Ar. When applied to the scale of the Tarim Basin, the results indicate the development of a shear zone approximately 100 km wide, comparable to the width of the Altyn Tagh fault zone. The formation of this shear zone does not require strain-weakening of the material or fault zones that extend through the lithosphere.

T21E MCC: 3005 Tuesday 1020h

Development of Fault Systems Through Time: Process and Rates II

Presiding: **N Dawers,** Tulane University**; D Commins,** Imperial College

T21E-01 1020h INVITED

Constraining Fault Evolution at an Active Extensional Relay: Star Valley, Wyoming

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Relay zones, the sites where faults overlap and become linked, provide important insights into the processes by which fault segments coalesce. Whilst numerous studies have been made of the detailed structural geometry of relay zones, our understanding of the temporal evolution of faulting during relay formation remains limited. We focus on the Grover relay, a 4-km-wide en echelon step in the Star Valley fault located at the eastern margin of the Basin and Range province, Wyoming. Several coeval latest Quaternary ruptures have been documented on both segments by paleoseismological studies suggesting that the north and south segments are well linked. We use sedimentological and geomorphic observations to investigate faulting-landscape interactions and to propose a model of relay evolution. Typically relay zones comprise an en echelon fault overlap of inboard and outboard faults. At the Grover relay, the outboard fault loses displacement northward into a N-plunging fault-related anticline that has deformed early synrift deposits. Early syn-rift and pre-rift rocks are also preserved between the segments of the Star Valley faults and are being exhumed in the footwall of the outboard fault suggesting that the relay is not a newly developing one. Stratigraphic relations at the initial point of fault overlap indicate that approximately 2-my-old syn-rift alluvial fan conglomerates derived from erosion of the inboard footwall onlap and are ponded against the hangingwall dipslope of the outboard segment. This indicates that the Star Valley segments were in overlap position and the outboard fault formed topography during conglomerate deposition. This pinning point provides a minimum age for onset of fault overlap and permits estimation of a propagation rate for the outboard fault tip of approximately 9 mm/yr. This is an order of magnitude greater than Holocene fault displacement rates derived from trenching studies. Analysis of drainage patterns indicates that streams on the outboard footwall have incised headward in response to displacement on the outboard fault and captured drainage that originally flowed down the relay. Captured streams show well-developed concave profiles. Streams on the outboard fault tip by contrast show convex-up profiles indicating that tectonics dominates the streams ability to incise and develop an equilibrium profile. Stream capture has resulted in major denudation of the outboard footwall suggesting that this may be an important process in local footwall erosion. Comparison with numerical landscape evolution models (Densmore et al. 2003) suggests that capture of early formed relay zone drainage occurs in situations where fault segments propagate into overlap position and link rapidly, after which displacement addition on the overlapped segments drives the rapid baselevel fall that leads to capture. We hypothesise that the relative timeframe of fault linkage plays a critical role in landscape evolution and sediment dispersal patterns at evolving relays.

T21E-02 1040h

Normal Fault Growth and Linkage in the Whakatane Graben, New Zealand, During the Last 1.3 Million Years

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Here we show how seismic reflection data of different spatial resolutions can be used to constrain the linkage history and displacement rate variations of a single major fault. Previous work on the determination of fault growth rates and fault network evolution at time-scales from 10^4 - 10^6 years has been hampered by a lack of a well-constrained stratigraphic succession that provides a high-fidelity record of fault development over these time periods. We present data collected in the offshore Whakatane Graben, Bay of Plenty, New Zealand, where intense normal faulting occurs as a result of active back extension. The focus of our study is the Rangitaiki Fault, a linked segmented normal fault which is the dominant active structure in the graben. The total linked fault length is c. 20 km long and has a displacement of up to 830 $\pm$ 130 m in the top 1.5 km of sediments. The fault has been actively growing for the last 1.34 $\pm$ 0.42 Ma and has developed from isolated fault segments to a fully linked fault system. Initially, the dominant process of fault growth was tip propagation, with an average and maximum displacement rates of 0.52 $\pm$ 0.18 mm yr^{-1} and 0.72 $\pm$ 0.23 mm yr^{-1} respectively. Interaction and linkage became more significant as the fault segments grew towards each other, resulting in the fault network becoming fully linked between 300 and 18 ka. Following fault segment linkages, the average displacement rate of the fault network increased by almost three-fold to 1.41 $\pm$ 0.31 mm yr^{-1}, while the maximum displacement rate increased to 2.72 $\pm$ 0.61 mm yr^{-1}.

