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### T31D-0872 0830h POSTER

## Formation of the Jan Mayen Microcontinent, the Norwegian Sea

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We have conducted a global study of microcontinents, which we define as crustal fragments with continental-like structure and composition, isolated in oceanic crust, with an extent of less than $10^6$ km $^2$. Microcontinents are formed in both extensional and transtensional tectonic regimes, and exhibit a range of distinct features such as (1) bathymetric highs, (2) positive free-air anomalies, (3) magnetic quiet zones, (4) prograding sedimentary sequences on the flanks, (5) older than surrounding crust, and (6) different heat flow signatures than the surrounding crust. They commonly also contain some amount of magmatic complexes. Only eight structures worldwide are true microcontinents by our definition, including the Jan Mayen microcontinent in the Norwegian Sea. The Jan Mayen microcontinent is a 500 km long and 160 km wide NNE-trending structure, comprising the bathymetric prominent Jan Mayen Ridge in the NE and a western and southern part with a more subdued bathymetric expression. Its crustal thickness reaches a maximum of 15 km with a lower crustal root displaced 10 km east of the axis of the ridge. The root has seismic velocities in the range from 6.7 to 7.0 km/s and is associated with a magnetic quiet zone, both suggesting a continental origin. A new continent-ocean boundary delimiting the microcontinent has been interpreted based on the extent of the magnetic quiet zone, the free-air gravity anomaly signature, seismic reflection data, and the velocity distribution. The Jan Mayen microcontinent separated from the volcanic rifted Voring and More margins off mid-Norway during Early Tertiary continental breakup and sea floor spreading. Close to the Eocene-Oligocene transition, the Kolbeinsey Ridge spreading axis started to propagate northwards from the Reykjanes Ridge into the East Greenland margin, thus constituting a prograding-retreating pair of axes with the Aegir Ridge. Sea floor spreading along the entire Kolbeinsey Ridge was obtained near the Oligocene-Miocene transition, leading to complete separation of the Jan Mayen microcontinent from the East Greenland continental margin. This event was concurrent with the extinction of the Aegir Ridge.

### T31D-0873 0830h POSTER

## Tectonic Flows Modeled by the Method of Smoothed Particle Hydrodynamics

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In order to study the flow of highly deformable yet heterogeneous material, we investigate the application of the Smoothed Particle Hydrodynamics modeling method to geophysical fluid dynamics. SPH is a grid-free, Lagrangian method that solves the continuum equations (continuity, momentum, energy) on a set of interpolation points (particles). These interpolation points correspond to representative volume elements which track the material points of the fluid and it's state variables (density, stress, temperature). The evolution of the state variables for a given volume element is calculated by considering the influence of each neighboring element and summing over all neighbors. Volume elements interact with boundaries through mirror particles which enforce a no-slip boundary condition by mirroring the element's material properties, stress and velocity. The method includes several advantages over irregular grid-based approaches including easy parallelization of the calculations and efficient tracking of material properties in regions of high deformation rate. We test two-dimensional, mechanical models of unconfined, viscous fluid flow for both quasi-static flows, applicable to tectonics, and dynamic flows such as landslides. Our SPH implementation is tested by comparing model results to analytic solutions for several confined and unconfined fluid flow problems. In particular, we compare our model with three test cases for homogeneous viscous flow; Poiseuille channel flow, Stoke's flow past a cylinder, and unconfined flow down an inclined plane.

