T31B-06 0830h POSTER

Anatomy of the Main Martir Thrust: a Non-terminal Suture in the Peninsular Ranges, Baja California, Mexico.

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We investigate part of the exhumed Peninsular Ranges batholith, a Mesozoic-Cenozoic continental margin magmatic arc. We use structural and microstructural data to constrain the displacement and kinematics of the Main Martir thrust (MMt) and compare these to a model. The thrust, which has been interpreted as a non-terminal suture, is a one to two kilometer-wide shear zone that divides the batholith into an eastern part underlain by continental crust and a western part underlain by juvenile oceanic crust. The thrust is not associated with any known occurrences of ophiolites or deep marine sediments, which could be expected if the oceanic arc had accreted with a continental margin above a subduction zone. From east to west the shear zone includes orthogneisses, epidote-bearing metavolcanic gneisses, migmatites, and garnet amphibolites in the hanging wall, as well as a 50m section of calc-silicates mostly underlain by upper greenschist-facies metavolcanic phyllites in the footwall. Phyllites form a continuous footwall assemblage in all traverses and are part of the Albian Alisitos Formation, which towards the thrust shows a progressive increase in metamorphic grade consistent with juxtaposition against hotter rocks of the hanging wall. Within the hanging wall some units are attenuated, discontinuous, or pinch out and the metamorphic grade varies from andalusite-bearing schists to sillimanite-bearing metapelitic migmatites. Metamorphism appears to have accompanied deformation. Oriented rock samples from both sides of the MMt record mylonitic fabrics with shallowly plunging mineral lineations. Rounding a bend in the MMt these lineations swing from northeast-plunging in the western segment to north-plunging in the southern segment. Our work shows that significant differences in lithology, metamorphic grade, and lineation orientation occur along strike of the MMt. The diverse lithologies suggest that some components of a subduction complex might be present, whereas the different peak metamorphic temperatures recorded could suggest that hanging wall metamorphism occurred during periodic, variable heating episodes. Our study area spans a sharp bend in the thrust, and we explore the possibility that an indentor corner caused the distinctive lineation pattern and variation in metamorphic grade.

T31B-07 0830h POSTER

Gravity analysis of the Bam Earthquake Region

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On 26 Dec. 2003, the city of Bam and surrounding villages of the Kerman Province in southeastern Iran were severely shaken by a 6.5 Mw earthquake. Preliminary results show the earthquake's epicenter at 29.004N, 58.337E with a 14 km focal depth. The earthquake was triggered by right-lateral strike-slip motion along a north-south oriented fault. The earthquake was centered at the intersection of three concentrated zones of earthquake activity. This area includes an aeromagnetic anomaly minimum that overlies the Qale Ali Hasan volcano. These results are consistent with regionally demagnetized crust by an elevated Curie isotherm. Spectral correlation analysis of available free-air gravity anomalies and the gravity effects of the terrain modeled by Gauss-Legendre quadrature integration suggest that the isostatic balance of the Bam earthquake region is strongly disturbed. In this study, we investigate these results for constraining the crustal stresses that may have triggered the earthquake.

T31B-08 0830h POSTER

Mountains of water and repeated release in earthquakes

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The largest earthquake-induced increase in streamflow ever recorded, with a total excess water of 0.7 km3, occurred in central Taiwan after the 1999 (Mw = 7.5) Chi-Chi earthquake. Analysis of stream gauge data and well records suggests that the excess water originated in the mountains that showed extensive high-angle tensile fractures after the earthquake. The consequent increase in vertical hydraulic conductivity allows rapid draining of water from the mountains. We suggest that mountains in tectonically active areas may be repeatedly flushed by meteoric water on a time scale comparable to the recurrence interval of large earthquakes.

T31B-09 0830h POSTER

Implications of Stratigraphic and Structural Data from the Bitter Spring Region, Southern Nevada