T21E-03 1055h

The Tectonic Evolution of the Tjörnes Fracture Zone, offshore Northern Iceland - Ridge Jumps and Rift Propagation

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The Tjörnes Fracture Zone (TFZ) links the rift zones in northern Iceland with the Kolbeinsey Ridge north of Iceland. The TFZ was initiated during the Miocene (7-9 Ma), following an eastward jump of the spreading axis in northern Iceland. A roughly 150 km long (EW) and 50 km wide (NS) deformation zone has since developed which includes both right-lateral, strike-slip faults and three N-S trending extensional grabens (from west to east the Eyjafjördur, Skjálfandi and Öxarfj"ordur basins) which are filled with a 0.5-4 km thick sedimentary sequence. There are two WNW-striking bands of seismicity in the TFZ, a northern band known as the Grímsey lineament and a southern band associated with the WNW-trending Húsavík-Flatey fault (HFF). Over the past three field seasons we have mapped a large portion of TFZ utilizing multibeam echo sounders (both EM300 and a Reson 8101 shallow water system), collected high-resolution multichannel seismics and Chirp sonar, and obtained bottom photographs. The HFF can be traced offshore from Húsavík village across Skjálfandi Bay as two WNW-trending, south-facing fault scarps and northwest of Flatey Island into the southern Eyjafjördur basin as a WNW-trending, north-facing scarp. In Skjálfandi Bay several smaller WNW-trending faults are located sub-parallel of the main HFF. Offshore Flateyjarskagi, west of Flatey Island, a zone of intense deformation has been mapped, including clear evidence of right-lateral strike-slip faulting. The sediment-filled basins north of the HFF are bounded by numerous NS-trending faults, some of which extend to the seafloor, suggesting they are actively extending. The very subtle expression of the HFF in eastern Skjálfandi Bay, and the more prominent but simple expression of recent (post-glacial) faulting along the western HFF near Flatey Island are consistent with historical and recent seismicity which is concentrated on the Húsavík fault system on the Tjörnes peninsula, along the western HFF and in the southern Eyjafjördur, basin. A GPS geodetic station on the Tjörnes peninsula, northeast of the HFF, maintained by the Iceland Meteorological Service shows that over the past 2 years the southern TFZ has been moving with the North American plate suggesting that little strain accommodation is currently occurring along the main HFF. These observations are consistent with a model for the tectonic evolution of the TFZ in which the continued northward propagation of the northern rift zone in Iceland has progressively shifted relative motion between the North American and Eurasian plates northward to the series of NNE-SSW trending rift zones along the Grímsey seismic lineation.

T21E-04 1110h

Seismic Reflection Imaging of the Tucson Basin and Subsurface Relations Between the Catalina Detachment System and the Santa Rita Fault, SE Arizona

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Industry seismic reflection data collected in SE Arizona in the 1970's imaged the structure of the Tucson basin, the low-angle Catalina detachment fault, and the Santa Rita fault. Recent reprocessing of these data, including detailed near-surface statics compensation and modern event-migration techniques, have served to better focus the subsurface images. The Tucson basin occupies an area of approximately 2600 km^2 and is bounded to the northeast by the Catalina-Rincon metamorphic core complex and to the south by the Santa Rita Mountains. The basin is characterized by an apparent half-graben structure down dropped along the eastern side and filled with up to 3700 m of Oligocene to recent volcanic and sedimentary rocks. In the northern portion of the basin, the gently-dipping (~30 degrees) Catalina detachment fault is imaged from the western flank of the core complex dipping to the southwest beneath the Tucson basin. The detachment surface is evident to several seconds two-way-time in the seismic data and is characterized by broad corrugations parallel to extension with wavelengths of tens of kilometers. In the southern portion of the basin, the Santa Rita fault is imaged at the northwest side of the Santa Rita Mountains and dips ~20 degrees to the northwest beneath the Tucson basin. Large, rotated hanging-wall blocks are also imaged above both the Catalina detachment and Santa Rita faults. While the Catalina detachment fault is no longer active, geomorphic analysis of fault scarps along the western flank of the Santa Rita Mountains supports recent (60-100 ka) movement on the Santa Rita fault. Preliminary results indicate that the Santa Rita fault terminates against the Catalina detachment fault beneath the central basin, suggesting that the recent movement observed on this fault may be, in part, a reactivation of the older fault surface.

