tridymite is destructive, the crystal is preserved in the transformation from behoite to its high-pressure analog. The mechanisms of transformation in the $\text{Be}(\text{OH})_2$ system could provide crucial information about the role of hydrogen as a lubricant in high pressure silicate transformations. Dr. Ronald Miletich's group has tried unsuccessfully to determine the structure of the high-pressure polymorph via powder X-ray diffraction. The current study uses natural single crystals from Mont St. Hilaire, Quebec, Canada. Samples $50\ \mu\text{m} \times 100\ \mu\text{m} \times 100\ \mu\text{m}$ are mounted in a four-post diamond anvil cell with methanol ethanol (4:1) as a pressure medium. High-pressure data are obtained on an automated Picker single crystal diffractometer using Mo radiation.

THE DETERMINATION AND CATEGORIZATION OF HYDROGEN ENVIRONMENTS IN NOMINALLY HYDROUS MINERALS

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The purpose of this project is to create a body of understanding on how Nature stores hydrogen in solids. One of the challenges facing society is alternative energy sources. The federal government has identified hydrogen fuel as a potentially clean and cheap solution. However, the practical aspects are hindered by the simple problem of how to store hydrogen safely and in concentration. The explosion of the Hindenburg, and more recently the explosion at the hydrogen plant of the Reliance Petroleum Jamnagar refinery, illustrates how difficult this can be. This project will identify the ways that nature stores hydrogen in minerals, and then explore the response of these systems to concentrating the hydrogen through compression and increase in density. This study examines hydrated minerals, determines the environment of the hydrogen atoms in them, and creates a natural classification based upon the hydrogen environments, which are characterized by the structural and atomic interactions of the hydrogen atom. Mineral names and structural data are obtained from the International Mineralogical Association Mineral List Database and the American Mineralogist Crystal Structure Database. There are about 4300 known minerals, 2503 of which contain the element hydrogen (57%). Aside from those minerals that contain ammonia or hydronium, 2487 minerals contain OH either as H₂O or isolated OH groups. Of these, 1592 have experimentally determined crystal structures with 600 that contain only OH without H₂O. The other 992 contain H₂O with or without additional OH. There are 450 known mineral species that contain OH without H₂O and have crystal structure determinations that include the location of the H atom. Seventeen unique classes of OH sites were determined.

SEDIMENTOLOGY, DETRITAL ZIRCON GEOCHRONOLOGY, AND STABLE ISOTOPE
PALEOALTIMETRY OF THE EARLY EOCENE WIND RIVER BASIN, CENTRAL WYOMING

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Large sedimentary basins in Wyoming archive information about tectonic setting and paleotopography during Laramide deformation. In the northwestern corner of the Wind River Basin, the early Eocene Indian Meadows Formation and overlying Wind River Formation are well exposed. Previous studies of fossil assemblages place the depositional age in the Wasatchian Land Mammal Age (51-55.5 Ma). We present results of a multidisciplinary study of sedimentology, detrital geochronology, and isotope paleoaltimetry.

Lithostratigraphic data show that the sedimentary environment changed from gravel-bedded fluvial fan with debris flow to anastomosed river, with paleocurrent directions change from southwestward to mainly eastward. Washakie Range to the north of the studied area experienced rapid unroofing in 55.5-54.5 Ma as the sediment exhibits a trend of increasing erosion depth in source terrane. Anastomosed river system was developed as the accommodation space is limited by tectonic damming of uplifting the Wind River Range by ~53-51 Ma.

Detrital zircon U-Pb age spectra show the majority of the zircons in sandstones were recycled from Paleozoic-Mesozoic sedimentary rocks. No zircon grains of depositional age were recovered. Zircon ages of a Precambrian granite pebble show that sediment in the Wind River Formation are dominantly denudated from the Wind River Range. The age spectra evolved into the shape of modern river sand at the top of the Wind River Formation, suggesting a paleodrainage similar to present was formed by 51 Ma.

The $\delta^{18}\text{O}$ values of early Eocene precipitation and river water in the Wind River Basin inferred from the $\delta^{18}\text{O}$ values of unaltered pedogenic carbonate and fluvial carbonate cement are $-5.8 \pm 1.9 \text{‰}$, and $-13.5 \pm 1.2 \text{‰}$ (VSMOW). The inferred elevation of basin floor was $\sim 0.5 \text{ km}$ and the surrounding ranges was $2.3 \pm 0.8 \text{ km}$. Post laramide regional uplift up to 1 km is required to form the present landscape in central Wyoming.

ZIRCON DATING AND ORIGIN ANALYSIS OF GRAND CANYON SEDIMENT

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We investigated the dates of sediment within detrital layers found in the Grand Canyon. Zircons were separated from Toroweap², Kaibab, Temple Butte and Watahomigi layers using standard mineral separation techniques. Ratios of U-Th-Pb were obtained from 100 individual zircon grains per sample using an inductively coupled plasma mass spectrometer. A software package called Age Calc was then used to reduce the data using a known U-Pb decay concordia curve to match our U-Th-Pb ratios. A provenance was established for each layer by matching the ages of the different zircons we gathered to ages of accretion and batholiths determined in previous research. The provenance combined with the periods of deposition enabled us to determine the paleogeography of each layer.

