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**Map of the Student Union**

**Map to the GeoDaze Party**
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We would also like to thank the session chairs and evaluators, as well as the many unmentioned students, professors and staff who contributed their time and effort in assisting us with GeODaze 2006.
Welcome to the University of Arizona’s 34th annual GeoDaze Geosciences Symposium! GeoDaze, a student-organized symposium, brings together members of the academic and professional communities to highlight graduate and undergraduate research. We are excited to bring you 38 presentations spanning many aspects of the geosciences.

This year’s topics include paleoecology, biogeochemistry, geomorphology, sedimentology, paleoclimatology, planetary geology, GIS and remote sensing, geophysics, economic geology, geochemistry, and tectonics. The 25 talks will be held on Thursday and Friday in the Arizona Ballroom A (North) and the 13 posters will be on display Thursday afternoon in the adjacent Tucson and Catalina rooms.

We would like to extend a warm welcome to this year’s keynote speaker, Dr. A. Wesley Ward, Western Regional Geologist, USGS. Dr. Ward has also held the position of Chief Scientist for the USGS Astrobiology Program. His talk, beginning at 3:00 PM on Friday in the Arizona Ballroom A (North), is entitled “From the South Side of Chicago to the South Side of Mars”.

We encourage you to attend the student slide show at 4:00 PM on Friday, as well as the awards ceremony at 4:30 PM. Following the awards ceremony and the slide show is the annual GeoDaze party, beginning at 6:30 PM. Dr. Randy Richardson, the Geosciences Department Head, will be hosting.

We also hope you will join us from 7:30 AM to 6:00 PM on Saturday for the field trip, led by Drs. Mark Barton and Eric Seedorff. While on this trip we will see a 3-D view into the Laramide arc, related hydrothermal systems, and Cretaceous to Middle Tertiary structural development in the northern Tortilla Mountains, Arizona.

The generous financial support of alumni and friends of the department makes the University of Arizona Geosciences Symposium possible. We would like to thank all of our sponsors, as well as the committee members, students and faculty who have worked so hard to make GeoDaze 2006 a success!

Sarah Thompson
James Girardi
Chairs, 2006 Geosciences Symposium
SCHEDULE OF EVENTS
THURSDAY, APRIL 6™
ARIZONA BALLROOM A (NORTH)
MEMORIAL STUDENT UNION

8:00 COFFEE AND PASTRIES
8:30 GeoDaze Welcome Address        DR. RANDY RICHARDSON

SESSION 1: GEOPHYSICS

9:00 SOURCE PARAMETERS AND RUPTURE PROCESSES OF 13 JUNE 2005 TARAPACA, CHILE EARTHQUAKE        C. BERK BIRYOL

9:15 SLIP RATE VARIABILITY ON THE SAN ANDREAS AND SAN JACINTO FAULT ZONES, SOUTHERN CALIFORNIA        CHRISTINE GANS

9:30 DEEP CRUSTAL EARTHQUAKES, REPEATING EARTHQUAKES AND CRUSTAL VELOCITY PROFILES OBSERVED FROM SIERRA NEVADA EARTHSCOPE PROJECT (SNEP) DATA, SIERRA NEVADA RANGE, WESTERN USA        OWEN V. HURD

9:45 COMPOSITION BENEATH A METAMORPHIC CORE COMPLEX FROM V_p/V_s ESTIMATES        ANDY FRASSETTO

10:00 COFFEE BREAK

SESSION 2: GEOPHYSICS

10:30 SEISMIC STUDY OF THE 1944 SAN JUAN, ARGENTINA (M_w 7.0) EARTHQUAKE IN THE ANDEAN BACKARC        PATRICIA ALVARADO

10:45 HIGH RESOLUTION GEODETIC INVESTIGATION OF THE SEPTEMBER 2005 EPISODIC TREMOR AND SLIP, OLYMPIC PENINSULA, WASHINGTON        SARAH THOMPSON

11:00 NORTH ANATOLIAN FAULT PASSIVE SEISMIC EXPERIMENT: CONTINENTAL LITHOSPHERIC DEFORMATION ALONG A MAJOR STRIKE-SLIP FAULT        A. ARDA OZACAR

11:15 LUNCH BREAK
SECTION 3: ECONOMIC GEOLOGY

1:00 Mineral composition trends of igneous biotites in granitic plutons
Mayo Thompson

1:15 3D modeling and interpretation of vein distribution in the Candelaria Fe-oxide-Cu-Au deposit, Northern Chile
Maria Zavala

1:30 A deeper look at the reconstructed Miami-Inspiration deposits, a productive Laramide porphyry copper system in the Globe-Miami District, Arizona
Dave Maher

1:45 Coffee Break

SECTION 4: POSTERS

2:00 U-Pb ages of detrital zircons in the Holbrook Member of the Moenkopi Formation near Winslow, Arizona
Carl E. Anderson

U-Pb ages of detrital zircons in middle to upper Jurassic eolianites of the Colorado Plateau

Evaluating the duration of the lunar cataclysm
Maria Banks, Robert G. Strom, and David A. Kring

U-Pb ages of detrital zircons in lower Jurassic eolianites of the Colorado Plateau and adjacent areas
Erin V. Brenneman, Joseph R. Amar, and William R. Dickinson

U-Pb ages of detrital zircons in fluvial lower Cretaceous and deltaic upper Cretaceous strata of the Four Corners Region
Jessica J. Bressmer, Erin H. Gleeson, and Erin V. Brenneman

Raman spectroscopic characteristics as compared the composition of aluminous garnets
Gelu Costin, Robert Dembowski, Robert T. Downs, Ren Lu, Layne J. Trinkley, and Hexiong Yang

Applying a process-based model of tree ring formation to high elevation trees
Rebecca S. Franklin, Malcolm K. Hughes, Eugene A. Vaganov, Kevin J. Anchukaitis, and Michael N. Evans
U-Pb ages and apatite fission track ages in the Canyon Range thrust fault group
Frank J. Guerrero and Peter G. DeCelles

U-Pb ages of detrital zircons in the Upper Jurassic Morrison Formation (Saltwater Wash and Westwater Canyon members) of the Four Corners Region, Southwest USA
Owen V. Hurd, Jennifer L. McGraw, and William R. Dickinson

Late Quaternary sequence stratigraphy of Central Lake Tanganyika, East Africa
Michael McGlue, Kiram Lezzar, Andrew Cohen, Anna Felton, and James Russell

Geology and mineral zoning of the San Cirilo intrusive complex, Cajamarca Province, Northern Peru
Rita Pinto

Application of reflectance spectroscopy to hydrothermal systems: development of an in-house practical approach to mineral characterization using available data and equipment
Gary Salais, Morgan Helfrich, Michael Strickler, and Mark Barton

Application of reflectance spectroscopy to hydrothermal systems: application to Fe-oxide (Cu-Au) mineralization near Copiapó, Chile
Michael Strickler, Morgan Helfrich, Gary Salais, Eric Jensen, and Mark Barton
FRIDAY, APRIL 7TH

8:00 COFFEE AND PASTRIES
8:30 WELCOME AND ANNOUNCEMENTS

SESSION 5: QUATERNARY GEOLOGY & PALEOCLIMATE

8:45 STREAMFLOW IN THE WINNIPEG RIVER BASIN, CANADA: TRENDS, EXTREMES, AND CLIMATE LINKAGES
   Scott St. George

9:00 DEPOSITION OF PLAYA WINDBLOWN DUST OVER GEOLOGIC TIME SCALES
   Joseph Cook

9:15 MODEL AND PROXY INSIGHTS INTO TROPICAL PACIFIC VARIABILITY
   Jess Conroy

9:30 GEOCHEMICAL AND SEDIMENTLOGICAL RECORDS OF LATE QUATERNARY CLIMATE CHANGE, LAKE TANGANYIKA, TROPICAL EAST AFRICA
   Anna A. Felton

9:45 COFFEE BREAK

SESSION 6: QUATERNARY GEOLOGY & PALEOCLIMATE

10:15 TEPHROCHRONOLOGY OF THE WESTERN MARGIN, GONA, ETHIOPIA: OR, HOW TO DATE A HOMINID
   Lynnette L. Kleinsasser

10:30 EXAMINATION OF SIWALIK GROUP SEDIMENTS, HIMALAYA: CONSIDERATION OF WEATHERING INTENSITY AND CLIMATE
   Amanda C. Reynolds

10:45 SEARCHING FOR A QUETZAL IN THE COALMINE: HIGH RESOLUTION TROPICAL PALEOCLIMATE RECORDS FROM CLOUD FOREST TREES
   Kevin J. Anchukaitis

11:00 DYNAMIC DECADE-SCALE VARIABILITY AS MEASURED BY A NETWORK OF CORAL δ¹⁸O RECORDS
   Toby R. Ault

11:15 LUNCH BREAK
SESSION 7: STRUCTURE & TECTONICS

1:00  A WINDOW INTO THE CRYSTALLINE CRUST OF CENTRAL TIBET: GEOCHRONOLOGY AND COMPOSITION OF THE AMDO GNEISSES
       JEROME GUYNN

       ALEXANDER PULLEN

1:30  PROVENANCE CONTRASTS REVEALED BY THE U-Pb POPULATIONS OF DETRITAL CHINLE SANDSTONES OF THE FOUR CORNERS REGION, SOUTHWEST US
       JENNIFER D. FOX

1:45  PRELIMINARY STRUCTURAL AND KINEMATIC ANALYSIS OF LATE CRETACEOUS-EARLY TERTIARY SHORTENING IN THE GALIUGUO MOUNTAINS, SOUTHEASTERN ARIZONA
       ROSS WALDRIP

2:00  METAMORPHIC CONSTRAINTS ON THE TECTONICS OF THE MESOZOIC BANGONG SUTURE, CENTRAL TIBET
       JEROME GUYNN

2:15  CALIBRATION AND INTERPRETATION OF THE OXYGEN ISOTOPE RECORD FROM ZADA BASIN, SW TIBET
       JOEL SAYLOR

2:30  COFFEE BREAK

3:00  KEYNOTE SPEAKER
       FROM THE SOUTH SIDE OF CHICAGO TO THE SOUTH SIDE OF MARS
       DR. A. WESLEY WARD
       USGS WESTERN REGIONAL GEOLOGIST

4:00  SLIDE SHOW
       JENNIFER BOERNER
       ANDREW FRASSETTO
       SCOTT ST. GEORGE

4:15  AWARDS CEREMONY

4:45  CLOSING ANNOUNCEMENTS

6:30  GEODAZE PARTY
       DR. RANDY RICHARDSON
Saturday, April 8th 2006 GeoDaze Field Trip

3-D VIEW OF THE LARAMIDE ARC, RELATED HYDROTHERMAL SYSTEMS, AND CRETACEOUS TO MIDDLE TERTIARY STRUCTURAL DEVELOPMENT, NORTHERN TORTILLA MOUNTAINS, ARIZONA (WITH THE GENEROUS SUPPORT OF CONOCOPHILLIPS)

LED BY DRS. MARK BARTON AND ERIC SEEDORFF

Trip Itinerary:

7:30 Depart from the Gould-Simpson loading dock and drive to Kearny, AZ. If time permits, we will stop at Winkelman, AZ.