# T31E MCC: Level 2 Wednesday 0830h

## Structure and Tectonics of the Western U.S. and the Gulf of California I Posters *(joint with G, S, V)*

***Presiding:*** **D R Lageson,** Montana State University

### T31E-0874 0830h POSTER

## Lithospheric Structure from the Jemez Lineament to the Cheyenne Belt, Southern Rocky Mountains

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We present the modeling and interpretation of a 955km long refraction profile and a 170km long deep reflection profile acquired as part of the Continental Dynamics of the Rocky Mountains (CD-ROM) project. The refraction profile extends across the major features of the Rocky Mountain region, from the Jemez Lineament (JL), in northern New Mexico through the Proterozoic Mazatzal and Yavapai Provinces, to the Cheyenne belt in southern Wyoming. The reflection profile parallels the refraction profile in northern New Mexico and targets the lithospheric structure of the Jemez Lineament. We inverted travel-time data from the 10 refraction records using both layer based travel-time inversion and first-arrival travel-time tomography methods. In the shot records we identified two refracted arrivals, one from the crystalline crust and one from the upper mantle (Pg, and Pn) as well as prominent reflections from the middle crust (PcP) and from the Moho (PmP). We modeled the Bouguer gravity along the profile using the interfaces of the layer based refraction model and densities derived from a standard density-velocity relationship. Calculated gravity fits the observations to +/- 14 mgal. The upper and middle crust shows low velocities (6.0-6.2 km/s) beneath the JL and at the center of the profile, beneath the Colorado Mineral Belt. Upper and mid crustal velocities increase (6.2-6.5 km/s) north of the Cheyenne belt and south of the JL, where the deep reflection profile images a Proterozoic crustal duplex. The lower crust across the profile exhibits a relatively low velocity, with an average velocity of 6.7 km/s, and a variable thickness, with the thinnest section (10 km) beneath the JL and the thickest section beneath the northern Colorado Mineral Belt (22 km). Moho depths vary from near 40 km beneath the JL to more than 50 km in the northern half of the profile. Upper mantle velocities are low (7.85 km/s) with the lowest velocities (7.70-7.76 km/s) found beneath the thinnest crust (40-41 km) across the JL. The average CD-ROM one dimensional velocity function has lower values for the crust and the upper mantle than the Christensen-Mooney global average velocities for continents and for orogens. Low velocities in the upper and middle crust can be explained by widespread Proterozoic and Phanerozoic felsic batholiths. Low velocities throughout the crust are also a result of high heat flow (63 to >105 mWm-2) in the Rocky Mountains south of the Cheyenne Belt. Attenuated velocities of the lower crust and the upper mantle, together with the Quaternary basalt flows, recent uplift and high heat flow, suggest temperatures in the mantle that are above the peridotite solidus, particularly beneath the JL. The reflection profile in the JL images bright linear reflections at mid-crustal depths which we interpret as modern mafic sills, consistent with the hypothesis that the mantle beneath the JL is partially molten and provides basaltic melt to the crust.

### T31E-0875 0830h POSTER

## High Resolution Aeromagnetic Survey of the Big Bend National Park Region, Texas

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The Big Bend National Park region of west Texas has experienced a complex geologic history, including such events as the Paleozoic Ouachita orogeny, Laramide compression, Tertiary magmatism, and Basin and Range/Rio Grande rift extension. During late fall of 2002, a high resolution aeromagnetic survey was flown over this region for the purposes of improving present geologic maps and developing a better understanding of igneous stratigraphy in the region. Total-field anomaly data was acquired with a 400 meter flight-line spacing and continued to a draped surface at a constant level of 400 meters above the ground surface. Reduction to pole, pseudogravity, and analytic signal filters were applied to the total-field anomaly grid, revealing many features that correlate well with mapped geology and many additional, unmapped features. A set of northeast trending, long wavelength anomalies correlate well with mapped trends of rocks of the Ouachita orogenic belt, especially a magnetic low that correlates with the Ouachita interior zone. A prominent magnetic and pseudogravity high indicates the presence of a large (30 by 25 km) igneous body underlying the Chisos Mountains. Superimposed on this anomaly is a set of smaller anomalies that correlate with mapped locations of the Pine Canyon and Sierra Quemada calderas. Numerous short wavelength anomalies correlate with mapped locations of Tertiary volcanoes and intrusions, plus many similar anomalies indicate the presence of unmapped and buried intrusions. In the Christmas Mountains, a large negative anomaly indicates that a magnetic reversal is recorded in the rocks of this area. Northwest-trending normal faults produced by Tertiary extension produce magnetic anomalies where they cut and offset magnetic rocks of the South Rim and Chisos Formations, most notably within the Terlingua Abaja and Punta de la Sierra fault belts. These faulting trends are enhanced in the analytic signal map, which will allow delineation of unexposed faults by extrapolation from their surface exposures. Future fieldwork to collect magnetic rock property data will allow detailed modeling to take place.

### T31E-0876 0830h POSTER

## Extensional Domains of the Northwestern Basin and Range Province

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Compilation of new and existing geologic, geochronologic, and thermochronologic data reveal that broad regions of northern Nevada have significantly different Tertiary histories in terms of timing and amount of extension. Definition of these different extensional domains allows better insight into the regional relationship of magmatism to extension and points to zones that acted as boundaries between areas that extended at different times. Much of central Nevada (roughly lat. 38-40) is blanketed by thick sections of Oligocene-Early Miocene volcanic rocks. Prominent unconformities in these sections indicate that parts of central Nevada underwent episodic and variable amounts of extensional faulting and tilting from Oligocene to Early Miocene time. Subsequently, rapid slip occurred along range-bounding faults at 17-15 Ma. Despite apparently synchronous and rapid extension across an area stretching from the Wasatch front to the Wassuk Range east of the Sierra Nevada, volcanic rocks were erupted only locally in central Nevada at this time. In contrast, the Oligocene to Early Miocene volcanic rocks in northwestern Nevada are capped by the voluminous 17-15 Ma basalt-rhyolite sequence associated with the Northern Nevada Rift and the Yellowstone hot spot. The absence of angular unconformities in the volcanic section demonstrates that no faulting and tilting took place over the interval 30-15 Ma. The only extension to occur in this large