Kaibab, deposited during the Permian, contained zircons from 0.5 Gya, 0.8 Gya, 1 Gya-2.5 Gya. These zircons came from the Suwanee, Grenville, Yavapi, Mazatzal, Wyoming-Hearne Rae, and Superior areas. Toroweap, laid down during the Permian, contained zircon deposits ranging from 0.5 Gya, 1 Gya, 1.4 Gya, 1.7-1.8 Gya, and 2.7 Gya, deposits which came from the Suwanee, Appalachian, Grenville, Mazatzal, Yavapai, and Wyoming-Hearne Rae areas, respectively. Watahomigi, deposited during the Pennsylvanian, contained zircons from 0.4 Gya, 1-2 Gya, and 2.5-3 Gya. The deposits came from the Appalachian, Grenville, Yavapai, Mazatzal, Superior, and Wyoming-Hearne Rae areas. Temple Butte, laid down in the late Devonian, contained zircon deposits that age 1.8, 1.4, and 0.5 Gya from the provenances of Yavapi, Trans-Hudson, and Appalachian areas.

U-Pb GEOCHRONOLOGY FROM SANTANDER MASSIF, NORTHERN COLOMBIA

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Global Neoproterozoic to Early Paleozoic paleogeography is influenced by the agglutination and break-up of Rodinia and Gondwana supercontinents (Cordani et al., 2003, Li et al., 2008,). Within this framework, terrane tectonics became a dominant process, either by a direct terrane transfer link through a continent-continent interaction or a more complex isolation during continental break-up, drift and its subsequent accretion to a new continental margin (Cawood, 2005). Most Early Paleozoic global orogenic events were the descendants of supercontinental drift and were redistributed along the newly created Iapetus and Rehic oceans (Keppie and Ramos, 1999, Nance and Linnemann, 2008).

Similarly, regional reconstructions have shown that during the supercontinent formations, the northwestern proto-Andean margin interacted with Laurentia, Baltica and other intra-oceanic arcs and continental blocks such as the Avalonian-Cadomian type terranes and the Mexican Oaxaquia (Ruiz et al., 1999, Murphy et al., 2004). However, overimposed Andean tectonics and paucity of data have not enabled testing of this paleogeography. Therefore, the character of the orogenic events and the origin of the different terranes that interacted with the continental margin is not yet well understood because of the lack of data.

Tectonostratigraphic and reconnaissance geochronology from the Santander Massif in the northeastern Colombian Andes have shown the existence of an almost continuous Neoproterozoic to Early Paleozoic geologic record. These analyses will certainly provide new clues for the interpretation of paleotectonic scenarios (Restrepo-Pace, 1995).

This contribution provides a regional profile including the three main lithostratigraphic units of the Santander Massif (Bucaramanga Gneiss, Santander Plutonic Complex and Silgara Formation), evaluated by U/Pb zircon geochronology. The results will establish a firm terrane-specific time scale for magmatic and metamorphic events that, together with reconnaissance detrital signatures, can be used to reconstruct the major tectonic events and evaluate their correlation within the regional paleogeography.

LOW-TEMPERATURE THERMOCHRONOLOGY OF THE ROCKY MOUNTAINS,
WYOMING AND MONTANA

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We dated borehole and surface samples from Laramide-age, basement-cored uplifts of the Rocky Mountain foreland using the apatite (U-Th)/He (AHe) and apatite fission-track (AFT) systems. Comparison of these results to previously-published AFT data, along with the incorporation of new He diffusion models, reveals new insights into the shallow exhumation histories of these ranges.

Two to 8 apatite crystals for AHe and 30 crystals for AFT were dated per sample. Mean AHe ages typically range from late Cretaceous to Paleocene within ~1 km of the surface, to Miocene and younger ages at depths greater than ~2 to 2.5 km. At least one sample per borehole shows a correlation between AHe age and effective uranium (eU) content of the crystal, indicating that radiation damage has affected AHe age. Thus an appropriate diffusion model for helium in radiation-damaged apatite should be used for modeling ages.

We use inverse and forward modeling to interpret thermal histories. Previously-published geologic and age data are used to constrain the timing of burial and exhumation. We first use inverse modeling to find a best-fit thermal history for a sample that shows good correlation between AHe age and eU. These temperatures are then extrapolated to other elevations by assuming a geothermal gradient.

AHe and AFT ages from wells through the hanging walls of the Wind River and Beartooth thrusts can only be reproduced using models with both Laramide-age and post-Laramide-age cooling. Thermal histories that best approximate the borehole data require Phanerozoic burial until the Paleocene-Eocene of ~3-4 km, followed by a cooling event of several tens of degrees (~3-4 km of exhumation) during the Paleocene-Eocene, and a smaller cooling event of a few tens of degrees (~1 km of exhumation) during the Miocene. Bighorn Range data can be matched by thermal models with and without post-Laramide exhumation.