9:00 Stop at Kearny, AZ for a regional overview. Drive to Ray mine overlook.

9:45 Overview of Granite Mountain-Ray intrusive complex, hydrothermal system, and structure; possible follow-up stop on AZ Hwy 177 to look at igneous rocks and hydrothermal alteration. Drive to Black Copper Wash.

10:45 Hike up Black Copper Wash to look at Proterozoic and Laramide igneous rocks, hydrothermal features, mid-Tertiary extensional faults, and active (natural) weathering of porphyry system (about 1.5 km round trip).


2:30 Field relationships and petrology of the Teacup pluton and overview of the Laramide arc; includes a 1 km hike along contact to look at various igneous rocks and hydrothermal features deep at deep structural levels in the Grayback-Riverside complex.

5:00 Drive back to Tucson, returning to Gould-Simpson no later than 7:00.

Participants should be prepared for hikes in the desert. Please bring proper footwear, clothing, sun protection, and plenty of water. Hammer, hand lens, acid bottles, and hand magnets are also suggested. Lunch will be provided.

To register, please go to www.geo.arizona.edu/geodaze/2006/fieldtrip/ to enter your name or speak with a GeoDaze volunteer at the information desk.
SESSION 1: GEOPHYSICS

SOURCE PARAMETERS AND RUPTURE PROCESSES OF 13 JUNE 2005 TARAPACA, CHILE EARTHQUAKE

C. BERK BIRYOL

Department of Geosciences, University of Arizona

The source process of 13 June 2005 Tarapaca, Chile (Mw 7.8) earthquake is studied using teleseismic body waves, and utilizing a pulse stripping inversion method. This earthquake occurred in the subducting Nazca plate at a depth of ~100 km. The large magnitude of this event encouraged us to study the faulting process to find out if the rupture penetrated through the entire subducting oceanic lithosphere or not. In this study, we used data from 34 Global Seismic Network stations with a good azimuthal distribution. The Harvard Centroid Moment Tensor solution for this earthquake is a normal fault mechanism with one steeply east dipping plane and another shallow, west dipping plane. The solution locates the hypocenter at a depth of 95 km, within the eastward subducting Nazca Plate. In order to test these source parameters and to get better constraints on the orientation of the rupture plane, we relocated the aftershocks of the main event using a single event relocation technique. We analyzed locations of aftershocks to check for the presence of a preferred orientation, favoring one of the two nodal planes suggested by the focal mechanism. In addition, body wave inversions are carried out for different fault orientations and depths of the rupture plane to determine the slip pattern and energy release during the rupture process. A simple parameter space search algorithm is utilized for this purpose and the inversions were more sensitive to the changes of the dip of the fault plane rather than the depth of the hypocenter. We also considered the fit between the polarities of the first P wave arrivals to test the focal mechanism solution. The results of this test suggest a slightly steeper east dipping plane and a shallower west dipping plane for the focal mechanism. The inversion results suggest a rupture process with the ~60% of the total energy release during the first 10 seconds of the event. The results also suggest that the positions of the main energy release occurred within ~ 25 km of the hypocenter. This indicates that, most of the displacement along the fault plane was localized in a relatively confined area around the hypocenter.

SLIP RATE VARIABILITY ON THE SAN ANDREAS AND SAN JACINTO FAULT ZONES, SOUTHERN CALIFORNIA

CHRISTINE GANS¹, KEVIN FURLONG², ANKE FRIEDRICH³, and RICK BENNETT⁴

(1) Department of Geosciences, University of Arizona
(2) Department of Geosciences, Penn State University
(3) Institute for Geology and Paleontology, University of Hannover

The San Andreas plate boundary fault system through Southern California (34° - 37° N) is composed of a complex suite of strike-slip faults, with the San Andreas and San Jacinto Fault
Zones playing a major role in partitioning deformation between the Pacific and North American plates. The total present-day (REVEL-1) Pacific-North American plate motion rate is \( \sim 50 \) mm/yr in Southern California, while the GPS velocity differences observed across the major faults in this region range from 35 to 40 mm/yr, accommodating only \( \sim 70\% \) of the total plate motion. A comparison of published geologic slip rates determined over varying time scales reveals variations in geologically determined fault slip rates (based mostly on paleoseismological investigations and offset geologic features), with the southernmost San Andreas having much slower slip rates for the recent past (\( \sim 30 \) ka) than the longer-term geologic rates. Further, these geologic rates are much slower than the present-day geodetically determined velocities for the same locations. Because there appear to be variations in slip rate along fault strike for current deformation (based on geodesy), it is plausible that such variations also existed in the past. Care should therefore be taken when inferring the temporal extent of geodetic data, because these data may not reflect long-term crustal deformation.

DEEP CRUSTAL EARTHQUAKES, REPEATING EARTHQUAKES AND CRUSTAL VELOCITY PROFILES OBSERVED FROM SIERRA NEVADA EARTHSCOPE PROJECT (SNEP) DATA, SIERRA NEVADA RANGE, WESTERN USA

OWEN HURD, GEORGE ZANDT, and HERSH GILBERT

Department of Geosciences, University of Arizona

The Sierra Nevada EarthScope Project (SNEP) is a multiple institution, collaborative research project focused on investigating the structure and evolution of the Sierra Nevada batholith in Eastern California. The first phase of the project (summer 2005-summer 2006) saw the deployment of over forty (40) broadband seismometers spanning the Central Sierra Nevada from Fresno, California to just south of the Lake Tahoe region. These seismic stations recorded several small, local earthquakes in the western Sierra Nevada foothills that were mostly located from 15 to 100 km north of Fresno and were not present in other regional catalogs. Seismicity in this region is notable because it occurs in the interior of a plate away from major known faults. Forty-three (43) events were picked on as many as 11 SNEP stations and located. These events occurred from late May to early October 2005 at a rate of \( \sim 10 \) per month and were located between 20 and 35 km depth. Past studies have found that events from similar locations in the western Sierra Nevada foothills exhibited \( M_L \) magnitudes from 0 to 3.2 (Wong and Savage, 1983, BSSA). Direct comparison between waveforms of picked events occurring in clusters (2-5 events) found that several events had nearly identical waveforms. This suggests similar rupture locations and characteristics despite the events having occurred a couple days to several weeks apart. A set of larger regional events that were present in the University of Nevada Reno catalog were picked from the SNEP data in order to estimate crustal velocities along various transects spanning the Sierra Nevada. Depths for this set of events ranged from 7 to 23 km. Average crustal \( V_p \) values obtained from one event (\( M_L \), 3.23, depth 18.8 km.) imply a decrease from approximately 6.0 km/s below the SW Sierra Nevada to less than 5.8 km/s below the NE Sierra Nevada Foothills for \( P_g \) arrivals within 140 km of the event. These velocities reflect lithologies shallower than the depth of the earthquake and are not sensitive to lower crust. This observation may be a consequence of the shift from cold plutonic rocks below the SW Sierra Nevada to...
warmer volcanic materials within Owens Valley to the east of the Sierra Nevada and/or regions
of partial melting beneath the valley.

**COMPOSITION BENEATH A METAMORPHIC CORE COMPLEX FROM Vp/Vs
ESTIMATES**

ANDY FRASSETTO, HERSH GILBERT, GEORGE ZANDT, and SUSAN BECK

*Department of Geosciences, University of Arizona*

The Consortium for Arizona Reconnaissance Seismic Experiment (COARSE) is an array of 9
broadband seismometers deployed across eastern Arizona. High quality teleseismic receiver
functions generated from these data provide constraints on crustal properties in the southern
Basin and Range. Most receiver functions in the COARSE dataset exhibit well-defined moveout
of the primary P-S converted phase from the Moho and its reverberation. By using a parameter
space search we can confidently estimate crustal Vp/Vs and thickness from these arrivals. Our
findings show that high elevation metamorphic core complexes in the southern Basin and Range
exhibit anomalously high Vp/Vs (1.83) and similar crustal thickness (29-30 km) when compared
to lower elevations in the region.

At station TUC an extensive set of receiver function data sample both the Catalina-Rincon
metamorphic core complex and the adjacent Tucson basin. There exists a distinct, well-
constrained trend towards high Vp/Vs (1.85) beneath the core complex and low Vp/Vs (1.71)
beneath the basin. Crustal thickness is similar for both settings. Geophysical studies have long
shown that generalized composition (e.g. mafic vs. felsic) strongly influences Vp/Vs, wavespeed
and density. Modeling of seismic properties based on the composition of plutons within the
Catalina-Rincon core complex indicates that the observed high Vp/Vs may result from
substantial amounts of a high density plagioclase-rich, quartz-poor rock intrusive series from 75-
65 Ma. These plutons contain higher density and Vp/Vs than both the Precambrian basement and
younger Tertiary plutons. Paradoxically, isostatic modeling suggests that the crust is ~85 kg/m³
less dense than the surrounding Basin and Range in order to keep the core complex at its high
elevation. These results support an existing model for core complex uplift that requires the crust
to be broken by high angle faulting, but differ in that no isostatic root is observed in the vicinity.
These results also argue that substantial compositional heterogeneity of the crust can occur over
a short distance and provide a clue as to how areas that underwent significant Tertiary extension
may have been preconditioned for orogenic collapse.
SESSION 2: GEOPHYSICS