URL: http://www.geo.arizona.edu/~/fwagner/projects.html

T21E-05 1125h INVITED

Constraining fault interactions and vertical displacement rates in a compressive proto-back-arc environment, South Wanganui Basin, New Zealand

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The Kapiti-Manawatu Fault System (KMFS) is a 25 km-wide network of steep, reverse and normal faults that runs parallel, and 200 km to the west of the Hikurangi subduction margin, New Zealand. The KMFS separates the 4 km-thick Plio-Pleistocene South Wanganui Basin from the recently uplifted North Island axial ranges, to the west and east, respectively. The KMFS represents the westernmost expression of upper plate deformation associated with Hikurangi subduction over the last 2 million years. A seismic reflection network of lines acquired 1.5 km apart across the KMFS provides a way of constraining the Plio-Pleistocene tectonic activity in the region. Strike-projected, vertical separation profiles (D/L) demonstrate the interplay between faults, and indicate a regional southeast migration of the compressive system with time. Basement fault geometry suggests reactivation of a normal fault system and a minor amount of strike-slip motion. Fault terminations suggest that these faults have remained fixed with no lateral propagation since at least 1350 kyr. Cumulative D/L profiles have clear bell shapes, which contrast with the asymmetric shapes of individual D/L profiles. This suggests that the KMFS is a mature fault system with fault lengths initiated early in the evolution of the fault zone due to the pre-existing crustal heterogeneities under a constant regional strain regime. Long-term slip rates were derived from vertical separations across horizons dated 120, 620, 1000, 1350, 2400 and 3000+ kyr, for 21 fault segments. The maximum vertical slip rate on any one fault is less than 1 mm/yr, but the maximum long-term (1350 kyr) cumulative slip rate across the whole KMFS reaches 2.1+/-0.6 mm/yr. Late Quaternary deformation suggests slip rate magnitudes ranging from 0.1-1.4 mm.yr-1 over the last 10,000 years. Slip rates for the 0-120 kyr period increased, and the cumulative maximum slip rate for the KMFS reaches 5.0 +/- 1.5 mm/yr.

T21E-06 1145h

Fault System Evolution and Fault Reactivation During Large-Scale Distributed Deformation in Continental Lithosphere

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Deformation within continents involves multi-scale responses such as localized brittle faulting (mainly in the upper crust) and more distributed deformation commonly modeled as elastic, viscous, or visco-elastic behavior (within the lower crust and upper mantle). This study investigates the interaction between localized faulting and distributed elastic flexure within intra-plate extensional settings. The geodynamic models presented are inspired by deformation observed at the Rio Grande rift, where Neogene extension appears to have been controlled by pre-existing lithospheric-scale heterogeneities and where pre-existing (Laramide) structures show evidence of rift-related extensional reactivation. The idealized models explore the evolution of new and pre-existing brittle faults in an upper crustal layer during flexural bending of the lithosphere. Particular attention is devoted to understanding how flexure interacts with faulting within both the hanging wall and footwall blocks of asymmetric half-graben (such as the Espanola or Albuquerque basins of the central Rio Grande rift). The model results suggest that the combination of flexure and faulting within a bending plate can explain certain enigmatic features of the central Rio Grande rift, including topographically high rift-flanks on both the hanging wall and footwall blocks of asymmetric basins.

T21E-07 1200h

Detail Structure of San Andreas Fault Jog in Cholame Valley From Small-Scale Topography and Sesmic Data

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The significance of the Parkfield area is in it being a transition zone between creeping NW and locked SE sections of San Andreas Fault (SAF), which makes it a most likely spot defining future seismic activity of the region. The detailed studies of seismicity generated by Parkfield 1996 M6 event revealed very high seismic activity in Cholame valley region SE of the Parkfield and ruptures along Cholame valley tracing the fault along the surface. In the middle of the valley SAF has about 1.5 km jog to SW after which it continues to go in SE staying parallel to the original direction. The jog geometry had no surface evidence and was determined on the basis of epicenter locations of multiple events in this area. Seismic and theoretical studies (Hanna, et. Al. 1972; Eaton et. Al. 1970; Harris and Segall, 1986) suggested a complex structure of the jog area, being and interacting segment of two parts of SAF. Such segments usually represent wide zones with multiple fractures oriented at 45 degrees with respect to main fault orientation and which connect isolated segments of a fault. The corresponding micro-fracturing was observed in multiple locations of Cholame valley. Extent and mechanical properties of interacting segments have strong impact on accumulated strain release. The fault structure studies in Cholame valley are mostly based on seismic information since valley sediments cover bedrock and do not allow accurate fault mapping. Nevertheless we have found that low amplitude topography features of the valley apparently affected by bedrock surface geometry. The fault can be traced along both sides through an existing point of connection of jog with SW strand of SAF. Also there is a wide shear zone of interaction between upper and lower parts of SAF. Multiple NS oriented faults which make 45-degree angles with traces of SAF are quite visible. Image features also suggest a straight continuation of NW part of the SAF in SE direction after passing the jog. In the same time the NW straight extension of SE part of the SAF connects it with mapped part of the South-West Fracture Zone (SWFZ). This result suggests the Cholame valley fault structure represent two faults SAF and SWFZ, which were separate at some point in history but began interacting through development of zone of shear faulting in the middle of the valley leaving some of their old parts temporarily inactive.