SEISMIC INVESTIGATION OF HIGLEY BASIN, CENTRAL ARIZONA

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Located near the western terminus of the Basin and Range Province in Central Arizona, Higley Basin provides a unique record of Tertiary extension and volcanism. In the spring of 2008, ~18 km of new medium- to high-resolution seismic data were collected in this basin to address several key questions. These include questions about depth to bedrock (inferred to be Ruin Granite or Pinal Schist), location and lateral extent of various stages of non-volcanic basin fill (largely poorly-cemented sands, gravels, and conglomerates), subsurface basalt distribution, and the location and nature of structures affecting basin fill. This medium- to high-resolution data is augmented by several vintage petroleum industry lines in the basin, and by an extensive catalogue of shallow well logs.

Initial processing and interpretation of recent and vintage seismic data in the basin indicates a roughly symmetric basin about a NW-SE axis. Laterally extensive Quaternary basalts, which outcrop near the southern terminus of the basin, are readily identified based on seismic character and direct tie to outcrop. Where imaged, these basalts appear to typically onlap basement, though pinch-outs into basin-fill are also observed. Quaternary basalts are not imaged in the NE corner of the basin. Layering within the non-volcanic basin fill is less readily identified, likely due to the absence of high-impedance-contrast interfaces within the basin fill.

Few faults with significant offsets are imaged within Higley Basin, with only one large-offset fault clearly identified. This fault appears to have a normal sense of displacement and offsets basement, but does not appear to offset overlying units. Other deeper basement faults may exist within the basin, but are not clearly resolved in the data.

INVESTIGATION OF THE SAN ANDREAS FAULT: GPS MONITORING FROM SAN GORGONIO
PEAK AND SAN JACINTO PEAK

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The San Andreas Fault transfers into a left stepping restrictional bend in the San Bernardino area. This portion of the San Andreas fault is bounded by San Jacinto Peak to the south and San Gorgonio Peak to the north. These two peaks are the highest peaks in southern California south of Mt. Whitney. The San Bernardino Mountains, of which Mt. San Gorgonio is a part, is also bounded to the north and south by east-striking thrust faults. The San Jacinto Mountains are not associated with a known thrust fault system. To improve our understanding of crustal kinematics in this region, we are repeatedly placing a GPS unit over benchmarks on each of the San Jacinto and San Gorgonio peaks for ~72 once every year for a total of three measurements, these measurements will show the direction and velocity of both peaks in relation to each other and relative to the stable interior of the North American plate. As of yet we have successfully completed two of the three campaigns. At this stage of the project, we are able to compare the measurements from the first campaign with the measurements from the second campaign. This comparison allows us to constrain the direction and rate of the relative motion between the peaks for the first time. With the data gathered from the first campaign we were able to predict the precision of our positioning measurements in the range of 2mm-4mm. From these positioning measurements, we are able to calculate a predicted velocity uncertainty in the range of 1 to 2 mm/yr in the horizontal component and 10 mm/yr in the vertical component after three measurements. We expect to achieve this precision at the end of the three year project. Using the data from the first two campaigns provides a first tantalizing glimpse at the relative direction and rate of both peaks in relation to one another. Current San Andreas Fault slip rate estimates for this region based on previous geological and geodetic measurements are highly variable, between 5 to 30 mm/yr. With the anticipated level of velocity precision that we will achieve with our experiment, we hope to shed new light on possible along strike variability of San Andreas slip rate, the role of local thrust faults, relative uplift of the ranges, and the accuracy of previous geodetic slip rate measurements.

NAF EXPERIMENT: SEISMIC ANISOTROPY BENEATH NORTHERN ANATOLIA FROM SHEAR-WAVE SPLITTING

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The North Anatolian Fault (NAF) is a 1400 km long transcurrent structure located at the northern margin of the westward-extruding Anatolian plate. Despite numerous geological studies along the fault, the deeper structure of this plate margin remains relatively unknown. One important question that can be addressed is the degree of coherency between the strain field in the upper crust and the upper mantle. Another unaddressed question concerns the lateral extent of the shear zone at depth associated with the North Anatolian Fault.

Our analysis of mantle anisotropy beneath NAF array using shear-wave splitting indicates that the observed mantle strain field is uniform underneath the array with consistently NE-SW trending fast directions as determined by shear-wave splitting analysis. This trend remains parallel or sub-parallel to the absolute plate motion vectors with a no net rotation reference frame calculated using Global Strain Rate Model (GSRM). However, the trend of anisotropy is oblique to the surface trace of the NAF. The observations of fast polarization directions agree well with the orientations of the modeled smallest principle strain rate axis (GSRM). The anisotropy directions do not vary across the NAF, suggesting that we are sampling anisotropy at a deeper source such as asthenosphere and the deformation associated with the plate boundary might be lithospheric. Lag times between the fast and slow polarizations measured for the study area varies within the range of 0.5 seconds to 1.6 seconds. Lower lag times are obtained consistently at the eastern part of our seismic array. This might suggest either a locally thinner anisotropic source or weaker anisotropy in the upper mantle.