SEISMIC STUDY OF THE 1944 SAN JUAN, ARGENTINA (Mw 7.0) EARTHQUAKE IN THE ANDEAN BACKARC

PATRICIA ALVARADO and SUSAN BECK

Department of Geosciences, University of Arizona

The large earthquakes during the last century makes San Juan a region of Argentina ideal for studying the crustal Andean back-arc deformation related to the flat slab subduction. Although there are a large number of slab earthquakes, the most destructive earthquakes are the moderate-to-large events located in the continental crust with focal depths < 35 km. Earthquakes in 1894, 1944, 1952, and 1977 have caused extensive destruction in the vicinity of San Juan. The earthquakes appear to occur on blind thrusts within the crust that do not break the surface but cause considerable damage when they occur near population centers. The earthquake on 15 January 1944 destroyed San Juan and caused ~5,000 deaths. It is considered the largest natural disaster in Argentinean history. The 1977 earthquake killed 65 people. This is the only event studied in any detail. Its (Mw 7.5) seismic source was composed of two shocks separated by 64 km and 20 seconds with epicenters related to blind thrust faults in the westernmost thick-skinned Sierras Pampeanas basement uplifts. Interestingly, the 1944 earthquake epicenter lies in between the Precordillera and the Sierras Pampeanas coincident with the most populated area of San Juan. We have analyzed historical seismograms of the 1944 earthquake. The long-period P waveform modeling, P-wave first motions and depth phase analysis indicate a compressional focal mechanism of Mw 7.0. The event had a simple pulse of moment release at a focal depth < 11 km suggesting that most of the moment release occurred near its epicenter. Reported maximum (IX) intensities for the 1944 earthquake includes downtown San Juan and its northern localities. Our results indicate that the 1944 event is very likely related to the thrust fault that generated 7-km surface rupture in the eastern Precordilleran La-Laja fault segment during this earthquake. This style of deformation is similar to that observed in the Sierras Pampeanas, dominated by east-dipping thrust faults responsible for their uplift. This enhances the seismic hazard around San Juan, located on a large synclinal structure with Neogene and Paleozoic strata, from both blind and exposed thrust faults.

HIGH RESOLUTION GEODETIC INVESTIGATION OF THE SEPTEMBER 2005 EPISODIC TREMOR AND SLIP, OLYMPIC PENINSULA, WASHINGTON

SARAH THOMPSON1, RICK BENNETT1, SIGRUN HREINSDÓTTIR1, DAN JOHNSON2

1. Department of Geosciences, University of Arizona
2. Department of Earth and Space Sciences, University of Washington

The recent discovery of periodic deformation transients along the Cascadia margin using continuous GPS altered the way we view the physical and geological processes occurring in
subduction zones. GPS provides a unique observation of such an event, during which the slip releases strain without detectable seismic shaking. The frictional properties of the interface are such that quasi-stable sliding can occur down-dip from the seismogenic zone thereby transferring stress to the upper, locked portion of the subduction interface\(^1\). The magnitude of this stress transfer, and thus its potential to trigger the next great earthquake, depends critically on the rates and pattern of aseismic slip accumulation. After the initial 1999 observation of this process, lasting a duration of ~10 days, analysis of data back to 1994 revealed multiple slip with an average recurrence time of ~14 months\(^1,2\). The surface expression of the transient deformation, which is opposite in direction to the long-term interseismic deformation, amounts to ~4-5 mm and is interpreted to represent ~20 mm of westward displacement along the interface over an area of 50 by 300 km\(^2\). In August 2005, a dense network of 29 semi-permanent GPS receivers was deployed in the Olympic Peninsula to capture an anticipated September event. The stations ran for approximately three months and successfully measured transient deformation. We present time series of GPS data collected during the three-month observation period and a map of the associated displacement field.


NORTH ANATOLIAN FAULT PASSIVE SEISMIC EXPERIMENT: CONTINENTAL LITHOSPHERIC DEFORMATION ALONG A MAJOR STRIKE-SLIP FAULT

A. ARDA OZACAR, C. BERK BIRYOL, SUSAN BECK, and GEORGE ZANDT

Department of Geosciences, University of Arizona

The North Anatolian Fault (NAF) is one of the world's largest active continental strike-slip faults. Despite much geological work at the surface, the deep structure of the NAF is relatively unknown. North Anatolian Fault Passive Seismic Experiment is mainly focused on the lithospheric deformation occurring along this newly coalescing continental transform plate boundary. In the summer of 2005, we deployed 5 broadband stations near the fault to gain more insight on the background seismicity and we will be deploying 35 additional broadband stations along two transects crossing the main strand of NAF and its splays.

In this study, we analyzed 6 months of data recorded by our 5 running stations. In the region recorded local seismicity is not limited to a narrow band near the NAF rather widely distributed suggesting widespread continental deformation especially in the southern block. We located two earthquakes (M>4) that are close to our stations. According to our results, both events occurred 40-50 km south of the NAF at the upper crust (6-9 km) along a normal fault with strike-slip component that previously ruptured during June 6, 2000 Orta-Cankiri earthquake (M=6).

In order to understand the ongoing deformation and present lithospheric structure, we computed over 40 teleseismic receiver functions at each station and applied a grid search scheme for crustal thickness and Vp/Vs using arrival times of the Moho pulse and its multiples. According to our results, crust is relatively thin (35 km) in a region of high topography and has a
relatively high Vp/Vs ratio (>1.8) supporting the presence of partial melt in the crust and the substantial role of mantle in maintaining the elevation.

Specifically, receiver functions at station ALIC which is located on the main strand of NAF shows a sharp change in crustal structure across the fault. These preliminary results show that future work with more data from our dense regional network will reveal more conclusive evidence regarding the structural details of the lithosphere near the NAF.

Session 3: Economic Geology

Mineral Composition Trends of Igneous Biotites in Granitic Plutons

Mayo Thompson, William Stavast, and David Johnson

Center for Mineral Resources, Department of Geosciences, University of Arizona

This study focuses on igneous mineral compositions from a host of granitic plutonic rocks associated with world-class copper porphyry deposits in the Globe-Miami, Ray, and Pima districts in Central and Southern Arizona. We studied six major igneous bodies in the Globe-Miami, Ray, and Pima districts: Schultze and Granite Mountain biotite granites, Teacup hornblende-biotite granodiorite, and Grayback and Solitude two mica granites. These plutons range in age from 60-75 Ma and are metaluminous to peraluminous in composition. Two plutons, the Granite Mountain and Schultze biotite granites, are spatially and temporally associated with multiple deposits containing economic Cu mineralization while others such as the Teacup granodiorite and the two mica granites are only known to contain minor Cu mineralization. Igneous biotite, hornblende, apatite, and other mineral compositions can be used to relate transition metals, halogens, and alkalis, including rare-earth metals with magmatic evolution and porphyry Cu formation. Comparison of mineralogical compositions between the various plutons illuminates important differences between copper-productive and -barren igneous systems.

The following values are normalized molar values based on electron microprobe analyses. The range of Fe/(Fe+Mg+Mn) values for biotites from the Grayback and Solitude two mica granite, Schultze biotite Granite, Teacup and Sierrita Granodiorite yield values 0.47-0.50, 0.51-0.65, 0.37-0.51, 0.37-0.51, 0.34-0.48 respectively. The range of F/Cl values for the same biotites were 15-266, 2-50, 1-356, 1-35, and 1-262 respectively. The range of Fe/(Fe+Mg+Mn) values for amphibole from the Teacup Granodiorite and Schultze biotite Granite are 0.27-0.48 and 0.32-0.46. For F/Cl, the ranges were 0-326 and 1-33 respectively. A significant conclusion at this point is that biotites from plutons associated with significant Cu mineralization contain lower iron contents than other similarly aged plutons in their respective districts and other plutons worldwide (i.e. Sierra Nevada Batholith). The data covering the “barren” plutons show similar mineral compositions to other fresh calc-alkaline plutons worldwide.
3D MODELING AND INTERPRETATION OF VEIN DISTRIBUTION IN THE CANDELARIA Fe-OXIDE-Cu-Au DEPOSIT, NORTHERN CHILE

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Understanding the distribution and types of veins and hydrothermal alteration can contribute to the practical understanding of the distribution of metal grades, metallurgical properties, and mining characteristics in a mineral deposit. The Candelaria copper-gold (-magnetite) deposit, located in northern Chile was discovered in 1985 and put into production in 1995. Over 1000 diamond drill holes have been logged using various methods (often incompatible) and digitized, yet much of this information, notably the types, distribution, and abundance of veins has not been utilized either for production purposes or for mine-, district-, or global-scale exploration.

This study uses the mine database of approximately 1100 diamond drill. Original databases describe lithological, structural, veins, mineralogical, and alteration features in four different formats. These were merged, as best as possible, to generate an internally consistent dataset that will be utilized to model the distribution of veins, rocks, and structures of the deposit. This has been performed using MineSight®, a spatial and statistical modeling program. With this approach, systematic, previously unrecognized patterns can be seen in the vein distributions and in related features. These include distribution of various types of quartz veins, and veins containing different calcium-rich mineral assemblages (including distinctive actinolite, anhydrite, epidote, and garnet). Preliminary models show that contrary to the suggested by Williams et al, 2005, calcite veins are common at depth. Quartz veins are widespread, but ptygmatic quartz veins are mostly at depth, and commonly with anhydrite veins. Ca-rich veins tend to be relative deep and commonly related to high Cu and Au grades.

The complexity of vein types and the inconsistent methods used in the original logging complicate interpretation of the patterns. The patterns may be useful in guiding mine- and district-scale development drilling. From a genetic perspective, it is apparent that the zoning does not match standard models for porphyry copper(-gold) deposits or copper(-gold) skarns (e.g., Seedoff et al., 2005; Meinert et al., 2005), nor does it fit the simple models suggested for igneous-hosted iron-oxide(-copper-gold) deposits (Williams et al., 2005). Instead, as recognized in earlier work (Ryan et al., 1995; Marschik and Fontbote, 2001), Candelaria represents an unusual variant probably reflecting its setting in supracrustal rocks adjacent to the causative (?) batholith. These results combined with other geologic, geochemical, geophysical information can create a more complete picture of this unusual, economically important deposit.
A DEEPER LOOK AT THE RECONSTRUCTED MIAMI-INSPIRATION DEPOSITS, A PRODUCTIVE LARAMIDE PORPHYRY COPPER SYSTEM IN THE GLOBE-MIAMI DISTRICT, ARIZONA

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Numerous porphyry copper deposits and prospects occur in and around the ~64 Ma (new U-Pb on zircon) Schultze Granite, a composite, felsic Laramide pluton that crops out over ~50 km² in the Globe-Miami-Superior region. There are more than 20 significant mines and larger prospects that contain more than 30 Mt of copper, and there are hundreds of smaller vein deposits and prospects. New interpretations of the middle Tertiary extensional structure in the area indicate the deposits and prospects are dismembered and tilted portions of perhaps as few as four, large, magmatic-hydrothermal systems, all formed roughly contemporaneously with the Schultze pluton. The Tertiary extensional dismemberment has vertically telescoped the rocks such that many crustal levels of the systems (from <1 km to ~10 km paleodepths) are exposed at the present-day land surface. Our new mapping, combined with a new structural interpretation, provides insights into the deepest levels of known, well-mineralized porphyry copper systems and leads to new exploration techniques for deposits in these highly extended terrains.