region formed the modern ranges and was of low magnitude. Apatite fission-track data indicate that faulting was ongoing at 7-10 Ma, postdating both bimodal volcanism and rapid extension in central Nevada. Regions with possibly similar, but less well-documented, histories include the region of northwestern Nevada stretching from the Pine Forest Range to the Warner Range in northern California, and the region south of I-80 characterized by Northern Nevada Rift-related basalts now cut and tilted by modern range-bounding faults. This new compilation suggests that rapid 17-15 Ma extension in central Nevada was coeval with bimodal Yellowstone hot spot/Northern Nevada Rift volcanism to the north, but, despite being the locus of active volcanism during this interval, the crust in northwestern Nevada remained unextended until 5-8 million years later. The difference in the timing and amount of extension between these areas implies that an east-west trending shear or accommodation zone separated rapidly extending crust in central Nevada from unextended crust in northwestern Nevada during Middle Miocene extension.

### T31E-0877 0830h POSTER

## 3-D Terrain Corrections to Heat Flow Data, Topographically-Driven Groundwater Flow, and the Strength of the San Andreas Fault at Parkfield, CA

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The lack of a detectable heat flow anomaly along the San Andreas Fault (SAF) constitutes one important piece of evidence used to argue that the fault supports low shear stresses (<20 MPa averaged over the upper 10 km). However, key uncertainties in existing heat flow data, such as the effects of heat advection by topographically-driven groundwater flow, topographic refraction (terrain effects), subsurface heterogeneity (refraction caused by variable thermal conductivity), and uncertainty in thermal conductivity limit the utility of such analyses. Previous studies using heat flow data to investigate the strength of the SAF have taken into account effects of topographically-driven groundwater flow along a transect NW of the SAFOD site and included limited two-dimensional heat flow terrain effects, but remain inconclusive for interpreting possible frictional heating along the SAF near Parkfield, CA due to significant scatter remaining in the data and uncertainty in the extent of three-dimensional terrain effects. Here, we re-evaluate the effects of topographically-driven groundwater flow at Parkfield using full 3-D corrections to the heat flow data and including additional transects. In this study, we apply three-dimensional terrain corrections to temperature data for 22 boreholes near the SAFOD site. The corrected thermal gradients and available thermal conductivity data allow us to determine heat flow values free of terrain effects. The difference in heat flow for each borehole between published 2-D corrected values and the values corrected for 3-D terrain effects range from 0.2 to 21.0 mW/m$^2$, 6.9% on average. The standard deviation of the heat flow data is reduced by 25.8% by including the 3-D correction. Error bars based on the standard deviation of the thermal conductivity measurements for each borehole range from ±3.2 to ±25.7 mW/m$^2$ (10.3% on average for all data and 6.8% for high-quality data alone). We use the finite-element modeling code, SUTRA, to simulate steady-state coupled heat and groundwater flow within three cross-sections perpendicular to the fault. We consider a suite of hydrologic (groundwater flow) conditions to evaluate effects of topographically-driven groundwater flow and compute simulated heat flow values for both strong and weak fault frictional heat sources. Simulated heat flow values are corrected for all terrain effects using a two-dimensional Birch method correction, and then compared with the 3-D corrected heat flow data to evaluate plausible hydrologic and fault strength scenarios. For high-permeability scenarios, we predict a large variability in heat flow, as well as a systematic decrease in heat flow with elevation. These patterns are not present in the data, allowing us to estimate an upper limit on advection caused by groundwater flow. In general, models that incorporate a weak fault fit the data better than those with a strong fault. Uncertainty from poorly constrained (undersampled) thermal conductivity in some boreholes, and scatter caused by subsurface thermal refraction due to heterogeneous thermal conductivity structure still remain, but a pronounced near fault heat flow anomaly as predicted for a strong fault is not evident.