CRUSTAL DEFORMATION IN THE TUCSON AREA USING GPS

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We use GPS data to examine crustal deformation in southern Arizona. Some of these data come from observation sites which have been monitored continuously for a period of years, while other data come from sparse “campaign” sets: short-duration measurements with years between separate observations. As part of our observation program, we configured and installed two new continuous sites. The continuous GPS (CGPS) sites used in this study are operated by various institutions, each with different missions. This can limit the effectiveness of these data sets for studying small-scale crustal deformation.

We use the GAMIT/GLOBK package to analyze the GPS data and produce position time-series and velocities for the individual sites. With these results we have developed a velocity field for southern Arizona. The results help constrain measurements of crustal extension in the region. Most of the CGPS sites we use have not been operational for long, which puts limits on our ability to interpret their associated time-series. As the sites’ operation duration grows, we should be able to evaluate hydrological loads in the Tucson basin.

Velocities in the Tucson area are about 1 mm/yr. west relative to SNARF. Early results indicate strain accumulating in southern Arizona in response to extension of the southern Basin and Range. This accumulation is supported by historic seismicity in the region.

A GEOMORPHIC MAP OF HALE CRATER, MARS

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Hale crater, an exceptionally well-preserved crater on the northern rim of Argyre Basin (323.6°E, 35.7°S), may be one of the youngest craters of its size (125 by 150 km) on Mars. Hale possesses an elaborate channel system that emanates from its ejecta blanket, though water is not presently stable on the Martian surface. The Hale-forming bolide impacted Uzboi Valles, one of the largest outflow systems on Mars, but never appears to have filled with water, so it is unlikely Uzboi Valles was active when Hale formed. However, ice was almost certainly stable at Hale's latitude in the relatively recent past, and the channels that radiate from this crater may have been produced by surface runoff released from an ice-rich target.

In order to map the crater, we first constructed a GIS database of a 20° by 20° region of Mars, centered on Hale, using data and images from the Mars Orbiter Laser Altimeter (MOLA), the Thermal Emission Imaging System (THEMIS), the Mars Orbiter Camera (MOC), the Context Camera (CTX), and the High Resolution Imaging Science Experiment (HiRISE). A 1:500,000 THEMIS daytime infrared mosaic, with a resolution of ~100 m/px, was used as the base map. Higher resolution imagery (MOC, CTX, HiRISE) allowed closer analysis of units, stratigraphic relations, and locations of contacts. Here we present our geomorphic map of Hale crater. If the Hale-forming impact was able to mobilize a significant volume of water, as our map suggests, it could have important implications for early climate and landscape evolution on Mars: if a single moderate impact released enough water to form a large number of channels, the combined release of water from all craters formed during the Noachian bombardment may have significantly contributed to the formation of valley networks without requiring a long-term, stable, warm and wet climate.

PRESENT-DAY LOADING RATE OF SOUTHERN SAN ANDREAS AND EASTERN CALIFORNIA SHEAR ZONE FAULTS FROM GPS

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We present the first results from a dense network of 23 campaign and 37 continuous GPS stations located in the eastern Transverse Ranges Province (ETR), a transition zone between the southernmost San Andreas fault (SSAF) and eastern California shear zone (ECSZ). A large subset of the campaign data was collected each September, February, and May from September 2005 to September 2007. We used data from the continuous stations for the period 1994-2007. We use the GPS velocity estimates to constrain elastic block models to investigate fault-loading rates under four assumed fault-block scenarios. These scenarios represent the Pinto Mountain, Blue Cut and Chiriaco faults of the ETR, a north-northwest striking structure (the "Landers-Mojave earthquake line") that cuts obliquely across the ETR and Mojave Desert faults, and various combinations of these end-member models. All models suggest that the slip rate of the SSAF varies appreciably along strike, generally consistent with slip rates derived from tectonic geomorphology and paleoseismology. Our preferred model incorporates transrotation of the ETR crustal blocks as well as a north-northwest striking feature that cuts through the ETR and into the ECSZ. In our preferred model, our fault slip rate estimates for the southern San Andreas fault reach a maximum of 21 mm/yr of right-lateral motion along the Coachella Valley strand and decreases systematically to 6 mm/yr of right-lateral motion through the San Geronio Pass region. We estimate rotation rates of $4.7 \pm 0.2^\circ/\text{Myr}$ for crustal blocks in the ETR in general agreement with long term rates from paleomagnetic and geologic data.