Several piercing points establish net displacements of faults across the Globe-Miami district, though several important faults are not observed at the present surface. A new cross section through the Schultze pluton has restored several deposits in the Miami-Inspiration system that, recombined, total ~9 Mt of copper. We recognize one area, exposed along Pinto Creek in the west-central portion of the district, to be the deep levels or “roots” of the well-mineralized Miami-Inspiration porphyry copper system. Within the center of the hydrothermal system, the deep levels contrast with the shallower levels. We observe dominantly phaneritic rocks rather than porphyries; alternating ductile and brittle deformation rather than mainly brittle deformation; variable vein and dike orientation rather than consistently oriented, sheeted veins; alteration dominated by K-feldspar and muscovite rather than biotite and sericite; and sparse rather than abundant sulfides.

The alternating ductile and brittle character exhibited by the dikes and veins at deep levels may reflect transient changes in the evolving magma chamber and correlate with episodic hydrothermal fluid release and/or introduction of new magma. Ultimately, these deep-level rocks potentially allow us to understand magma chamber dynamics, to recognize faults that were active during Laramide arc magmatism, and to explore paleo-upwards in the crust for economic mineralization in these structurally complicated regions.
SESSION 4: Posters

U-Pb Ages of Detrital Zircons in the Holbrook Member of the Moenkopi Formation Near Winslow, Arizona

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Detrital zircon grains for this study were sampled from Middle Triassic (Anisian) fluvial sandstone forming the Holbrook Member of uppermost Moenkopi Formation as exposed on a prominent butte near Winslow, Arizona. U-Pb ages of 100 detrital zircon grains were analyzed by LA-ICP-MS using a beam diameter of 50 microns. Analytical data were then filtered to reject grains with >20% age discordance, leaving 88 grains that yielded reliable results. Varied detrital zircon age populations include prominent clusters of Permian-Triassic grains (16% in the range of 240-270 Ma) and Neoproterozoic grains (7% in the range of 560-620), with the largest tight cluster being Mesoproterozoic grains (25% in the range of 1400-1500 Ma). Subordinate and more subdued age clusters include both younger and older Mesoproterozoic grains (16% Grenville in the range of 1000-1300 Ma; 16% Yavapai-Mazatzal in the range of 1600-1800 Ma). The Permian-Triassic grains were probably derived from the East Mexico arc, Paleozoic and Neoproterozoic grains most likely from the Ouachita-Appalachian orogen, and the sharp Mesoproterozoic cluster (1400-1500 Ma) almost certainly from granitic rocks intruded into the nearby Yavapai-Mazatzal belt of southwestern Laurentia. Other Mesoproterozoic grains could also have been derived from southwestern Laurentia, although Grenville grains could have come from the Ouachita-Appalachian orogen or nearby eastern Mexico (Oaxaquia). In nonmarine Moenkopi strata, paleocurrents flowing to the west and northwest toward marine equivalents in Utah and Nevada are compatible with a fluvial system with headwaters embracing southwest Laurentia (Yavapai-Mazatzal belt), the Marathon suture of the Ouachita system, and the Permian-Triassic East Mexico arc built on Gondwanan crust in eastern Mexico.

U-Pb Ages of Detrital Zircons in Middle to Upper Jurassic Eolianites of the Colorado Plateau

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U-Pb ages were determined for detrital zircon grains (~100 per sample) in six samples of Middle to Upper Jurassic eolianites from the Colorado Plateau: Page Sandstone interfingering with Carmel Formation; younger Entrada Sandstone at North Wash in Utah, near Moab in eastern Utah, and near Gallup in northern New Mexico; and still younger Bluff Sandstone in southern Utah and Zuni Sandstone near Gallup. Zircon grains were dated by laser ablation ICP-MS using a beam diameter of 35-50 microns. After analysis, 4%-15% of the grains from each sample were removed from consideration because of either >20% age discordance or poor
analytical precision. Approximately 80%-90% of the detrital zircon grains are older than 300 Ma, and include age populations similar to those in Early Jurassic ergs of the Colorado Plateau. By analogy, grains >300 Ma represent sediment derived primarily from the Appalachian orogen and secondarily from interior Laurentia. Nevertheless, 10%-20% of the detrital zircons (<300 Ma) were evidently derived from post-Carboniferous magmatic arcs lying south or west of the Colorado Plateau. Page Sandstone and Entrada Sandstone from west of the Colorado River contain only 1%-2% of the arc-derived grains, and are not amenable to close analysis. Entrada Sandstone from farther east near Moab and Gallup contains 7%-25% of the arc-derived grains, and approximately two-thirds in each case are 240-300 Ma, suggesting ultimate derivation from the East Mexico Permian-Triassic arc developed along the flank of Gondwanan Mexico after closure of the Ouachita suture belt with Laurentia. Jurassic paleorivers flowing northward from Mexico may have transported East Mexico arc detritus into the continental interior where prevailing paleowinds blowing toward the southwest could then have delivered sediment to the Entrada erg. Younger Bluff Sandstone and Zuni Sandstone of probable Oxfordian age contain 11%-14% arc-derived grains, and more than two-thirds in each case are 160-240 Ma, suggesting derivation from the continental-margin arc of the Cordilleran orogen. Prevailing paleowinds blowing from the west by Oxfordian time may have influenced eastward transport of sandy Cordilleran arc detritus to the Colorado Plateau.

EVALUATING THE DURATION OF THE LUNAR CATACLYSM

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The Late Heavy Bombardment (LHB) of the Moon represents an intense flux of impacting asteroids around ~3.9 Ga that appears to have affected the entire inner solar system. The size distribution of craters on the Moon suggests the impacting objects were delivered from the Main Asteroid Belt in a size-independent manner, implying that the bombardment was triggered by a rapid orbital migration of the giant planets and sweeping of resonances through the asteroid belt over a time scale of ~10 - 150 My. In this study, we examined the size distributions of impact craters around 3 impact basins of the Moon and integrated that data with measured ages of the 2 youngest basins to independently evaluate the duration of the bombardment.

Craters were counted and measured in Nectaris Basin and the South Pole-Aitken Basin (SPA), and compared to pre-existing counts for the Orientale Basin and the average nearside lunar highlands. Crater diameters were plotted utilizing the “Relative” plot method in order to determine relative ages and then re-arranged to illustrate R values vs. age. An exponential fit was calibrated using radiometric ages for Orientale (3.80-3.84 Ga) and Nectaris (3.90-3.92 Ga) so that the age of the SPA and the average age of the highlands could be determined from their R-values.

The Orientale Basin was found to have the youngest relative surface age followed by the Nectaris Basin, the average highlands and the SPA. The exponential fit gives age ranges of ~3.92-3.96 Gy for the nearside highlands, ~3.96-4.04 Gy for the SPA, and a predicted LHB duration of ~120-240 My. The range predicted for the duration of the LHB lies partially within
the constraint of ~10-150 My established by previous studies. We have assumed that the SPA formed at or after the peak bombardment of the LHB and that the cratering rate decayed exponentially. Greater rates of decay or a spike in the rate after the formation of the SPA would make these ages and the LHB duration upper limits and thus the lower portions of these ranges are more realistic.

**U-Pb AGES OF DETRITAL ZIRCONS IN LOWER JURASSIC EOLIANITES OF THE COLORADO PLATEAU AND ADJACENT AREAS**

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U-Pb ages of detrital zircons from Lower Jurassic eolian sandstones (180-200 Ma) of the Colorado Plateau were obtained by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). Units analyzed include the Navajo Sandstone and Wingate Sandstone of the Glen Canyon Group at North Wash, Nugget Sandstone equivalent to the Glen Canyon Group near Thistle, and Aztec Sandstone equivalent to Navajo Sandstone at Whitney Pockets. For each sample, one hundred individual zircon grains were analyzed, but analyses with >20% discordance or >10% uncertainty were removed from consideration. $^{206}\text{Pb}/^{238}\text{U}$ ages (for grains <1.0 Ga) and $^{206}\text{Pb}/^{237}\text{Pb}$ ages (for grains >1.0 Ga) were plotted on an age probability diagram of frequency versus age. All four samples contain six similar zircon age populations: Paleozoic (240-540 Ma), Pan-African (580-780 Ma), Grenvillean (860-1260 Ma), Mesoproterozoic (1300-1520 Ma), Late Paleoproterozoic (1560-1860), and Early Paleoproterozoic and Archean (>1860 Ma combined). The principal provenance of the Glen Canyon Group and its equivalents to the northwest (Nugget) and southwest (Aztec) is interpreted to have been the Appalachian orogen. Approximately 75% of the grains for each sample exhibit Paleozoic, Pan-African, or Grenvillean ages, with the most prominent age spike at 1.0 Ga – 1.2 Ga (Grenvillean). Our sample of Navajo Sandstone contains a relatively large population of 1850-2150 Ma Early Paleoproterozoic grains (n=15), provisionally from northwest Laurentia, but such grains are rare, one or two per sample, in samples of Wingate, Nugget, and Aztec Sandstones. All samples lack significant populations of Mesoproterozoic and Late Paleoproterozoic grains, suggesting that nearby basement sources of detritus including the Ancestral Rocky Mountains contributed little to the Jurassic eolian sands. To transport large volumes of sandy detritus from the Appalachian margin of the continent to the western interior during Early Jurassic time, a system of east-west flowing paleorivers is postulated, with headwaters in the incipient Atlantic rift belt. Paleowinds blowing toward southerly azimuths then transported sand into the Early Jurassic ergs of the Colorado Plateau.
U-Pb AGES OF DETRITAL ZIRCONS IN FLUVIAL LOWER CRETACEOUS AND DELTAIC UPPER CRETACEOUS STRATA OF THE FOUR COUNCERS REGION