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Deposition of the Tertiary Horse Spring Formation (HSF) in southern Nevada has been used to infer varying styles of extensional and strike-slip basin formation. Beard (1996) proposes an initial large contiguous basin of Rainbow Gardens age (ca. 26-18 Ma) that is subsequently broken up into sub-basins during Thumb time (16-14 Ma). A key locality to test this hypothesis is near the southern end of East and West Longwell Ridges, on the Bitter Spring USGS 1:24000 quadrangle (BSQ). However, the stratigraphic framework in this area is poorly defined. The BSQ is located west of the Overton arm of Lake Mead near the junction of the Las Vegas Valley Shear Zone and the Lake Mead Fault System. By mapping a portion of the quadrangle at 1:5000 scale, measuring detailed sections, and collecting ash samples from key localities, we investigated the structural and sedimentary framework of the area and have begun to clarify the stratigraphic relationships between members of the HSF. Faults fall into three categories: one set strikes north and dips moderately to the west; another strikes east-northeast and dips shallowly to the northwest; and the last strikes north and dips to the east. Many of these faults show an oblique sense of movement and may be related to movement on the White Basin (WBF) and Rodgers Spring Faults (Bohannon, 1983). A distinctive resistant limestone caps gypsiferous and clastic units on both sides of the north-south trending WBF. To the west of the WBF, this limestone is mapped as the Bitter Ridge Limestone Member of the HSF, whereas to the east it is mapped as the Thumb Member by Beard (unpub) and as the Rainbow Gardens Member by Bohannon (1983). We suspect that these limestones may be correlative; geochemical and petrographic fingerprinting of numerous ashes from our sections should allow correlation of these units across the WBF. In addition, sections from the east side of the WBF spaced over 1.5 km show conglomerate at the base, overlain by a sequence of red sandstone, gypsum, and carbonates (mainly oncolitic and peloidal limestone). These units show rapid lateral facies changes and thickness variation suggesting comparable changes in accommodation-space creation, possibly related to extensionally-induced subsidence. Paleocurrent data from the central portion of the mapping area indicate that flow was east- to southeast-directed, indicating that West Longwell Ridge may have been a topographic high during Thumb time. This interpretation is further supported by stratigraphic relationships near the basin margin, where conglomerate was deposited in buttress contact against Paleozoic limestones at the southern end of the ridge. Future work in this area includes continued mapping, Ar-Ar dating of ash mineral phases, and provenance analysis of sedimentary units.

T31C CC: 516 B Wednesday 0830h

Strain Partioning: Theory and Measurement *(joint with G, S)*

Presiding: **K Tiampo,** University of Western Ontario**; D Bowman,** California State University, Fullerton

T31C-01 0830h INVITED

Strain and stress partitioning of the North America/Pacific interaction along the Queen Charlotte margin

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Based on GPS data acquired over the last 5 years, we estimate the distribution and partitioning of crustal strain associated with the Pacific/North America (PA/NA) relative motion along the western margin of central British Columbia and southernmost Alaska. Combining GPS velocities and earthquake focal mechanisms, we show that the present-day transpressive PA/NA interaction is partitioned, from offshore to inland, between shortening in the Queen Charlotte Terrace, pure strike-slip along the Queen Charlotte Fault, and distributed dextral shear along the continental margin. The Queen Charlotte Fault was the locus of the great 1949 M=8.1 earthquake and is currently fully locked. Our GPS data cannot yet resolve whether the Pacific plate is actively subducting underneath North America or not. Partitioning of the PA/NA motion over the last 5 Myr is also supported by seismic reflection profiles that indicate shortening in the Queen Charlotte Terrace and in the Queen Charlotte Basin formations, respectively seaward and landward of the main strike-slip plate boundary. In order to assess the importance of lateral heterogeneities in composition and strength across the margin (sedimentary basins, major faults, etc.), we are developing a 3D finite-element model to investigate the distribution of crustal and lithospheric strain in response to the PA/NA relative motion.

T31C-02 0845h

Strain Partitioning of Oblique Convergence: Initiation of Subduction on the Queen Charlotte Margin?

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The seismic hazard within the Queen Charlotte Islands (QCI) is poorly understood. The present tectonic setting of the region is dominated by the Queen Charlotte Fault (QCF), the transpressive plate boundary ($\sim 320^{\circ}$) between the North American and Pacific plates along the western margin of Canada. The plate motion along the fault is primarily right-lateral transform at rates of $\sim$50 mm/a with a small component ($\sim$20 mm/a) of compression across the boundary. Convergence is confirmed by GPS velocities indicating northward oblique to the margin motions of 5-15 mm/a and the distribution of seismicity in the region of the QCF, which is partitioned into strike-slip events along the main fault and thrust events on subsidiary faults within the Queen Charlotte Terrace. Two end-member models have been proposed for the accommodation of the oblique convergence, internal deformation of both plates and underthrusting of the oceanic Pacific plate. Evidence for underthrusting includes the characteristic subduction zone trench and accretionary prism, low heat flow over the west coast of the Island consistent with a model of subduction, and the presence of an underthrust slab of oceanic crust imaged by teleseismic

receiver function analysis. A receiver function analysis was previously performed on the MOBC seismometer in the QCI. The study revealed a low velocity zone (LVZ) dipping eastwards at 20° beneath the continental Moho, with a depth of 34 km, a thickness of 10 km, and velocities consistent with oceanic crust. Receiver functions have recently been calculated from waveform data recorded at 6 temporary seismometers installed on the QCI during the summer of 1999. Preliminary results indicate a structure similar to that observed under MOBC with a LVZ increasing in depth eastwards across the QCI, consistent with an underthrust slab of Pacific plate. The largest recorded earthquakes in the region are dextral strike-slip events along the QCF; however, if underthrusting is confirmed, as suggested by the receiver function results, then megathrust earthquakes to M ∼8 will also be expected beneath the margin.