SLIP RATE ESTIMATES FOR THE GARLOCK FAULT BASED ON GEODETIC SURVEYS

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Previous geodetic studies of the Garlock fault of Southern California have found left lateral slip rates that are below geologic rates. Our study develops a model for crustal deformation based on Quaternary faults of the southwest United States, and new Global Positioning System (GPS) velocities. We used velocity measurements from 118 GPS stations of the PBO NUCLEUS, SCIGN, and BARGEN networks to constrain this model. Using a simplified model of a constant fault locking depth and various block rotations, relative block motions were estimated to match observational crustal velocities. The Eastern Californian Shear zone was divided into 22 fault segments and 8 blocks. Dividing the Garlock fault into five segments allowed for variation in slip rate along the fault system. We estimate rates of 2.96 ± 0.07 , 2.81 ± 0.07 , 3.04 ± 0.08 , and 2.79 ± 0.08 mm/yr of left lateral slip starting along the western Garlock and moving east. On the east most segment a rate of 0.82 ± 0.04 mm/yr of right lateral slip was found. Slip rates are fairly consistent to the west with a large drop in amplitude along the east most segment of the Garlock fault. Despite the consistency of the western segments, these rates are significantly lower than geologic rates of 7 ± 2.5 mm/yr. The discrepancy of rates along with the right lateral motion along the eastern segment may suggest a complex role of the Garlock fault in the Eastern California Shear zone. The difference between the geological rates and geodetic rates implies the importance that a time scale has on fault rates.

METAMORPHIC ROCKS IN CENTRAL TIBET: LATERAL VARIATIONS AND IMPLICATIONS FOR CRUSTAL STRUCTURE

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Insights about lateral variations in the age, composition, and structure of the central Tibetan crust are provided by geologic investigations of metamorphic rocks in the Qiangtang terrane. Previous studies have shown that blueschist- and eclogite-bearing tectonic mélange of Triassic age is exposed over an E-W distance of ~600 km in the central Qiangtang terrane. New mapping shows that the mélange extends over a N-S distance of ~150 km, nearly to the trace of the early Mesozoic Jinsha suture in the north. The mélange, exposed structurally beneath upper Paleozoic to Mesozoic strata in the footwalls of early Mesozoic normal faults and is composed mostly of Paleozoic metasedimentary and crystalline rocks. These findings support the hypothesis that a large part of the central and northern Qiangtang terrane crust is composed of supracrustal rocks that were subducted southward along the Jinsha suture and underplated beneath Qiangtang terrane continental crust. In contrast, the Duguer Range south of the mélange exposes high-temperature low-pressure metasedimentary rocks and orthogneisses. The orthogneisses yield U-Pb crystallization ages in the 476–471 Ma range and represent peri-Gondwanan continental basement of the Qiangtang terrane. We interpret the Duguer Range metamorphic rocks to represent peri-Gondwanan continental basement of the Qiangtang terrane upon which upper Paleozoic and younger strata were deposited. The surface boundary between underthrust mélange basement in the north and autochthonous peri-Gondwanan basement in the south corresponds spatially to a major N-S change in crustal geophysical properties, which in turn allows us to extrapolate the contact between the contrasting basement rocks to lower-crustal depths. The most prominent dipping geophysical features can be explained by structures that have been mapped at the surface and demonstrated to be pre-Cenozoic in age. This geologically-supported interpretation casts doubt on the widely-argued efficacy of flow in the mid- to lower-crust in modifying the architecture of the central Tibetan crust during the Indo-Asian collision.

CRETACEOUS – TERTIARY GEOLOGY OF CENTRAL TIBET AND IMPLICATIONS FOR
PLATEAU FORMATION: A SYNTHESIS

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Here we summarize recent geologic data pertaining to the tectonic history of the central Tibetan Plateau since the Early Cretaceous. The Bangong suture, between the Qiangtang and Lhasa terranes, marks the closure of the Meso-Tethys and was the site of deep-marine sedimentation until ~125 Ma. The presence of ~118 Ma non-marine clastic rocks unconformably overlying these marine rocks show that the Bangong suture had closed and underwent sufficient deformation and uplift to raise the region above sea level. Paleocurrent measurements indicate south-directed drainage, off of the Qiangtang terrane toward an epeiric seaway in the Lhasa terrane. By ~100 Ma this pattern was reversed, with the former seaway providing sediment to basins in the Bangong suture. This reversal was in response to the developing northern Lhasa terrane thrust belt. This thin-skinned thrust belt was active between ~100 Ma and 50 Ma, accommodated >50% shortening and could have produced substantial elevation gain prior to the Indo-Asian collision. The Bangong suture underwent structural reactivation during the mid-Tertiary and achieved high elevation (~4.5 km) by 26 Ma based on oxygen isotope paleoaltimetry. The latter requires that any subsequent flow of mid-crust eastward from beneath central Tibet must have been balanced by a northward influx of Indian crust. Low-temperature thermochronologic studies reveal that central Tibet experienced <3 km of denudation since ~50 Ma, and show little signal of the Indo-Asian collision. These results suggest that central Tibet may have been characterized by significant elevation and low regional relief by 50 Ma, and that plateau development may have initiated centrally and propagated outward.