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Detrital zircon grains were collected from the fluvial Lower Cretaceous Burro Canyon Formation (two samples, one near Bluff UT and one near Ghost Ranch NM) and three Upper Cretaceous deltaic sandstone units: Turonian Toreva Formation of the Black Mesa basin and Gallup Sandstone of the San Juan basin; Campanian Menefee Formation of the Mesaverde Group in the San Juan basin. Paleocurrent indicators and facies relations for all units sampled document stream paleoflow from southwest to northeast. U-Pb ages of 100 detrital zircon grains per sample were analyzed by LA-ICP-MS using a beam diameter of 50 microns. Analytical data were filtered to exclude detrital zircon grains with >20% age discordance. All three deltaic Upper Cretaceous samples contain a prominent spike in detrital zircon ages at 1600-1800 Ma and a more subdued spike at 1400-1500 Ma, both probably derived from Precambrian basement of the Yavapai-Mazatzal belt as exposed along the Mogollon highlands of the Bisbee rift shoulder, with Grenvillian grains (1040-1280 Ma) distinctly subordinate. Upper Cretaceous samples also include variable proportions of Mesozoic grains (<250 Ma) derived from the Cordilleran arc, with the largest proportion present in the youngest (Menefee) sample. The fluvial Lower Cretaceous (Burro Canyon) samples also contain subordinate grains (<250 Ma) derived from the Cordilleran arc, and Mesoproterozoic grains (1400-1900 Ma) probably derived mainly from Yavapai-Mazatzal exposures in the Mogollon highlands, but the most prominent age spikes are Grenvillian (900-1300 Ma), and both Paleozoic-Panafrican (300-850 Ma) and Archean (2500-2800 Ma) age clusters are present as well. The more varied detrital zircon population of the Lower Cretaceous Burro Canyon Formation, as compared to the Upper Cretaceous units, is interpreted to reflect recycling of detrital zircons from Paleozoic-Mesozoic sedimentary cover eroded from the basement of the Mogollon highlands prior to mid-Cretaceous Dakota onlap of the Bisbee rift shoulder. The shift in detrital zircon content from Lower to Upper Cretaceous strata of the Four Corners region is thus viewed as a record of unroofing (inverted stratigraphy) in the provenance lying southwest of the Black Mesa and San Juan basins.

RAMAN SPECTROSCOPIC CHARACTERISTICS AS COMPARED TO THE COMPOSITION OF ALUMINOUS GARNETS

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Raman spectroscopy exemplifies a fast, non-destructive way to identify a mineral without sample preparation. Through research conducted on the RRUFF project, it is well documented that peak positions vary in frequency as a function of mineral composition. Two papers have illustrated a relationship that exists between the peak positions of the spectra and the
I experimentally observed chemistry of minerals for (Mg-Fe-Ca) pyroxenes, highlighting the change in spectra from a cation transfer of Mg to Fe (Huang 2000, Wang 2001). After seeing this possible correlation, we undertook a study of Raman spectroscopy and chemical variance to distinguish if we could use Raman spectroscopy to analyze the spectra of aluminum-bearing garnets. We analyzed the spectra of the five Al-bearing garnets: almandine (Fe₃Al₃(SiO₄)₃), andradite (Ca₃Fe₂(SiO₄)₃), grossular (Ca₃Al₂(SiO₄)₃), pyrope (Mg₃Al₂(SiO₄)₃), and spessartine (Mn₃Al₂(SiO₄)₃). Of these five garnets, we have sixteen samples which we have analyzed chemical composition using an electron microprobe and obtained oriented Raman spectra. We propose that a correlation exists in the spectra of our sixteen samples and their chemistry. We have analyzed the dominant Raman peaks of each sample’s spectrum, which reflect the major shift and movements in the structure of the mineral. Through multi-variant analysis, we have interpreted the frequency of the peaks as a function of the minerals’ composition. We will present the correlation in this poster.

APPLYING A PROCESS-BASED MODEL OF TREE-RING FORMATION TO HIGH ELEVATION TREES

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High elevation bristlecone pines (Pinus longaeva), including those in the White Mountains of California have experienced a dramatic increase in annual ring width increment in the 19th and 20th centuries unique in the past 5000 years. To examine potential causes of variation in ring width formation, we applied a process-based model which uses first principles of tree biology and climate data rather than statistical predictions to derive annual growth increments. The Vaganov-Shashkin tree-ring model uses the principles of limiting factors to calculate conifer tree-ring formation integrated over the growing season from daily temperature, precipitation, and sunlight. We used meteorological data from station records of daily precipitation and mean temperature from the comprehensive Global Daily Climatology Network that are, somewhat unusually, available at two high elevation stations in the White Mountains to simulate bristlecone pine tree-ring chronologies there. Missing temperature data are replaced by linearly interpolated values; missing precipitation data were simply set to zero. Temperature is partially corrected for elevational differences by using an adiabatic correction for the mean elevation difference between the actual tree-ring chronologies and the meteorological stations. Increased tree ring growth is noticed to be more evident at higher elevations. This is evident in both actual and simulated ring width, showing that climate data alone can produce this larger upward trend in annual growth increment at higher elevations. We explore how climate and possible CO₂ fertilization might combine to produce the observed trends in high elevation tree growth in western North America.
**U-Pb AGES AND APATITE FISSION TRACK AGES IN THE CANYON RANGE THRUST FAULT GROUP**

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Zircon and apatite fission track ages will yield information to the provenance of the Canyon Range Thrust Fault group and their rate of uplift. The Canyon Range Mountains were once a part of the Sevier Fold and Thrust Belt in the western North American Cordillera. Thermochronology ages of the minerals sampled in the rocks will give an improved idea of the evolution of the Canyon Range Mountains as well as the movement of the Sevier Thrust Belt.

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**U-Pb AGES OF DETRITAL ZIRCONS IN THE UPPER JURASSIC MORRISON FORMATION (SALT WASH AND WESTWATER CANYON MEMBERS) OF THE FOUR CORNERS REGION, SOUTHWEST USA**

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Detrital zircons were collected from the Kimmeridgian Salt Wash and the Kimmeridgian/Tithonian Westwater Canyon Members of the Upper Jurassic Morrison Formation at sites in Utah, Colorado, and New Mexico near Four Corners (Salt Wash from Montezuma Canyon UT and Slick Rock CO on the Dolores River; Westwater Canyon near Recapture Creek UT and Todilto Park NM). A total of 400 detrital zircon grains (100 from each sample) were individually dated using LA-ICP-MS with a beam diameter of 50 microns. Due to >20% discordance or poor precision, 54 grains were removed from consideration, leaving 346 reliable analyses (86.5% of the total). Grains from the Salt Wash Member fall primarily into three dominant age populations at 155-200 Ma, 350-650 Ma, and 950-1250 Ma, with subordinate populations at 1380-1500 Ma, 1640-1850 Ma, and 2580-2800 Ma. Grains from the Westwater Canyon Member are mainly 150-200 Ma and 1020-1740 Ma with broad peaks in the ranges 1020-1200 Ma, 1420-1500 Ma, and 1580-1740 Ma. Prominent age spikes in the 150-200 Ma range strongly suggest derivation of some detritus from the Cordilleran magmatic arc in both members. Other age populations in the Salt Wash Member suggest reworking of sand into the Salt Wash fluvial system from older Jurassic eolianites. Reworking of older sediment is supported by the high quartz content (~90%) and low feldspar content (~3%) of the Salt Wash Member samples, with half the lithic fragments (~7%) resistant chert grains. Other age populations in the Westwater Canyon Member imply more direct derivation of detritus from basement rocks underlying Cordilleran arc assemblages. The lower quartz content (~70%) and higher feldspar content (~20%) of the Westwater Canyon samples, coupled with mainly non-chert lithic fragments (~10%), are supportive of that interpretation. Paleocurrent indicators from the Morrison Formation imply stream flow fanning across the Colorado Plateau from the west and southwest. The differences in the populations of detrital zircon grains and in petrographic modal composition between our samples of Salt Wash and Westwater Canyon Members suggest...
that the two members were deposited as partly overlapping but separate fluvial megafans with apices that tapped different provenances, with Salt Wash sources lying farther west than Westwater Canyon sources.

LATE QUATERNARY SEQUENCE STRATIGRAPHY OF CENTRAL LAKE TANGANYIKA, EAST AFRICA

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The stratigraphic record housed within Lake Tanganyika’s central basin (9-12 Ma) represents an important and unique archive of continental tropical climate change for East Africa. New intermediate resolution, normal incidence seismic reflection data collected by the Nyanza Project (NSF-REU) in the Kalya Accommodation Zone region of Lake Tanganyika records evidence of dramatic lake level changes and fluctuating depositional environments over the late Quaternary. Stacked oblique and sigmoidal clinoforms imaged in lower depositional sequences on the Kalya flexural margin platform are interpreted as coarse-grained, prograding deltas deposited during low lake level conditions. The topset-to-foreset transitions in these Gilbert-style deltas are key geomorphic markers and define a westward shift of the paleo-lake shore by at least 21 km and a hydraulic drawdown of lake level by a minimum of 345 m. High angle seismic discordances and deeply incised channels record the exposure of the Kalya platform to subaerial processes during this regression. In the upper most depositional sequence, low amplitude, parallel, continuous reflections onlap and drape the underlying clinoforms, marking a shift in the lake’s depositional mode to highstand sedimentation accompanying a major transgression. Ground truth data in the form of dated sediment cores indicates significant environmental variability within the youngest depositional sequence over the past ~ 40 ka, which is dominated by organic-rich, fine-grained sediments and diatomaceous oozes. Although seismic facies variability does exist in this sequence, unmistakable indications of large lake level fluctuations are not present or below seismic resolution. The results of this analysis imply that the arid conditions that forced low lake levels in Lake Tanganyika during the Last Glacial Maximum were less severe and perhaps less protracted than earlier intervals of the Pleistocene in tropical East Africa.

GEOLOGY AND MINERAL ZONING OF THE SAN CIRILO INTRUSIVE COMPLEX, CAJAMARCA PROVINCE, NORTHERN PERU

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The San Cirilo intrusive complex is located in the Province of Cajamarca, northern Peru, approximately 570 km north of Lima and 15 km north of the Yanacocha gold mine.
The study area occurs within the northwest trending Miocene metallogenic belt of northern Peru, which includes porphyry type gold-copper systems such as La Granja, Cerro Corona, the Minas Conga belt, Galeno, Michiquillay, and dominate high-sulfidation epithermal gold ± silver systems such as the Yanacocha, Sipan, and La Zanja.