### T31E-0878 0830h POSTER

## Crustal Seismic Investigation of the Southern Rio Grande Rift at the Potrillo Volcanic Field, Southern New Mexico

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The southern portion of the Rio Grande Rift (SRGR) has undergone a complicated volcanic and tectonic history culminating in the modern extensional environment. Previous geophysical studies, shallow basement exposures, and petrologic investigations of xenolith suites recovered from two Quaternary maars (Kilbourne Hole and Potrillo Maar) and Eocene intrusions in the Potrillo Volcanic Field (PVF), have provided much insight into the structure and crustal evolution of the southern Rio Grande rift. Earlier seismic results indicate distinct thinning of the crust by 4-6 km into the SRGR from both the northern Rio Grande rift and the adjacent Basin and Range province, and a regional Pn velocity of approximately 7.7 km/s. A broad gravity high of 20-30 mGal as well as high heat flow values in the range of 75 to 125 mWm-2 are also associated with the SRGR. In May of 2003, a seismic survey was carried out to investigate the crustal structure of the SRGR and relate it to xenoliths from the PVF. This experiment comprised of 8 shots of 1000-2000 lbs., 793 seismic recorders (TEXANS) deployed at variable spacing of 100 m, 200m and 600m over 205 km with the help of volunteers from 6 universities within the US and the United Kingdom. Preliminary results show energy propagation across the entire length of each shot gather as well as several distinct phases. Crossover distance of the Pn phase is at approximately 160 km shooting from west to east while it is at approximately 130 km shooting from east to west suggesting an eastward dipping Moho interface. Near vertical reflection data that straddles the PVF shows complex PmP reflections at approximately 11 s as well as a possible PmS phase at approximately 15 seconds.

URL: http://www.geo.utep.edu/pub/miller/pvfweb

### T31E-0879 0830h POSTER

## Preliminary structural analysis of the newly discovered Anaconda metamorphic core complex, western Montana, USA

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A sinuous zone of gently, generally east-dipping, low-angle Tertiary normal faults is exposed for 100 km along the eastern margins of the Anaconda and Flint Creek Ranges in southwest Montana. Faults in the zone variously place Mesoproterozoic through Cretaceous sedimentary rocks on younger Tertiary granitic rocks, or on sedimentary strata older than the overlying detached units. Lower plate rocks are lineated and mylonitic at the main fault and, below the penetratively deformed mylonite, are cut by mylonitic, vein-like micro faults. The upper plate consists of an extensional imbricate array of younger-on-older sedimentary rocks that are locally mylonitic at the main, lowermost detachment fault, but are characteristically strongly brecciated or broken. Kinematic indicators in the lineated mylonite indicate tectonic transport to the east-southeast. Syntectonic sedimentary breccia and coarse conglomerate derived solely from upper plate rocks were deposited locally on top of hanging wall rocks in low-lying areas between fault blocks and breccia zones. Muscovite occurs locally as mica fish in mylonitic quartzites at or near the main detachment. 40Ar/39Ar age spectrum obtained from muscovite in one mylonitic quartzite yielded an age of 47.2, plus/minus 0.14 Ma, interpreted to be the age of mylonitization. The fault zone is interpreted as a detachment fault that bounds a newly discovered Cordilleran metamorphic core complex, herein termed the Anaconda metamorphic core complex, similar in age and character to the Bitterroot mylonite that bounds the Bitterroot metamorphic core complex along the Idaho-Montana state line 100 km to the west.

### T31E-0880 0830h POSTER

## Timing, Style, and Magnitude of Upper Crustal Extension, Sierra San Felipe, NE Baja California, Mexico: Constraints on Rift Processes in the NW Gulf of California Extensional Province

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The Gulf Extensional province (GEP), NSF-MARGINS Rupturing Continental Lithosphere focus site, has extended primarily since Late Miocene time. Rift processes in NE Baja California include ENE-directed extension, distributed dextral shear, and detachment faulting, which were partly synchronous with formation of proto-oceanic pull-apart basins in the adjacent Gulf of California. New geologic mapping in the Sierra San Felipe constrains the age and magnitude of extension in the onshore part of the rift, allowing better understanding of strain partitioning in this strongly oblique rift. Strata in the Cañon El Parral (CEP) area, SSW of San Felipe, record early gulf-related extension. Early Miocene sedimentary strata intercalated with olivine basalt (Tb1) are overlain by the 12.6 Ma tuff of San Felipe (Tmr1). Unconformably above Tmr1 are tuffaceous sandstone (Tsst) and laterally equivalent fault-scarp facies, and higher ∼6.3 Ma ignimbrite deposits (Tmr3-4). These are overlain unconformably by Plio-Pleistocene conglomerate (TQcg1). Thickness changes, paleoflow indicators, and grain-size changes show that an ENE-striking, W-down fault controlled deposition of Tsst. Extension magnitude increased after Tmr3-4 time and began to wane during TQcg1deposition. Few faults cut TQcg1, implying very little Pleistocene strain; area-balanced cross sections indicate <40% extension there. The top-to-the-E Las Cuevitas detachment (LCD), W of San Felipe, was active in Miocene-Pleistocene time, controlling marine incursion. Pre-extensional hanging-wall conglomerate and eolian sandstone are overlain by basalt and ignimbrite, then by syn-LCD fluvial and marine beds, which were deposited in N and S sub-basins. Marine strata (∼6.0-1.8 Ma) in the N sub-basin grade W and upsection from silts to fault-scarp facies breccia at the LCD. A dextral E-striking fault separates the sub-basins, probably controlling the S edge of the deeper northern basin and offsetting a distinctive marine-fluvial contact ∼1 km. Associated fault-related topography suggests that it is still active. Initial extension in the Sierra San Felipe appears to be recorded in the CEP area and on the top-to-E Santa Rosa detachment (SRD, N of CEP and S of LCD) between ∼12.5-8.9±1.2 Ma. The age of earliest LCD slip is unknown, but by ∼6.0 Ma the LCD bounded a deep marine basin. Sedimentation changed to fluvial deposition at ∼1.8 Ma, possibly due to slowed slip rate on the LCD. The LCD and SRD are en echelon structures; slip on them overlapped in time and may have been entirely synchronous. Major extension in the Sierra San Felipe apparently ended in Pleistocene time; active extension now occurs on the Sierra San Pedro Mártir fault to the W and in the Delfin Basin to the E, indicating a change of strain partitioning in the NW GEP in Pleistocene time. It appears that ∼E-directed extension in the onshore NW part of the GEP was minor (10-25 km) compared with the ∼270 km of NW-directed gulf extension since ∼6 Ma.