T31C-03 0900h INVITED

Could a Complex Earthquake like the 2002 Denali Fault Event hit the Los Angeles area?

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The Denali Fault earthquake sequence began with the 23 October 2002 Mw6.7 Nenana Mountain foreshock, followed on 3 November 2002 by the Mw7.9 Denali Fault mainshock. The transfer of slip from the Susitna Glacier fault to the Denali fault during the mainshock demonstrated that rupture of secondary thrust faults can trigger nearby strike-slip faults, highlighting the possibility that such dangerous earthquakes could occur in more densely populated regions with similar tectonics. For example, previous workers [Eberhart-Phillips et al., 2003] have suggested that an earthquake similar to the Denali Fault mainshock could occur in the Los Angeles metropolitan region, home to more than 13 million people. We have tested this proposal of intraevent triggering by first creating a dynamic rupture model of the Denali Fault earthquake that replicates the transition of rupture from the Susitna Glacier fault to the Denali fault. From this model, we find that the geometry of the faults and the orientation of the regional stress field explain why slip on the Susitna Glacier fault triggered rupture on the Denali fault. We then applied the same methodology to study these short term interactions, as well as static modeling to examine longer term interactions (foreshock/mainshock triggering), between the Sierra Madre-Cucamonga thrust and San Andreas/San Jacinto strike-slip fault systems near Los Angeles. We find that the comparison between these faults and the Denali Fault mainshock breaks down due to differences in background stress and fault geometry. In particular, rupture of the Sierra Madre-Cucamonga system is unlikely to trigger immediate rupture of either the San Andreas or San Jacinto fault, as the Susitna Glacier fault triggered the Denali fault during the 2002 event. However, our modeling suggests that under rare circumstances, a large earthquake on the northern San Jacinto fault could immediately trigger a cascading rupture of the Sierra Madre-Cucamonga system, potentially growing into a dangerous Mw7.5-7.8 earthquake on the edge of the heavily populated Los Angeles metropolitan region. The static modeling yields similar results, suggesting longer term triggering of events is more favorable for events originating on the strike-slip systems.

T31C-04 0915h

Forearc Slivers, Arcs, and Migrating Terranes: Strain Partitioning in a Sandbox

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Using automated image analysis, we determine displacements and strains throughout an analog experiment, for comparison with other models and with structural, geodetic and seismic data from active convergent margins. The rate at which a model forearc sliver or accreted block moves depends upon the geometry of the convergence and the yield criterion, and experiments with frictional blocks are sensitive to many of the same rate and wear-dependent aspect of friction that complicate the behavior of frictional faults in nature. Nonetheless, they illustrate the expected overall behavior, with a minimum obliquity angle below which there is no margin-parallel slip. With moderate to large convergence obliquity, sand experiments with rigid forearc slivers show substantial, but not total, partitioning of the margin-parallel convergence to along the strike-slip boundary between the sliver and the overlying plate. The degree of such partitioning decreases with smaller convergence obliquity and, less so, with increasing quantities of accreted sediment or with the buttressing effects of thrusting at the leading edge of the sliver as it moves parallel to the margin. Without such a rigid sliver and with small convergence obliquities, the margin-parallel component of convergence is broadly diffused throughout the deforming critical wedge, with thrusts throughout the wedge accommodating a small strike-slip component of motion, along with the dominant dip slip. At moderate obliquities, increasingly large portions of that margin-parallel motion are accommodated toward the rear of the wedge, over the backstop formed by the front of the overlying plate. At high obliquities, that region develops distinct strike-slip faults and other structures clearly related to accommodating the margin-parallel part of convergence. Arcuate frictional model margins display all of these features, as obliquity varies around the margin. Those with a nearly Newtonian viscous rheology display a less localized progression of strain distributions including true extension, reflecting stresses due to both plate convergence and topography. A sliver of small aspect ratio, essentially a migrating terrane, produces sweeping lobate features. The extreme partitioning of strain in such a case can lead to the formation of orogens with pronounced reentrants and foldbelts that display nearly pure dip slip faulting in a direction normal to the overall plate convergence vector, features that are absent when the terrane is docked instead of migrating.