The San Cirilo area contains Early Cretaceous sedimentary rocks and contact-metamorphosed sedimentary rocks of the Goayllarizquisga Group; four types of Tertiary intrusive rocks (gabbro, diorite, rhyodacite and andesite), and middle to upper Tertiary andesitic to rhyolitic volcanic rocks. Isotopic dating by the zircon $^{206}\text{Pb}^{238}\text{U}$ method suggests at least two periods of intermediate (diorite) to felsic (rhyodacite) intrusive activity within the San Cirilo area. Analysis of zircons yielded weighted average $^{206}\text{Pb}/^{238}\text{U}$ ages of 36.4± 0.9 Ma on a diorite and 10.2 ± 0.3 Ma on a rhyodacite. Skarn and possible porphyry style mineralization is related to rhyodacitic and dioritic intrusions that generated stockwork quartz veins and polymetallic, massive sulfide replacement skarn mineralization containing Zn+Pb+Ag+Cu±Au. Mineralization is localized at the contact between siliciclastic rocks of the Carahuaz Formation and underlying limestone of the Lower Cretaceous Santa Formation. A 1:5000-scale outcrop map showing lithology, alteration, and structures identified a northwest-southeast structural corridor that is interpreted to control massive sulfide mineralization and the emplacement of a rhyodacitic stock and associated domes and dikes. The secondary structural controls are dominated by east-west, northeast and north-northeast structures that include silica-matrix limonitic breccias, dikes, hetrolithic pebbles dikes, quartz veins, and polymetallic sulfide veins.

Hydrothermal alteration assemblages are zoned outward from a central zone of quartz-sericite-pyrite within dioritic and rhyodacitic intrusives, to a silicified hornfels assemblage in contact with sandstone, siltstone, and shale of the Lower Cretaceous Carhuaz Formation, to endoskarn-exoskarn assemblages of diopside + garnet + epidote ± serpentine in contact with the underlying limestone of the Santa Formation.

APPLICATION OF REFLECTANCE SPECTROSCOPY TO HYDROTHERMAL SYSTEMS: DEVELOPMENT OF AN IN-HOUSE PRACTICAL APPROACH TO MINERAL CHARACTERIZATION USING AVAILABLE DATA AND EQUIPMENT

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Reflectance spectroscopy using visible, near- infrared (VNIR) and shortwave infrared (SWIR) wavelengths is a powerful tool for identifying many minerals and characterizing selected aspects of their compositions and structural states. Using publicly available data (USGS) and our own results on previously characterized samples, we developed a set of data libraries and routines to examine sheet silicates and mafic minerals that occur in igneous, metamorphic and hydrothermally altered rocks. For this work, we use a recently acquired Applied Spectral Devices (ASD) FieldSpec Pro spectrometer belonging the mineral deposits group within the department of Geosciences. The FieldSpec Pro rapidly
acquires reflectance (or other) spectral data at wavelengths between 350 and 2500 nm with variable resolution (2 nm increasing to 12 nm at long wavelengths). As a result, this method offers a rapid, semi-quantitative approach to mineral characterization – an essential step in mapping, interpreting, and understanding hydrothermal mineral deposits.

To make good use of this instrument, we converted spectral and compositional data from the U.S. Geological Survey (splib05a, Clark et al., 2003) into formats that are simple to use with the spectrometer. This library includes about 500 samples representing about 200 mineral species. Of these, 136 samples have compositional information. For this study we focus on sheet silicates, which are key alteration minerals and petrologic indicators, and on mafic silicates (amphiboles, pyroxenes, garnets) for which compositional data (and ID) would be helpful.

Consistent with published results (see http://speclab.cr.usgs.gov/), we find that it is possible to readily distinguish different sheet silicates based on their reflectance minima. With the mafic silicates, peak positions and spectral shapes readily distinguish between the major mineral groups. Moreover, we find that there is a systematic difference with iron contents and, in some cases, with other compositional differences. We have also generated new spectral data on certain minerals or compositions that are not represented in the USGS database, including orthoamphiboles. These data are being used in a companion study (Strickler et al., GeoDaze 2006) for investigating the nature and distribution of hydrothermal minerals associated with Fe-Cu-Au mineralization in the Copiapo area of northern Chile.


APPLICATION OF REFLECTANCE SPECTROSCOPY TO HYDROTHERMAL SYSTEMS: APPLICATION TO FE-OXIDE (CU-AU) MINERALIZATION NEAR COPIAPO, CHILE

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Center for Mineral Resources, Department of Geosciences, University of Arizona

Based on newly generated and reformatted publicly available spectroscopic data we have used VNIR-SWIR reflectance spectroscopy to examine hydrothermal and igneous minerals from the Copiapo area in northern Chile. The purpose of this study is to determine the nature and distribution of sheet silicates and mafic silicates that are indicators of the intensity and type of hydrothermal alteration. Key characteristics include mineral ID, mineral assemblages, and, insofar as possible, compositions of the minerals. These results can then be used in better understanding zoning of hydrothermal minerals and the distribution of other rock types. We are testing a model that predicts that strongly acid alteration assemblages are generated at high structural levels and may overlie economic mineralization.
Reflectance spectra have been obtained on multiple samples that were collected as part of an ongoing field project in the Copiapo batholith and surrounding rocks. This project has been sponsored by Phelps Dodge Exploration and contributes to district-scale exploration around their Candelaria deposit. We have examined a large number of located samples from the district and some from the deposits to determine: (1) the identity of the sheet silicates and related minerals, (2) variations in the compositions of mafic minerals which can indicate differences in conditions of origin, and (3) spatial distribution of minerals in light of existing mapping.

Preliminary results from spectroscopy, mapping, and electron microprobe analyses show that there are systematic changes in mineral assemblages and compositions across the district. Some zones contain minerals characteristic of advanced argillic hydrothermal alteration, which forms under highly acidic conditions (Meyer and Hemley, 1967) and is postulated to represent the tops of upwelling zones, possibly overlying deeper Fe-Cu-Au mineralization (Barton and Johnson, 2000). Mafic silicates can be readily distinguished when they are abundant, but it is a challenge when they are sparse or intimately intergrown with other minerals, or when they form complex solid solutions within the same mineral group. Nevertheless significant reflectivity differences exist between different mineral associations in the Copiapo batholith, its metamorphic aureole, and the various parts of the hydrothermal systems. These results might also be used as a foundation for remote sensing applications using airborne or satellite hyperspectral datasets.


**Session 5: Quaternary & Paleoclimate**

**Streamflow in the Winnipeg River Basin, Canada: Trends, Extremes and Climate Linkages**

**Scott St. George**

*Department of Geosciences, University of Arizona*

This study uses a network of long-term discharge gauges to examine how river flow in the Winnipeg River basin, Canada has behaved during the last one hundred years. The
Winnipeg River influences the production of over 4600 megawatts of hydroelectricity, and is the most important component of the hydrological system used to generate power in Manitoba. Extreme low annual flows are caused by severe reductions in runoff from spring snowmelt, and follow dry weather during the previous summer and autumn over much of the basin. These conditions are associated with enhanced meridional flow across western Canada, and geopotential height anomalies during the previous autumn and winter that are very similar to the positive phase of the Pacific/North American (PNA) pattern. The winter PNA index appears to be an important control on streamflow in the Winnipeg River at both interannual and decadal time-scales, but may be modulated by conditions in the North Atlantic sector. Mean annual flows have increased by 52% since 1924, primarily because of large increases in winter discharge. Because similar trends are observed for both regulated and unregulated rivers, these increases are not artefacts caused by direct anthropogenic interference in the hydrological system. Increasing summer and autumn precipitation is the most probable cause of the changes in streamflow. The observed trends toward higher flows, combined with recent model projections, suggest that the potential threats to water supply faced by the Canadian Prairie provinces over the next few decades will not include decreasing streamflow in the Winnipeg River basin.

DEPOSITION OF PLAYA WINDBLOWN DUST OVER GEOLOGIC TIME SCALES

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Department of Geosciences, University of Arizona

Desert-pavement-mantled geomorphic surfaces are characteristic features of low-elevation, relatively undisturbed arid environments. They are subjected to various fluxes of windblown dust. The surface layer of interlocking pebble-sized and larger clasts both protects previously deposited eolian material from remobilization and helps trap additional material as it is blown across the surface. This gradual process contributes to a thickening silty and/or sandy horizon beneath the surface. The thickness of this eolian epipedon has been used as an indicator of geomorphic surface age. Pavement-armored surfaces located in close proximity to a significant dust source accumulate a thick, silt-dominated A horizon more rapidly than those located farther from a local source due to higher eolian silt concentration. In order to better understand the physical processes controlling deposition, a numerical model was developed to predict the spatial distribution of eolian deposits derived from a spatially distributed playa source interacting with downwind topography through geologic time (Pelletier and Cook, 2005). To test model accuracy, predicted eolian thickness was compared to field measurements of eolian epipedon thickness beneath desert pavement near a significant dust source, Franklin Lake Playa in Amargosa Valley, CA. Geomorphic piedmont surfaces near Franklin Lake Playa range in age from mid-Pleistocene to ephemerally-active Holocene alluvial deposits. Modeled zones of high eolian deposition rates are in good agreement with thick silt deposits measured in the field. Measurements of silt-dominated A horizons on equal-aged surfaces show a distinct increase in eolian thickness near the source as well as a somewhat rapid
decrease in measured thickness moving away from the playa, approaching a relatively uniform "background" thickness. Additionally, the youngest pavements exhibit very thin A horizons regardless of distance from the playa while the oldest pavements observed demonstrate a decrease in A horizon thickness that deviates from the expected trend of increasing thickness with age. These observations suggest there is a minimum time or threshold that must be reached in order for significant silt thickness to develop even in areas of high windblown silt concentration. We also suggest the high degree of hillslope diffusion and pavement degradation observed in the oldest surfaces results in a deflation of an otherwise thick A horizon.