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### T31E-0881 0830h POSTER

## San José Island Accommodation Zone, Baja California Sur, Mexico: A Key to Onshore-Offshore Fault Relationships along the Western Margin of the Southern Gulf of California

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The two-stage evolution of the southern Gulf of California included protogulf orthogonal rifting from ∼12 to ∼6 Ma, followed by overprinting from ∼6 to 0 Ma by the highly oblique-divergent, modern plate boundary. The San José Island accommodation zone, located ∼70 km north-northwest of La Paz, Baja California Sur, represents the transition between strike-slip partitioning to the south and the oblique-divergent structural overprinting to the north. The accommodation zone includes San José and San Francisquito islands, the San José Canal, and a 4 to 6 km wide belt along the coast of the Baja California peninsula. The accommodation zone separates the La Paz rift segment to the south from the Timbabichi rift segment to the north. The El Carrizal fault bounds the La Paz rift segment, and likely splays onshore in the southernmost accommodation zone. Kinematic data, fault mapping, and geomorphologic and bathymetric observations along the shoreline suggest the presence of en echelon, offshore faults in the San José Canal between the Baja peninsula and islands. The main faults in the southern San José Canal appear to be a series of right-stepping, east-dipping normal faults branching northward from the El Carrizal fault. Based on onshore fault trends in the northern accommodation zone, the northern Canal faults form a left-stepping link to the main bounding fault of the Timbabichi rift segment. The faults bounding the western edge of the islands are likely left-stepping, west-dipping normal faults. Steep, triangular facets and cliffs characterize the western edge of San José Island and suggest that the western island-bounding faults are active. The Pliocene basin, basin-bounding fault, and line of steep coastal cliffs on the eastern side of San José Island are likely associated with the northern end of the Espíritu Santo normal fault, which experienced a major earthquake in 1995. The basin and faults also may be the termination of a series of faults related to the fracture zone emanating from the Alarcón spreading ridge. A similar relationship between basin and accommodation zone development and the evolution of strike-slip/fracture zone systems has been demonstrated in other rifts. Formation of San José and San Francisquito islands along normal faults may be a result of (1) the latest Miocene-early Pliocene tectonic reorganization to oblique rifting, and (2) active normal faulting in the San José Island accommodation zone and southward.

## T31E-0882 0830h POSTER

### A possible widespread Upper Miocene to Lower Pliocene rift-related sequence under the marine shelf from Mazatlan to the Tres Marias islands, southeastern Gulf of California, Gulf of California MARGINS project