T31C-05 0930h

Strain Partitioning and the Geometry of Oblique Plate Convergence

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Strain partitioning occurs at convergent margins where oblique subduction takes place, a fact that has been known for a number of years. The geometry of plate subduction controls strain-partitioning mode in the forearc region. Deformation in the forearc depends on the direction of relative plate convergence, earthquake slip vectors, and trench-normal direction. Two basic angles are derived from these vectors: obliquity of plate convergence, the angle of plate motion direction and trench normal, and slip partitioning which is the angle between the earthquake slip vector and trench normal. Traditionally, oblique convergence models consider the trench (convergent margin) a straight line on a flat Earth. This is correct for small-scale (in the order of a few kilometers) models. However, earthquakes along convergent margins often have fault lengths of tens and even hundreds (for magnitude 7 or greater) of kilometers. On the other hand, the direction normal to the trench is usually calculated averaging contiguous points along the deepest part of the digitized bathymetry, yielding the local trend of the trench. The direction normal to the trench thus calculated varies greatly along a specific trench. In this work we propose an alternate treatment of the geometry of the trench. On a spherical Earth, trench segments form arcs of small circles. Usually, a trench of interest will contain a few (three-five) such segments, which can be fitted (in a least-squares sense) with small circles with a known center of curvature (or pole) on the surface of the Earth. Also known are the initial and final points. Instead of the standard direction normal to the trench, we use the average azimuth from the segment of small circle to its corresponding pole. We use this direction instead of trench normal and calculate obliquity of plate convergence. We test our model along the western Sunda arc, from the eastern Himalayan sintaxis to Sumatra. Five contiguos small circles were fitted to the trench: one along the Indoburman ranges, two on the Andaman sea, and two offshore Sumatra. Direction of forearc deformation appears to be governed by the angle between the vector of plate convergence and the average direction of the trench, with earthquake slip vectors playing no role whatsoever. In fact, along the Indoburman ranges there are are no shallow, thrust-faulting earthquakes, although there is a subducted slab.

T31C-06 0945h

Current deformation in eastern Alaska and northwestern Canada related to the Yakutat collision: constraints from GPS and seismicity

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The northern Canadian Cordillera is very tectonically active with exceptionally high seismicity in southwestern Yukon and neighboring Alaska, and surprisingly high seismicity 800 km to the northeast in the Mackenzie and Richardson mountains adjacent to the craton. The Yakutat block has been colliding with North America in the corner of the Gulf of Alaska for the last *sim*5 m.y. The oblique collision results in partitioning of strain into strike-slip (e.g., Denali Fault) and convergent components. The intense seismicity occurs in the collision zone, where deformation is taken up mainly by thrust and strike-slip faulting in the Chugach-Saint-Elias Mountains. Some of the convergent component of strain is transferred across the Cordillera to the northeast, where seismicity rates and Global Positioning System (GPS) vectors indicate that motion is taken up in a broad zone of the fold-and-thrust belt, with little internal deformation of the intervening Cordillera. Simple numerical models for the collisional deformation and strain transfer show the development of both a coastal mountain belt and a foreland thrust front. The high crustal temperatures inferred from high heat flow measured in the northern Cordillera facilitate decoupling in the weak lower crust, allowing the upper crust to transfer stress across the Cordillera to be taken up in the weak foreland sedimentary belt. The strong craton acts as a backstop. Ongoing GPS and seismicity studies are in progress to determine the nature of the internal deformation of the Cordillera.

T31D CC: 516 D Wednesday 0830h

The Structure and Formation of Atlantic Rifted Margins: Observations and Numerical Models I

(joint with GP, S, V, NS)

Presiding: **K E Louden,** Dalhousie University**; R S Huismans,** Dalhousie University

T31D-01 0830h INVITED

30 Years of Volcanic Margin Research: From Conceptual Process Oriented Thinking to Present day 3D Reality'

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Over the past 30 years the Norwegian segment of the NE Atlantic continental margin has been a focus area for both continental margin research and hydrocarbon exploration. A gradually improving data coverage and quality, combined with an increasing number of people involved in interpretation and geological evaluation, has resulted in a more advanced understanding of the margin structure and its geodynamic development. The aims of this presentation are (1) to review the exploration history of the Norwegian margin, (2) to address the links between conceptual and process oriented research in the past with the present day 3D reality', and (3) to point towards type of challenges that likely characterise most volcanic margins globally. The Norwegian margin can be used to understand how large-scale lithospheric processes are coupled to temporal and spatial changes in vertical motions, development of rift structures and the nature of igneous activity. This is due to the fact that the volcanic cover adjacent to the Continent Ocean Boundary (COB) is sufficiently narrow to allow seismic imaging of a highly attenuated rift zone, a broad zone of intrusive complexes, and a resolvable stratigraphy for the syn- and post-rift sedimentary succession. Today we can review the accumulated knowledge in the framework of detailed observations from 3D seismic surveys. In particular, extensional faults, intrusive igneous complexes, and a large number of hydrothermal vent complexes associated with the igneous activity are exceptionally well imaged on the 3D data. The 3D data reveal a coupled system that 2D data never could resolve. Linking the

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