MODEL AND PROXY INSIGHTS INTO TROPICAL PACIFIC VARIABILITY

JESS CONROY\textsuperscript{1}, JONATHAN T. OVERPECK\textsuperscript{1,2} and M. STEINITZ-KANNAN\textsuperscript{3}

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Changes in modern Galápagos precipitation, temperature, cloudiness, and other climatic variables are directly associated with local changes in sea-surface temperatures, which in turn are reflective of tropical Pacific Basin ocean-atmosphere dynamics, namely the El Niño/Southern Oscillation (ENSO). Simulations of lake level changes in El Junco, a small crater lake in the highlands of San Cristobal Island, Galápagos, reveal that lake level is sensitive to the increases in precipitation associated with El Niño events. El Junco planktonic diatom \textit{Frustulia saxonica} displays a linear, positive relationship with local sea-surface temperatures, the Multivariate ENSO Index, and the Niño1+2 sea-surface temperature index. The time series of \% \textit{F. saxonica} reveals three periods of warmer sea-surface temperatures and El Niño-like conditions from 850-1100 AD, 1350-1500 AD, and 1800 AD-present. The present trend toward more El Niño-like conditions in El Junco is unprecedented in amplitude in the last \textasciitilde1250 years and parallels warming/freshening trends in tropical Pacific and Indian Ocean corals, as well as an increase in the frequency of El Niño events in the Quinn documentary record.
GEOCHEMICAL AND SEDIMENTILOGICAL RECORDS OF LATE QUATERNARY CLIMATE CHANGE, LAKE TANGANYIKA, TROPICAL EAST AFRICA

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Piston core records from Lake Tanganyika are analyzed to investigate possible signals of tropical paleoclimate change during the Late Quaternary. Long paleoclimate records from East Africa are of importance for understanding climatic processes such as the role of solar variability in regulating tropical climates at Milankovitch time scales, and the relationship between abrupt climate changes, migration of Intertropical Convergence Zone, and regional climate variability (Nicholson, 2000). Long records from Lake Tanganyika are of particular interest given the lake’s antiquity and its demonstrated potential for producing high-resolution sedimentary records (Cohen et al., 1993).

Many physical properties have been analyzed including, grain size, total organic carbon, major, minor and trace element variability, and biogenic silica data for a 7.75 m core from the Kalya slope and horst region of central Lake Tanganyika at 640m water depth. Eleven ¹⁴C dates provide an age model for the core, which spans ~58 cal kyr. Elemental concentrations preserved in Lake Tanganyika sediments record variability in deposition and runoff into the lake basin. Under conditions of rapid erosion, exposure and rapid weathering of bedrock has been shown to generate high concentrations of original silicate minerals enriched in soluble cations such as sodium and potassium, elements that are also biologically conservative.

Prior to 40ka cal yr. core sediments are characterized by high magnetic susceptibility, intermediate levels of organic carbon, low to intermediate levels of biogenic silica, fine grain size, and modern levels of major elements, indicative of relatively high precipitation. There is a profound decrease in magnetic susceptibility, a decrease in organic carbon and an increase in grain size at 40ka cal yr, which persists until ~16ka cal yr. Seismic reflection profiles demonstrate the existence of paleodeltas at ~360m below modern lake level that may have formed during this period, although it is unclear whether this deposit represents a Late Quaternary (OIS 2) or earlier (OIS 6) event. Maximum aridity occurred at about 20-20.5ka cal yr, consist with earlier interpretations of lake lowstands (Gasse et al., 1989, Scholz et al., 1997). The late Pleistocene and earliest Holocene sediments in our record are characterized by generally rising magnetic susceptibility, declining organic carbon and biogenic silica, and finer grain size. However, during this period there are marked fluctuations in magnetic susceptibility and biogenic silica at millennial timescales. These indicate intervals of fluctuating precipitation, productivity, and possibly windiness and are particularly prominent during the Pleistocene-Holocene transition.
SESSION 6: QUATERNARY & PALEOCLIMATE

TEPHROCHRONOLOGY OF THE WESTERN MARGIN, GONA, ETHIOPIA
or, How to date a Hominid

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The Gona Paleoanthropological Research Project (GPRP) area includes many rich fossil localities that are of great consequence to the study of human evolution. Genetic estimates of the divergence between human and chimpanzee lineages indicate that this split happened between 5 and 7 Mya. The sedimentary deposits at Gona range in age from 1.15 Ma to 4.5 Ma at the base of the Sagantole Formation, with additional minor sedimentary deposits in the underlying Adu-Asa Formation. These older sedimentary deposits occur as small, disconnected packages interlayered with lava flows and are repeated due to NS-trending normal faults that accommodated extension in the Afar rift.

While the ages of the sedimentary deposits of the Adu-Asa Formation must predate 4.5 mya, their exact age is not yet known. However, the relative ages of many deposits have been clarified through studies of the major element geochemistry of glass shards from ashfall tuffs, which occur as beds within the sedimentary deposits. These geochemical comparisons, along with detailed stratigraphic sections through many sedimentary packages, have allowed the identification and correlation of four major tuffs throughout the pre-4.5 Mya deposits of the Gona project area, with potential for larger-scale correlations between the Gona project and other paleoanthropological projects in Ethiopia. Many tuffs in the GPRP area are in direct association with known fossil sites, and thus provide the needed constraints on the ages of these important hominid finds.

Additional work on the tephrochronology and stratigraphy in the younger Sagantole Formation has furthered our understanding of those deposits as well. ⁴⁰Ar-³⁹Ar dates on tuffs from the Adu-Asa and Sagantole Formations are forthcoming.

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EXAMINATION OF SIWALIK GROUP SEDIMENTS, HIMALAYA: CONSIDERATION OF WEATHERING INTENSITY AND CLIMATE

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Siwalik group paleosols from ancestral Himalayan river deposits provide an archive for studying the impact of weathering reactions on lowland river composition during the Neogene. While it is well established that the dissolved chemical flux in the Ganges-Brahmaputra system is large, the overall contribution from silicate weathering to the flux remained uncertain. This study quantifies present-day mass losses from both carbonate and silicate weathering along a traverse extending from the Himalayan crest to the Bengal lowlands and, then, compares alkalinity losses from individual soil/paleosol profiles to the Ganges-Brahmaputra aquatic chemistry to estimate silicate weathering on the floodplain (and hence CO2 drawdown) over the Neogene. The Himalayan foreland is the wettest and warmest part of the Himalayan system, and as such, provides the maximum silicate alkalinity contributions to the Ganges and Brahmaputra Rivers.

SEARCHING FOR A QUETZAL IN THE COALMINE: HIGH RESOLUTION TROPICAL PALEOClimATE RECORDS FROM CLOUD FOREST TREES

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In temperate regions, networks of tree-ring chronologies provide proxies for paleoclimatic analysis. Many tropical trees do not form reliably annual rings, making it difficult to develop chronologies in these regions. We seek to establish high-resolution proxy paleoclimate records from trees without rings using stable isotope dendroclimatology. We apply our protocols to trees from the Monteverde Cloud Forest, where changes in ecology and hydrometeorology are related to variability in the tropical ocean-atmosphere system and climate change. Because they are associated with specific hydroclimatic conditions, cloud forests may be particularly sensitive to climate variability and change, such that proxy records from these sites record the behavior of the tropical ocean-atmosphere system. The calibration of an age model for trees without rings is a prerequisite for paleoclimate reconstructions. Our approach uses microsampling, rapid cellulose preparation, and CFIRMS to identify isotope cycles in wood that are associated with the change in the δ¹⁸O of water sources used by trees over a year. Trees of known age and growth increment were sampled in plantation sites to test our age model. High-
resolution stable isotope measurements reveal coherent δ¹⁸O cycles up to 10%. The
growth rates derived from the isotope time series match those from measurements. These
data support our hypothesis that isotope cycles can be used to provide chronological
control in the absence of rings. The ability of trees to record interannual climate variability
is evaluated using the isotope signal from multiple trees and sites, and meteorological and
climate field data for well-observed warm ENSO events.

DYNAMIC DECADE-SCALE VARIABILITY AS MEASURED BY A NETWORK
OF CORAL δ¹⁸O RECORDS

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The motivation for this study comes from attempting to answer the following
questions: has the preferred timescale of decadal variability remained stable over time?
And, has the warming trend during the 19th and 20th century influenced decadal
variability? To address these inquiries, I used a network of 30 coral δ¹⁸O records, which
are proxies for sea surface temperature. Previous work has focused on describing the
characteristics of the individual time series themselves or using the network to reconstruct
basin-wide sea surface temperature before the instrumental record. Though most corals
show some type of decadal component, there has been no in-depth study examining the
coherent frequency components across sites. One problem has been that tradition EOF
analysis fails to isolate the decadal component by including it as part of the interannual (El
Niño) or long-term trend signals. Other limitations of the data include differing temporal
resolution, spatial distribution, interval coverage, and proxy sensitivity, both
geographically and biologically, to different types of decade-scale variability. These issues
need to be resolved before addressing key questions about tropical pacific decade-scale
variability.

To address the limitations of the data and answer the above questions, I first generated
a suite of synthetic sets of time series that have similar characteristics to the proxy data.
The signal-to-noise ratio in the synthetic data ranges from an idealized scenario with s/n =
~90% to pure noise. Since the synthetic sets have variances scaled to the true data, the
strength of the patterns derived from real records can be compared with two extreme end
members (very strong signals to noise).

In the second phase, a number of multivariate signal processing techniques are applied
to the synthetic and real data. In this phase the goal is to develop the most parsimonious
description of decadal variability. These methods include EOF analysis, CH-PCA, MTM-
SVD, M-SSA, and wavelet-SVD. Uncertainties associated with each method are
discussed, with MTM-SVD presented as the most reliable measure of decade-scale
variability.
SESSION 7: STRUCTURE & TECTONICS

A WINDOW INTO THE CRYSTALLINE CRUST OF CENTRAL TIBET: GEOCHRONOLOGY AND COMPOSITION OF THE AMDO GNEISSES

JEROME GUYNN, PAUL KAPP, ALEX PULLEN and GEORGE GEHRELS

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Gneisses exposed in the Amdo area in central Tibet represent the only known occurrence of basement rocks in the main part of the Tibetan plateau and are therefore an important window into the nature of the Tibetan crust and the pre-Asian origin of the Gondwanan terranes that make up southern Tibet. The majority of rocks exposed in the plateau are Phanerozoic sedimentary and igneous rocks that do not reflect the Precambrian history of the terranes that make up Tibet. We have conducted U-Pb, geochemical and isotopic analysis on the Amdo gneisses in order to constrain their origin and composition. The majority of the basement is composed of well-foliated orthogneisses, with minor garnet amphibolites, paragneisses and migmatites. U-Pb geochronology reveals a bimodal distribution of ages, Cambrian (500-550 Ma) and earliest Late-Proterozoic (850-900 Ma). The later ages are similar to orthogneiss ages seen in the Himalaya and may be related to late Pan-African orogenesis along the margins of Gondwana; this age range is also common in detrital zircon populations from Himalayan and Tibetan Paleozoic sedimentary rocks. The earlier ages are more enigmatic and may be a good point for tying the Lhasa-Qiangtang terranes to Gondwanan continents. Initial Nd and Sr isotopic data (εNd: -2 to -7 and 87Sr/86Sr: 0.71 to 0.725) indicates a mix of mature crust and juvenile material, suggesting a continental arc source, similar to Cenozoic granitoids of the Nyainquentanglha Shan in southern Tibet. The Nd model ages suggest a Proterozoic age for crustal formation, which is consistent with a lack of Archean ages in Tibetan Paleozoic detrital zircon distributions. Major and trace element data reveal a relatively wide range of petrogenesis processes.