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The margins of the plate boundary on either side of the southern Gulf of California differ substantially. The western margin along Baja California is narrower and has mush less sediment than the eastern margin. The eastern margin is dominated by a 30 - 60-km wide coastal plain and a 40 - 100-km wide marine shelf, both of which cover faults and basins. The Tres Marias islands are the only chance for a detailed geologic window into the shelf. Therefore, seismic reflection lines and the Tres Marias islands are critical to understanding the geology of the southeastern margin of the plate boundary. Previous workers described 1100 - 1600 m of strata on Maria Madre Island that is Late Miocene ( 8 Ma) to Pleistocene in age. The section changes abruptly from basal marginal(?) marine sandstone into thick mudstone and diatomite formed in a Late Miocene to Early Pliocene slope to deep marine setting. Within the Lower Pliocene section is an angular unconformity. The Pliocene section shallows up to outer shelf to upper slope conditions, possibly across a second major unconformity that separates the lower and upper Pliocene. The Pliocene marine strata are overlain abruptly across a third unconformity by Pleistocene nonmarine to shallow marine sandstone and conglomerate. Two of our seismic reflection lines run onto the modern shelf between the Tres Marias islands and Puerta Vallarta. The lines show an undeformed upper sequence that lies on a major unconformity above a lower sequence. The upper sequence is 100 m to 1 km thick and onlaps and fills previous topography. The lower sequence is consistently broken by normal faults and shows common growth sedimentation related to faulting. The lower sequence is most commonly from 0.5 to 1.0 seconds (two-way travel time). The upper and lower sequences are also well defined on a seismic line offshore of Mazatlan; the lower sequence is under the shelf and slope out to 80 km offshore; the upper sequence is unfaulted, while the lower sequence is commonly faulted. A final seismic line that runs across the shelf between Mazatlan and Puerta Vallarta has hints of the lower sequence. We tentatively correlate the upper seismic sequence with the upper Pliocene to Quaternary shallowing up section on the Tres Marias islands. We correlate our lower synrift sequence with the upper Miocene to lower Pliocene deep marine section on the island ( 8 - 3.5 Ma). Further seismic processing and geologic work on the Tres Marias islands should clarify the spatial extent and age of the lower sequence.

## T31E-0883 0830h POSTER

### Gravity Modeling of a Batholith and Low-Velocity Mantle Zone Beneath the Colorado Mineral Belt

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The Colorado Mineral Belt (CMB) is delineated as a belt of mostly Laramide mineralization within a broader zone of Laramide and older magmatism in central Colorado. One of North America's largest Bouguer gravity anomalies coincides with this broad NE-trending zone of protracted magmatic activity. Seismic studies suggest that parts of the CMB region are underlain by anomalously low-density crust and that the CMB lies within a broad zone of low seismic velocities in the uppermost mantle. Our gravity modeling explores simple distributions of subsurface mass deficits that can explain the CMB negative Bouguer gravity anomaly, and are constrained by geologic estimates of the extent of crustal plutonic bodies and by seismically-inferred crustal and upper mantle velocity anomalies. Specifically, our forward models include (1) a low-density batholithic body in a 20-km thick upper crust with a density contrast of 150 kg/m3, (2) a 25-km thick lower crust with a potential low-density body of density contrast 150 kg/m3, and (3) an upper mantle with a low-density body of variable density contrast placed at variable depth. The viability of the crust and mantle low-density bodies in our first-order forward models is tied to their consistency with seismic observations, and we work toward refinement of the models using empirical density/velocity relationships and the upper crustal structure established by the CDROM seismic refraction line.

## T31E-0884 0830h POSTER

### New Low-Temperature Thermochronology Reveals Contrasting Modes of Continental Extension Across the Sonoran Rifted Margin

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The Sonoran rifted margin extends 250 km from the western flanks of the Sierra Madre Occidental to the Gulf of California and contains a classic Basin and Range morphology that indicates "broad-rift" mode of continental extension. However, new low-temperature thermochronology reveals that the Sonoran rifted margin is also internally composed of at least two temporally and spatially distinct belts that display other distinct styles of extension. Mountain ranges that lie within a narrow belt (20 km wide) along the coast of the Gulf of California between Puerto Libertad and Bahia Kino yield highly discordant apatite fission track (AFT) ages that range from 5 to 54 Ma and likely reflect the strong tilting of these tectonic blocks. The widespread occurrence of AFT ages between 5 and 7 Ma, which are typically found in the deepest crustal levels of the tilt blocks, and the presence of Quaternary scarps indicate that extension in the coastal region largely occurred from late Miocene to recent times. We infer that this belt is dominated by a "narrow-rift" mode of extension where deformation has been focused to produce the Gulf depression. Well inland from the coast (175 km east) is a belt of metamorphic core complexes that extends more than 200 km from Magdalena to Mazatan and typically yields older and more concordant AFT ages from 14 to 23 Ma. However, the presence of ages as young as 8 to 11 Ma indicate that the "metamorphic-core-complex" mode of extension in this belt likely overlapped in time with the "narrow-rift" mode of extension in the Gulf of California. We conclude that the juxtaposition of major deformation belts each with different modes of continental extension reflects the diverse processes that have affected the Sonoran margin through time.

## T31E-0885 0830h POSTER

### Continent- Ocean Transition Across the Alarcon Basin, Gulf of California from Seismic Reflection and Refraction Data.