**CORDILLERAN FOLD-THRUST BELT AND FORELAND BASIN SYSTEM OF
NORTHWESTERN MONTANA**

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At the latitude of northwestern Montana a continuous evolution of the Cordilleran retroarc fold-thrust belt is recorded in strata of the Middle Jurassic-Eocene foreland basin system. Detrital zircon ages and modal sandstone petrography suggest that by Bajocian times (~170 Ma) miogeoclinal strata were being deformed and eroded in hinterland regions. Oxfordian-Kimmeridgian sandstones of the Swift and Morrison Formations contain detrital zircons derived from the Intermontane belt to the west. This early record of the onset of orogenic deformation is preserved in relatively thin, tabular, shallow marine and fluvial deposits that possibly accumulated in a back-bulge depozone. By late Early Cretaceous time the fold-thrust belt had propagated eastward and a classic foredeep was deposited on top of distal Middle Jurassic deposits. Pre mid-Cretaceous movement of major thrust sheets in hinterland regions involving Proterozoic Belt Supergroup rocks is constrained by provenance data and cross-cutting relations of stitching plutons. By Campanian time the Lewis and related thrust sheets were active and being eroded, and previous foreland basin deposits were cannibalized. The last stage of evolution of the fold-thrust belt deformed Paleozoic and Mesozoic strata in the footwall of the Lewis thrust and produced the Sawtooth Range, in part an exhumed duplex active until early Paleogene time. A new balanced cross-section indicates a minimum shortening of 125 km for the frontal part of the fold-thrust belt of northwestern Montana.

**CRUSTAL ANISOTROPY IN SOUTHERN CALIFORNIA:
EVIDENCE FOR TECTONIC UNDERPLATING?**

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Receiver functions were calculated for stations in southwestern California to explore a proposed fossilized mid/lower crustal regional detachment related to past subduction. The location and extent of this shear zone is inferred using common conversion point (CCP) stacks of receiver functions and through the identification of lower crustal anisotropic zones. The CCP stacks identify a low velocity zone at the base of the crust west of the San Andreas and show an increase in Moho depth inland from the coast. When receiver functions are stacked by backazimuth a consistent move out pattern is visible on radial and tangential components. The consistency of this signal over a large geographic area suggests that it stems from an anisotropic lower-crustal low velocity zone. While dipping interfaces may contribute to the complexity of the signal seen in individual stations, it is unlikely that similar dipping interfaces could be present throughout the region. In order to better understand the regional anisotropic signature, a neighborhood algorithm search was run on 43 stations to invert for interface depth, strike and dip, percent anisotropy and orientation of anisotropy. The results of the inversion vary throughout the region; but when crustal blocks were rotated back to their Laramide orientations the trend of anisotropy suggests a regional-scale lower crustal anisotropic zone at the base of the crust oriented ENE-WSW. We attribute this anisotropic lower crustal layer to the removal of the lower crust and the emplacement of slab-derived schists during Laramide flat slab subduction.

LITHOSPHERIC STRUCTURE OF THE CENTRAL NORTH ANATOLIA FROM S-WAVE RECEIVER FUNCTION ANALYSIS

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The North Anatolian Fault is a nearly 1400 km long major right-lateral strike-slip fault. It forms the northern margin of the Anatolian plate, which escapes westward as a result of the convergence between the northward moving Arabian plate and the relatively stable Eurasian plate. The North Anatolian Fault, which has caused many destructive earthquakes, is a young and active continental transform boundary located in part along an old suture zone. In order to investigate the lithospheric deformation and deep structure beneath the middle portion of the North Anatolian Fault, we deployed 39 broadband seismic stations as part of the North Anatolian Fault Passive Seismic Experiment (2005-2008).

Our aim is to identify the differences in the lithospheric structure along and across the fault, and to determine how deep the surface structure and deformation along this major continental transform boundary extends into the mantle. The structure and thickness of the crust and mantle lithosphere is investigated using the high-quality teleseismic data from the NAF project through S-wave receiver function analysis. The S-wave receiver function technique (using the method of Hansen et al., 2007) isolates the S-to-P conversion generated at discontinuities beneath the station. To identify the converted phases more clearly, 30 events with epicentral distances between 60-75 degrees, magnitudes greater than 6.0 and depths shallower than 60 km have been processed. The Moho discontinuity is observed at all the stations between 4-5 seconds corresponding to a crustal thickness of 35-40 km. The results do not indicate a distinctive change in the Moho across or along the fault zone, assuming a constant V_p/V_s ratio. A negative phase corresponding to 70-120 km depth is observed in several record sections, which we tentatively identify as the lithosphere asthenosphere boundary (LAB). This suggests that under much of the region the lithosphere is thin and we do not see a mantle signature of the NAF.