T21F MCC: 3007 Tuesday 1020h

New Views of the Structure and Composition of the Deep Earth III

(joint with GP, S, V, MR, DI)

Presiding: **D L Farber,** Lawrence Livermore National Laboratory**; J Badro,** University Paris VI - Institut de Physique du Globe

T21F-01 1020h INVITED

Lower Mantle Composition From Mineral Physics Data

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The questions of lower mantle composition and thermal structure pose a considerable challenge for mineral physics. The pressures and temperatures of this region are difficult to simulate and measure accurately in the laboratory, and the phases likely present in this region are difficult to synthesize as high quality samples for accurate physical properties measurements. Nevertheless, over the last decade there has been enormous progress on characterizing the elastic and thermal properties of lower mantle phases. We review some of the recent experimental breakthroughs. These results have been used to infer the average composition of the lower mantle by extrapolation of mineral properties to lower mantle conditions and comparing them to global 1D Earth models, and also via formal inversion of seismic velocity and density profiles for composition. Inversions of density and bulk sound velocity are able to place constraints on the Mg/Si and the Mg/Fe ratios, but are less sensitive to Al and insensitive to Ca contents. This is in part due to recent experimental results which indicate that the bulk modulus of (Mg,Fe,Al)(Si,Al)O3 perovskite does not change much with Al content (contrary to previous experiments). However, the shear properties of aluminous perovskite differ substantially from those of Al-free perovskite, making the shear properties of the lower mantle a sensitive indicator of Al content. We discuss the range of compositional models consistent with the present laboratory results, and the most critical mineral physics results needed to further refine compositional and thermal models for the lower mantle.

T21F-02 1035h

Inversions for lower mantle composition and temperature from elasticity parameters and thermodynamic modeling

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Most constraints on lower mantle composition come from comparison of seismic profiles with their equivalents deduced from mineral physics. For seismologists, the parameters of primary interest are the velocities V_P and V_S and their lateral variations, whereas the most readily determined properties experimentally are K_S and ρ. Therefore, the two sets of results cannot be directly compared. Additional data analysis and thermodynamic modeling are then necessary. In this study, we apply a generalized inverse method and recent and highest quality experimental and seismological observations to compute the lower mantle composition and corresponding temperature profile. This method calculates the parameters (composition and temperature) which minimize a misfit function (density and bulk sound velocity) to best match global 1-D seismological profiles. We demonstrate that the Fe/Si and Mg/Si (molar) ratios are well constrained, and that there is a degree of covariance between the Ca/Si ratio and the Mg/Si ratio. The Al/Si ratio is only poorly constrained. The physical properties we have chosen yield a lower mantle model which is chemically homogeneous from 800 to 2700 km. Our method also gives the a posteriori uncertainties on the inverted parameters and, therefore, allows us to precisely evaluate how the experimental uncertainties on elastic parameters affect the composition and temperature. We show that if the bulk modulus of Mg-perovskite is 246 GPa instead of 261 GPa (5% difference), the resulting perovskite fraction is increased by 30%. Finally, if the temperature profile and composition are not simultaneously inverted, then the resulting lower mantle composition is highly dependent of the choice of the thermal regime.

T21F-03 1050h

Direct Measurements Of The Elastic Properties Of Iron To 115 GPa

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The velocity of an acoustic wave propagating at the interface between diamond and polycrystalline iron has been measured using impulsive stimulated light scattering (ISLS) to 115 GPa in a diamond anvil cell. Our data provide the first direct measurements of the elastic properties of hexagonal close-packed iron at pressures comparable to that at the boundary between the Earth's core and mantle. The corresponding compressional and shear velocities are found to be linearly dependent on density, and consequently suggest a reliable extrapolation to inner-core conditions. Velocities thus obtained are compared with those of the Preliminary Reference Earth, and implications for core composition and structure are discussed.

T21F-04 1105h

Sound Velocity Measurements in Textured hcp-Iron and the Anisotropy and Structure of Earth's Inner Core

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Seismological studies show that the Earth's inner core is elastically anisotropic. The anisotropy has an axial symmetry and an amplitude of about 3-4%, with the fast direction oriented parallel to the Earth's rotation axis. Several hypotheses have been proposed to explain this feature, but the lack of evidence from mineral physics does not allow to address them.
Indeed, the experimental determination of sound velocity anisotropy in hcp-iron, the main constituent of