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A transect of seismic reflection and onshore/offshore refraction data was collected across the Alarcon Basin, Gulf of California in Fall 2002 as part of the MARGINS Rupturing Continental Lithosphere (RCL) initiative. The dataset consists of 600 km of seismic reflection data together with data from 53 ocean-bottom seismometers and 11 land seismometers along a coincident 900 km refraction line. This transect crosses the entire conjugate rift system from continent to the thinned and faulted crust of the transition zone, and then to oceanic crust with an active seafloor spreading center. The Alarcon Rise is the southernmost spreading segment in the Gulf of California, separated from the East Pacific Rise by the Tamayo transform fault. Extension in the gulf began about 12 Ma and rifting was initiated at the mouth of the Gulf at the now inactive Magdalena spreading ridge about 5 Ma. Magnetic anomalies reveal that the Alarcon Rise has been spreading at an intermediate rate since 3.6 Ma. The current ridge crest is about 10 km wide, 150 m high and with a small axial valley.

The data quality from the ocean-bottom seismometers is excellent, with first arrivals to at least 75 km offset, and past 100 km on many instruments. Land seismometers also produced excellent results- first arrivals are typically observed out to 200 km offset. Pg/Pn crossover distances are around 40 km in the oceanic crust of the Alarcon basin, increase to about 60-75 km in the transition zone and reach a maximum of about 100km for the continental land instruments. The total width of oceanic crust created at the Alarcon Rise, as determined from reflection profiles and initial refraction processing is about 130 km, which agrees with the bathymetric data. The transition zone is characterized by normal faulting- synrift faulting created sedimentary basins, which were later modified by additional normal faulting. The rifted margin appears to be symmetric, with about 180 km of transition zone on either side. However the southern margin is complicated by the fossil Magdalena spreading ridge, which lies about 150 km southeast of the Alarcon rise. We will present MCS results and an initial velocity model across the Alarcon basin.

### T31E-0886 0830h POSTER

## Crustal structure and rift evolution across the Guaymas Basin, Gulf of California

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A crustal-scale, active-source seismic experiment was conducted in the Gulf of California in the fall of 2002. This experiment, funded through NSF MARGINS, aimed to image crustal structure across conjugate margins of major basins throughout the gulf to determine the modes of extension, the influence of sedimentation and magmatism on breakup, and other features leading to a better understanding of the rifting process. Here we present results from Guaymas Basin, including analyses of marine MCS data recorded using the R/V Maurice Ewing's 6-km streamer and wide-angle data recorded on 39 OPSIP OBSs and 19 PASSCAL RefTeks onshore. The Guaymas Basin is heavily sedimented, with 0.5 km of sediments at the rift axis thickening to as much as 2 km at the margins. These sediments have masked the rift structure of this basin, which had seemed to have begun a true drift phase later than the basins in the south. Analysis of the seismic data show, however, that rifting proceeded to completion rapidly, and most of the crust underlying the Guaymas Basin is new igneous crust. In contrast to the southern gulf, rifting and subsequent crustal construction in Guaymas has been "magmatic", with crustal thicknesses of 12 km near the margin and 8 km near the spreading center, suggesting an along-axis gradient in either mantle temperature or dynamic upwelling that has persisted since the onset of rifting. Ingeous crustal structure generally mimics oceanic crust, with a 2- to 4-km-thick 4-5 km/s upper layer (likely intercalated sediments and sills) overlying a plutonic layer. A striking feature of the crust here is the asymmetry about the rift axis in plutonic-layer velocities and gradients, with velocities to the west of 6.4-6.9 km/s and a 6.6-7.0 km/s velocity gradient to the east. This is mimicked in the upper crust, with an average velocity of 5.0 km/s in the west and 4.0 km/s in the east. The rift axis features a 2-km-high, down-to-the east, low-angle fault(?) bounding a depression in the plutonic crust beneath the rift axis, which itself is offset from the geometric center of the basin. A combination of a rift axis offset from the locus of mantle upwelling and asymmetric tectonics at the rift may lead to evolved melts being emplaced west of the spreading center and more residual melts to the east, possibly representing a previously unknown type of tectono-magmatic asymmetry.