STRUCTURE OF THE SOUTH END OF THE CRAWFORD THRUST, SEVIER THRUST BELT, UTAH

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We have reprocessed five early-1980s vintage 2D seismic lines belonging to ExxonMobil in the Lost Creek Reservoir area of northern Utah. These lines were acquired over the hanging wall of the Crawford thrust, within ~10 km of its mapped southern limit. Modern processing techniques, particularly refraction statics and pre-stack time migration, have resulted in dramatic improvement in image quality. The seismic data were converted to depth by applying interval velocity models to the pre-stack time migrations.

A cross-section was built through the area by integrating the seismic data with well logs and surface mapping by Coogan (2001). This has led to a modified interpretation to that of earlier published cross-sections. The Lost Creek thrust, a frontal imbricate of the Willard thrust, is now interpreted to cut down through Paleozoic rocks as far as the Cambrian, rather than becoming a flat in the Triassic as previously proposed. It shares a common detachment with the Crawford thrust for a short distance, but ultimately diverges from the Crawford detachment at the Precambrian Farmington Canyon complex. The Lost Creek thrust, along with the Willard thrust, are structurally above (and older than) the Farmington Canyon complex and are thus deformed by it.

The reprocessed data provide new constraints on the regional geometry of the Crawford thrust system in northeast Utah. Future work will involve building cross-sections to document the structure of the Crawford thrust to the south of the Lost Creek area, where this major thrust system changes laterally southwestward from a simple forethrust, to a fault propagation forethrust, to a largely blind triangle zone/passive roof duplex, to a blind thrust tip anticline as it loses slip toward its lateral southwestern tip.

TIMING OF UPLIFT ALONG THE WESTERN EDGE OF THE CENTRAL ANDES, NORTHERN CHILE

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The western edge of the central Andean orogenic system in northern Chile is marked by a crustal scale, west-dipping monocline in the transition zone between the forearc and arc. The monocline is well exposed in the Sierra de Moreno and Sierra del Medio with maximum elevations greater than 4000 meters. Recent reconnaissance work suggests the area is transpressional with many discontinuous thrust faults and strike-slip faults, and the stratigraphy records a change from backarc, fine-grained rocks during the Jurassic to Oligo-Miocene forearc alluvial deposits of coarsening upward conglomerates. Two opposing hypotheses have been put forth to explain the development of the high elevation of this region. One hypothesis proposes uplift of the western edge of the Andes during late Miocene to Recent times in response to thickening of the ductile lower crust. The second hypothesis attributes the high topography to fault motion along a west-vergent thrust system starting in the late Oligocene. I am testing these hypotheses by conducting detailed provenance and stratigraphic analysis constrained by U-Th-Pb ages, field mapping, and (U-Th)/He thermochronology. This region of the forearc contains a stratigraphic record extending from the Jurassic through the Miocene, which will elucidate how paleogeography has evolved during this time interval, and the integration of these data sets will resolve the controversy between the two hypotheses. Understanding the geometry, kinematics, exhumation history, and the history of basin development of the Sierra de Moreno and Sierra del Medio will expound on the forearc tectonic processes operating in this classic Cordilleran orogenic system.

TRACING TURQUOISE FROM SITE TO SOURCE USING RADIOGENIC ISOTOPES

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Turquoise was widely mined and traded throughout the Greater Southwest and Mesoamerica. Reconstructing the networks through which this mineral moved has long been a goal of archaeologists working in these regions. The ability to pinpoint the source of turquoise recovered from archaeological contexts has great potential to enhance our knowledge of both regional and inter-regional trade routes, and better our understanding how the mineral may have linked prehistoric Southwestern societies with Mesoamerica.

We show that high-precision measurements of lead isotopes by multi-collector inductively coupled mass spectrometry (MC-ICP-MS) and conventional strontium isotope analysis by thermal ionization mass spectrometry (TIMS) can effectively discriminate between important turquoise sources in the American Southwest. We have created a database with over 200-paired lead and strontium isotopic measurements on samples from over a dozen important turquoise mining areas to support this assertion. We also present, for the first time, the lead and strontium isotopic measurements of turquoise artifacts found at Redtail Village, a Hohokam site in the Tucson Basin occupied during the Colonial Period (~AD 750-1150). Redtail Village is a significant site because it may have been a locus for the manufacture and distribution of turquoise objects in the Hohokam region at an early date. We have compared these measurements to our existing isotopic database and are able to identify the Silverbell Mountains as the probable (and single) source of the turquoise at Redtail Village.

The results of this study provide strong evidence that lead and strontium isotopes can be used to successfully trace turquoise from archaeological site to geologic source. The development of this database provides a framework for the archaeological community to test hypotheses about ancient turquoise mining and trade in the Greater American Southwest, and should set the foundation for a clearer understanding of the past interactions and connections between Southwestern and Mesoamerican societies.