ALEXANDER PULLEN, PAUL KAPP, GEORGE GEHRELS, PETER DECELLES, EDWIN BROWN, MATHEW FABIJANIC, DING LIN

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The metaclastic rocks of the northern Nyainqentanglha (NQTL) of southern Tibet record early Tertiary (~50 Ma) N-S contraction along the Damxung, Lagen La and Southern Nam Co thrust systems. This contraction is located north of the Cretaceous-early Tertiary Gangdese batholith and is therefore likely related to a retro-arc fold-thrust belt system. U-Pb dating of detrital zircons from Damxung thrust footwall subgreenschist to greenschist rocks reveal Eocene age zircons buried by Permian-Carboniferous hangingwall rocks prior to the onset of Oligocene-mid-Miocene E-W extension and exhumation. Damxung thrust footwall metaclastic rocks thrust northward and Cretaceous (Aptian-Albian) limestone thrust southward along the Lagen La and Southern Nam Co thrusts respectively, forming a triangular depositional zone in which the Lagen La synorogenic conglomerate was deposited. U-Th-Pb dating of monazite and preliminary geothermobarometry of a low-mid amphibolite grade grt-bio-sill schist exposed in the footwall of the Damxung thrust indicate metamorphic conditions of ~595 °C at 3.9-4.3 kbar during Permian-Triassic time and is likely associated with the Lhasa terrane rifting from Gondwana.

PROVENANCE CONTRASTS REVEALED BY THE U-Pb POPULATIONS OF DETRITAL CHINLE SANDSTONES OF THE FOUR CORNERS REGION, SOUTHWEST US

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Detrital zircons (DZ) were sampled from five fluvial sandstone units of the Upper Triassic Chinle Group in the Four Corners region of the Colorado Plateau: Karnian lower Chinle (Shinarump) near Cameron (NW AZ) and Sanders (NE AZ), and Norian upper Chinle on the Defiance Plateau (Sonsela of NE AZ), in the Chama basin (Poleo of NW NM), and near Elk Ridge (Moss Back of SE UT). Shinarump and Sonsela in Arizona were deposited by streams flowing north, whereas Poleo and Moss Back farther north were deposited by northwesterly flow. U-Pb ages were determined for 500 individual DZ grains (~100 per sample) by laser ablation ICPMS using a beam diameter of 35 microns.
Analytical data were filtered to exclude DZ grains with >20% age discordance or poor precision, leaving 448 reliably dated grains. The DZ grains range dominantly from 210 Ma to ~1800 Ma, with a few older Paleoproterozoic and Archean grains present in all except Cameron Shinarump. A prominent Permian-Triassic age spike of 225-295 Ma in southern samples may reflect derivation of detritus in part from the coeval Cordilleran arc assemblage, although the older (>245 Ma) fraction of that age population was probably derived instead from the Gondwanan East Mexico arc (232-284 Ma).

Penecontemporaneous grains of arc derivation are present only in Cameron Shinarump (~220 Ma) and Sonsela (~210 Ma) samples. Abundant Paleozoic-Panafrican (300-950 Ma) grains in northern samples were probably reworked from the Ouachita orogen, but are less abundant in southern samples. Grains of Grenville age (950-1350 Ma) in most samples were probably recycled from older sedimentary successions, but are nearly absent from the Cameron Shinarump sample. Southern samples contain numerous 1400-1800 Ma grains derived from basement rocks of southwest Laurentia, but that age population is less abundant in northern samples. The DZ age pattern implies that southern samples were derived mainly from exposed basement and arc assemblages lying south of the Colorado Plateau, whereas detritus in northern samples were fed mainly from eastern headwaters flanking the Ouachita orogen. The DZ age spectra for Moss Back and Poleo are closely comparable to those for coeval Trujillo Formation (Chinle-Dockum Group) exposed farther east and closer to the Ouachita orogen on the High Plains of northeast New Mexico and northwest Texas.

PRELIMINARY STRUCTURAL AND KINEMATIC ANALYSIS OF LATE CRETACEOUS—EARLY TERTIARY SHORTENING IN THE GALIURO MOUNTAINS, SOUTHEASTERN ARIZONA

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Late Cretaceous contractional deformation in Arizona is one of the most poorly understood segments of the North American Cordilleran fold-thrust belt. The style, geometry and dominant vergence direction is not well documented. This is due in large part to disruption by mid-Tertiary extension and denudation. In an effort to better constrain this key orogenic period in AZ, a detailed structural and kinematic analysis of Cretaceous aged contractional features is under way.

Late Cretaceous – early Tertiary (?) thrust faults are well exposed to both the east and west of the San Pedro Trough (SPT). Structural and kinematic analysis of Late Cretaceous aged thrust relationships on the west side of the Galiuro Mountains in Hot Springs and Kelsey Canyons indicates a dominant vergence direction to the NE. In addition, ductile imprinting of Cretaceous shear indicators is seen in the hangingwall Proterozoic schist of this thrust system, indicating these thrust were rooted in the mid crust and were likely large magnitude features capable of significant crustal shortening. These observations raise the possibility for field evidence in support of a thickened crustal welt of Late Cretaceous age, a prediction of models where gravitational instability drives
subsequent extensional collapse as seen in southern Arizona during the mid Tertiary. Additional work is required to constrain the style of deformation and geometry of Cretaceous shortening in southern Arizona, but these initial results begin building a framework toward understanding Late Cretaceous-Early Tertiary contractional deformation in southern Arizona.

METAMORPHIC CONSTRAINTS ON THE TECTONICS OF THE MESOZOIC BANGONG SUTURE, CENTRAL TIBET

JEROME GUYN and PAUL KAPP

Department of Geosciences, University of Arizona

The Amdo basement is a large exposure of gneisses, metasediments and intruding granitoids located along the Mesozoic Bangong suture zone in central Tibet. The basement rocks allow thermochronology and thermobarometry that provides detailed information regarding the tectonic history of the Bangong suture zone. Our thermochronologic and geochronologic studies have shown that the basement rocks record high-grade metamorphism, coeval with magmatism, related to closure of the Bangong ocean between the Lhasa and Qiangtang terranes from the Late Jurassic to the Early Cretaceous. The nature of this metamorphism is somewhat enigmatic, as it appears to predate collision and many of the tectonic contacts related to this event are obscured by more recent tectonics and basin fill. Petrologic assemblages in metapelites, including the occurrence of sillimanite and K-feldspar, and geothermometry of the gneisses reveal high-grade metamorphism in the upper-amphibolite facies across the entire basement, with temperatures in the range 700-800°C. The only exception is the occurrence of lower-amphibolite facies metapelitic assemblages along the southern edge of the basement, which supports southward thrusting of the basement. Elucidation of burial depth during metamorphism is more difficult to constrain due to the complicated zoning of garnet and retrograde metamorphic reactions involving garnet. Preliminary data based on the GASP geobarometer and on equilibria involving titanite-anorthite-epidote-rutile-quartz suggest pressures on the order of ~10 kbar. Combined with thermochronologic data and the coeval magmatism, we attribute the metamorphism and magmatism due to underthrusting of the Amdo basement into the arc associated with the Bangong subduction zone. Our preferred interpretation is that the Amdo basement may have been a small, rifted piece of the Qiangtang terrane that than re-attached in a collision in the middle Jurassic, likely resulting in a clock-wise P-T path where the heat of magmatism helped heat the Amdo basement to upper-amphibolite conditions. The actual Lhasa-Qiangtang collision did not occur until the Early Cretaceous, when the Amdo basement was exhumed from mid- to upper-crustal levels.
CALIBRATION AND INTERPRETATION OF THE OXYGEN ISOTOPE RECORD FROM ZADA BAIN, SW TIBET

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Oxygen isotope analysis has recently emerged as a popular tool in establishing paleo-elevations. However, research since the middle of the 20th century has noted that the O isotope of precipitation value varies as a function of temperature of source region, O isotope composition of the source region, condensation temperature, precipitation temperature, latitude, continentality, monthly precipitation (the amount effect), fall distance, evaporation during fall and altitude (e.g.: Dansgaard, 1954; Dansgaard, 1964; Drever, 1997; Poage and Chamberlain, 2001; Rowley et. al., 2001). Groundwater is further complicated by evaporation and possible interaction with O bearing compounds in the substrate. In order for O isotopes to be effectively used to estimate paleo-elevation the multiplicity of factors that can influence the O isotopic composition of surface water must be accounted for. The results of this calibration study of the stable isotopic composition of modern water and ancient gastropods from the Zada basin indicate that moisture is from the same source and took the same pathway as water sampled by Garzione et. al. (2000b) and it is, therefore, reasonable to use their relationship to understand modern water in this area. Modern water from the Zada basin behaves consistently with predictions based on the $\delta^{18}O$ vs. elevation relationship established by Garzione et. al. (2000b). Onset of sedimentation was probably mid-Miocene (possibly before 10-11 Ma). The initiation of the Asian monsoon by 10.7 Ma means that we can reliably use the modern relationships and understanding of those relationships to interpret the stable isotope record from the Zada basin fill. The stratigraphically lowest values are also the most negative and are consistent with predictions for precipitation at high elevations. They are more negative, even, than modern water from the Zada basin. The fact that water that was stagnant at all (either marshy intervals or lacustrine intervals) is enriched shows that the climate was extremely arid throughout sedimentation in the basin. With regards to climate and elevation Zada basin looked much the same in the late Miocene as it does now.
Student Union: 3rd Floor (2nd floor from ground)

Talks will be in Ballroom A (North Ballroom)
Posters & coffee will be in the Catalina room
Directions from the Student Union
1. Start out going EAST on SPEEDWAY BLVD
2. Turn LEFT onto N. CAMPBELL AVE
3. Turn RIGHT onto E. RIVER RD (see map above)
4. Turn LEFT onto N. CAMINO REAL; go 0.8 mi.
5. Turn LEFT onto N. CALLE ANGOSTA
6. End on LEFT at **4925 N. Camino Real**

*Approximately 6.5 miles, about 15 minutes*