### T31E-0887 0830h POSTER

## Contributions to the Elevation North America

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Continental elevations result from a combination of buoyancy (i.e. compositional and thermal) and geodynamic forces. Thermal isostasy can produce nearly three kilometers of relief between cold shield platforms and hot rift zones. However, changes in bulk density and crustal thickness can potentially produce relief greater than nine kilometers; whereas, geodynamic contributions to elevation are frequently no greater than a few meters to a few kilometers. Therefore, elevation resulting from buoyant forces must first be removed before assessing the magnitude of geodyamic contributions to elevation. The extensive geologic and geophysical data coverage of North America as well as diverse tectonic settings are ideal for determining the buoyancy contributions to elevation and examining a range of possible geodynamic processes affecting elevation. Compositional buoyancy is removed for each of 15 tectonic provinces by determining the average bulk density and crustal thickness. An adjusted elevation is computed by equating the density-thickness product of an observed region to a standard crustal section (e.g. 40 km thick crust with average density of 2830 $kg/m^3$). Mean province elevations are computed using the digital elevation model GTOPO30 with a spatial resolution of 1 km2. Crustal thickness is determined from seismic refraction models. Rock types are estimated from a combination of surface geology, drill cores, xenoliths, seismic refraction velocities, and tectonic history; densities are then estimated by correlating rock types to laboratory Vp-P-T-density investigations. Thermal buoyancy is removed by computing the difference between the integrated thermal structure of the province and a standard continental lithospheric geotherm (characteristic of surface heat flow 40 $mW/m^2$) to 250 km depth. Heat flow is drawn from a global data set and supplemented with more recent heat flow data. Anomalous heat flow at individual sites are examined for possible disturbances resulting from thermal conductivity and heat production variations. Using the continental heat flow and elevation relation derived from this study, it is possible to identify province outliers where the thermal state is anomalous (transient, disturbed, etc.), the elevation is anomalous (dynamically supported, anomalous mantle, etc.) or both. Discriminating between these sources of elevation provide insights into the geodynamics of North America.

### T31E-0888 0830h POSTER

## Seismic imaging of the continent-ocean transition in the southern Gulf of California

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We present seismic reflection images and a preliminary velocity model of the crust at the mouth of the Gulf of California. The Gulf of California is a unique place to study rifting because the transition from rifted continental margin to oceanic crust to conjugate rifted margin occurs within a fairly short distance, making segments easy to recognize. In the fall of 2002, multichannel seismic (MCS) data were collected along an 550 km northwest southeast trending transect from the southern tip of the Baja peninsula over the East Pacific Rise to mainland Mexico. In addition, thirty-six ocean bottom seismometers (OBS) were deployed at 10 km spacing along the transect to collect wide-angle seismic data. Our goals are 1) to examine the relationships between extensional style, lithospheric composition, and rheology, and 2) to determine whether the Gulf of California margins are volcanic or non-volcanic. MCS images show oceanic crust that lacks seaward dipping reflectors or voluminous extrusives, indicating a non-volcanic rifted margin in the southernmost Gulf of California. Preliminary velocity models of the northwestern margin show an abrupt transition from a 25-km-thick continental crust to an oceanic crust of normal thickness.

# T31F MCC: Level 2 Wednesday 0830h

## Orogenesis, Metamorphism, and Exhumation I Posters *(joint with H, V)*

***Presiding:*** **R N Pysklywec,** University of Toronto**; J Rahl,** Yale University

### T31F-0889 0830h POSTER

## Surface Heat Flow vs. Helium Isotopes in the Thermal Anomaly Areas of Tuscany (Italy)

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A wide part of Tuscany (North-Central Italy) is affected by a large heat flow anomaly: the highest values of heat flow correspond to the two geothermal fields of Larderello and Mt. Amiata, where values up to $1W/m^2$ and 0.6 $W/m^2$ are reached, respectively. Several other thermal manifestations are scattered in the region. These geothermal fields are located in the inner Northern Apennines, affected by post-collisional extensional tectonics and widespread Late Miocene-Quaternary magmatism. The geothermal fields of Larderello and Mt. Amiata display considerable similarities from the geological-structural and thermal point of view, with some important difference. They differ with regard to fluids characteristics: the Larderello field is steam-dominated while the Mt. Amiata field is water-dominated. We compare the distribution at surface of $^3He/^4He$ ratio (R/Ra), a sensitive geochemical tracer of source, with heat flow and other geophysical and structural parameters like Bouguer anomaly and normal fault geometry, to improve knowledge on the two geothermal systems. To investigate the relationship among normal faults, geothermal fluids pathways, He surface distribution and heat flow, we constructed targeted geological sections through the geothermal areas of Tuscany. The geological sections were drawn down to the K-horizon (a regional seismic reflector discontinuously underlying the whole geothermal areas at a depth ranging between 3 and 7 km), integrating field data with borehole stratigraphies and reflection seismic surveys. Though slightly biased in space at surface, due to the normal fault geometry governing the fluids pathways, the highest R/Ra values show a good correspondence to the heat flow maxima. These results account for the role of the extensional shear zones as preferential ways of mantle-derived fluids uprise in the Larderello field. We stress the importance of mapping simple primary geophysical (temperature gradient, heat flow) and geochemical (He isotopic composition) data, compared with the structural geology, to define the principal fluid-flow paths in geothermal areas.

### T31F-0890 0830h POSTER

## Along-strike Variation in the Sandino Basin of Nicaragua and Implications for the Development of the Central American Forearc

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