RECENT TRANSITION IN REGIONAL MANTLE CHEMISTRY BENEATH THE WESTERN CANADIAN CORDILLERA

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New geochemical data from a suite of mafic dike and lava flow samples collected from sites within the western Canadian Cordillera range in age from Eocene to Quaternary, and document a significant transition in mantle chemistry after 10 Ma. Eocene to Miocene age basalts (45 – 10 Ma) emplaced as dikes within the Coast Mountains Batholith contain abundant hornblende, are enriched in large ion lithophile elements (LILE), have negative high field strength element (HFSE) anomalies, and were likely derived from lithospheric mantle ($^{87}\text{Sr}/^{86}\text{Sr}_{\text{avg}} = 0.70430$; $\epsilon_{\text{Nd}} = +4.1$). By contrast, Quaternary valley-filling lava flows have lower LILE concentrations, positive HFSE anomalies, and were likely generated by upwelling asthenosphere ($^{87}\text{Sr}/^{86}\text{Sr}_{\text{avg}} = 0.70292$; $\epsilon_{\text{Nd}} = +8.2$). A regional comparison of numerous mafic rocks from western Canada that are also Eocene to Quaternary in age indicates that the transition in mantle chemistry after 10 Ma was pervasive and widespread. This transition occurred ~40 Ma after the cessation of Cordilleran arc magmatism, suggesting that large-scale transitions in mantle chemistry beneath magmatic arcs may occur on the order of tens of millions of years after the final subduction of oceanic lithosphere.

¹²⁹I AND SR ISOTOPES AS TRACERS OF LARGE-SCALE FLUID MIGRATION IN THE NORTHERN APPALACHIAN BASIN

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Results from previous studies of ore deposits, fluid inclusions, clay mineral assemblages, and hydrologic modeling suggest that brines and hydrocarbons have migrated long distances across the Appalachian basin, driven by topographic gradients and tectonic forces. This pilot study uses iodine and strontium isotopes of basinal fluids as tracers of brine migration in the northern Appalachian basin (W. NY and N.W. PA).

Ten brine samples were collected from oil and gas wells producing from Mississippian, Devonian, and Silurian age formations and analyzed for ¹²⁹I/I, ⁸⁷Sr/⁸⁶Sr, stable isotopes (O, H, and C), and elemental composition. Measured ¹²⁹I/I values (28-1890X10⁻¹⁵) are 5 to 9 orders of magnitude greater than expected cosmogenic values (10⁻¹⁹ to 10⁻²¹), given the depositional age (>350 Ma) of the source organic matter. Fissiogenic ¹²⁹I/I values (50-100X10⁻¹⁵) in Devonian shales were estimated from published ²³⁸U (spontaneous fission to ¹²⁹I) data and can account for only 7 of the high ¹²⁹I/I values. Large ²³⁸U deposits in S.E. PA represent a regional fissiogenic iodine source (calculated ¹²⁹I/I up to 17,000X10⁻¹⁵) that may have been mobilized during the Alleghanian orogeny (~315 Ma). Strontium isotope results show a mixing trend between a radiogenic (0.7210) end-member (consistent with exchangeable ⁸⁷Sr/⁸⁶Sr on smectite-illite clay assemblages), with a low ⁸⁷Sr/⁸⁶Sr (0.7100) end-member (within the range of Paleozoic marine carbonates in the Appalachian Basin). K⁺/Cl⁻ ratios, less than the evaporated seawater trend, have a weak correlation with radiogenic Sr values and may provide evidence for punctuated clay diagenesis (illitization) by high temperature fluids expelled basinward, likely during orogenic events.

GIS APPLIED TO FLOW DIRECTION AND SOURCE AREA OF THE 22.0 MA HARMONY HILLS TUFF, SOUTHWESTERN UTAH, SOUTHEASTERN NEVADA

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Anisotropy of magnetic susceptibility (AMS) is widely used by paleomagnetic scientists as a viable analysis method for determining the flow direction of lava flows and ashflow tuffs. AMS is a measure of the preferred orientation of the magnetic mineral grains within an igneous rock. For this study, AMS is used in conjunction with raster-based GIS to determine the eruption source of the 22.0 Ma Harmony Hills Tuff. To do this, it is assumed that ashflow tuffs flow radially from their source caldera and also that post-eruptive tectonics have not horizontally rotated sample locales or that this deformation can be accurately restored. The analysis in this study follows the method of Hillhouse and Wells (1991), in which the simple area of greatest overlap of the 95% confidence interval cones describing the statistical direction of Kmax axis (axis of greatest magnetic susceptibility, which is aligned parallel to flow direction in ashflow tuffs) defines the most likely map area for the caldera from which the Harmony Hills Tuff was erupted. The use of GIS to perform this process greatly reduces the workload and increases efficiency and accuracy of the method compared with the manual methods proposed by Hillhouse and Wells. Results of the analysis conclusively show a distinct area of greatest overlap suggesting the Harmony Hills Tuff was erupted from a caldera to the north and west of the sample sites. This study is the first application of GIS to this simple technique.

Arizona Historical Society Museum

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