image, as well as to its structures, scales and detection frequencies.

T51F-0227 0830h POSTER

A Single Method for the Inversion of Anisotropic Data Sets With Application to Structural Studies

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Due to the intrinsic characteristics as to the shape and arrangment of their components, rocks are naturally anisotropic, that is traditionally pointed out through the measurement in different directions of a given physical property. These anisotropies are in general easy to observe and quantify but not to interprete in terms of microstructure or, what remains the same, in terms of deformation if the measurements are performed for a structural study. For instance, a usual problem is to distinguish, giving an anisotropy fabric, the deformation contribution from the inherited part. Here, a unified method to analyse magnetic susceptibility and P-wave velocity data is proposed, assuming that both measurement sets can be described by a second rank tensor, which is rigorously true only for the magnetic data. For the velocity data, this hypothesis is discussed by estimating the error made during inversion with respect to theoretical estimations for transverse isotropic media. We find that the error mostly falls below 1% for simulations on published experimental data for several sandstones and limestones. Therefore our analysis promotes the use of a unique and simple method to analyse anisotropy from different data sets in structural applications. We also discuss the best strategy for data sampling in order to get a comprehensive knowledge of the anisotropic behaviour of rocks in structural studies. The method is applied to different sedimentary rocks (mainly sandstones), retrieved in both deformed and undeformed structures. We emphasize that combining data sets for different physical properties and using a single inversion scheme leads to a better understanding of the deformation processes at the microstructural scale.

T51F-0228 0830h POSTER

The Conjugate Volcanic Continental Margins Of Argentina And Southern Africa

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In April-June 2003 the German Federal Institute for Geosciences and Natural Resources (BGR) undertook a new marine geophysical cruise along the South Atlantic continental margin off South Africa. In total more than 3,000 km of combined multi-channel reflection seismic (MCS), magnetic and gravity and an additional of 1,300 km with only magnetic and gravity were acquired. In combination with the extensive MCS (>20,000 km) data set from the Argentine margin we are able to interpret seven conjugate traverses available over almost exact conjugate parts of these volcanic passive margins. A first interpretation of the raw stacked seismic data from the South African side shows that the volcanic features seem to be mirror images to the structures found on the Argentine margin. Continental break-up and initial sea-floor spreading were accompanied by large-scale magmatism and volcanism as manifested in the seismic data by a huge wedge of seaward dipping reflectors (SDRS), and a distinct high-velocity (average value 7.3 km/s) lower crustal body beneath the SDRS. The data from the Argentine margin already suggested that the emplacement of the deeply buried, 60-120km wide SDRS was episodic as documented by at least three superimposed SDRS units. A similar distinct partitioning of the SDRS into three to four individual wedges is present on the South African margin. From the new data a detailed correlation of timing of these individual pulses is intended. Furthermore, it is possible to estimate the amount of extruded material during the phases of emplacement. The seismic data from the Argentine margin document the presence of a narrow, north-east striking half-graben system beneath the upper slope. This buried half-graben system developed during the final stage of rifting in the Early Cretaceous, whereas the east-west trending Colorado-Basin probably formed earlier. In the new data from South Africa only one half graben was identified up to now.

T51G MCC: 3007 Friday 1020h

Analysis of Plate Boundary Deformation Using Stress and Strain Rate Data in Tandem II *(joint with G, S)*

Presiding: **J Townend,** Victoria University of Wellington**; S Mazzotti,** Geological Survey of Canada

T51G-01 1020h INVITED

Using finite and infinitesimal strain indicators to decipher the evolution and vertical coherency of deformation in the northern Aegean

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For an increasing number of deforming regions extensive sets of geodetic data are currently available. One of the challenging prospects of this newly available information is the potential to study the relationship between the present-day surface deformation field and the magnitude and direction of 1) past crustal deformation, and 2) the inferred deformation of the lithosphere and underlying mantle. We have started an investigation into the 3-D deformation evolution of the Northern Aegean, a tectonically complex area that is known to have experienced drastic tectonic regimes changes over the last few million years. We have modelled the surface strain rate field through an interpolation of published GPS velocity vectors and with additional constraints from active faulting. The strain rate field in the northern Aegean is dominated by a shear zone along the North Aegean Trough which accommodates $\sim$25 mm/yr of motion, similar to the North Anatolian fault (NAF) to the east, and which terminates abruptly offshore central Greece. In variance with what is argued earlier by others, the direction of the extensional strain rate axes do not agree with published shear-wave-splitting directions that are thought to indicate anisotropy directions of the underlying lithosphere and upper mantle. Shear-wave-splitting directions also do not agree with calculated no-length-change directions from our model. Instead we find that extensional strain rate directions are oriented consistently (and significantly) 17°-40° more northward than the NE-SW oriented shear-wave-splitting directions. We argue that the shear-wave-splitting directions are relatively more consistent with published directions of middle-upper extension directions during the Miocene as inferred from stretching lineations in metamorphic core complexes. We postulate that 1) present-day extension directions are different from those in the Miocene because of the westward prolongation of the NAF which has changed the dominating regime from extension to shear, and 2) the significant extension in the Miocene has involved or affected the whole lithosphere and possibly upper mantle. We infer that the major shear zone in the northern Aegean has been established too recently to rotate anisotropy directions at depth along the direction of shear, as happened along some other major shear zones. This would agree with the fact that the timing of the westward prolongation of the NAF into the Aegean domain is estimated at 1-3 Ma. To further investigate the possible relationship between Miocene crustal and inferred lithospheric deformation, we attempt to obtain crustal finite strain estimates in order to do a relative and/or absolute comparison between Miocene crustal deformation and the seismic delay-times observed in the published shear-wave-splitting study. When we use available crustal thickness estimates we observe a strong correlation between the inferred lateral variation in beta-factors and seismic delay time. This would be the first study to observe such a correlation and this could have profound implications on our understanding of the large-scale mechanics in an extensional regime. However the validity of published crustal thickness estimates needs to be considered first, and this will be discussed as well.

T51G-02 1040h

Present Day Deformation of the Aegean Region: Short- and Long-Term Motions, Stress State and Lithospheric Rheology

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We analyze an unusually complete set of GPS measurements to define the current pattern of lithospheric deformation in the Aegean. These results, complemented by geologic, geomorphic and seismologic data, permit us to determine the long-term kinematics, relate it to the stresses driving and resisting deformation, and constrain lateral variations in lithospheric rheology. We find that active continental deformation in the Aegean is explained well to first order using rigid plate kinematics. The intraplate stress field is dominantly extensional or trans-tensional, and deformation is focused in narrow zones that are weaker than the bounding microplates. Site velocities from 5 separate GPS networks comprising over 400 stations have been combined into a single common Eurasia-fixed reference frame to map the velocity distribution over the entire Aegean. We build upon previous work by others, especially McKenzie and Jackson (1983, 1988), Le Pichon et al. (1995), and McClusky et al. (2000) to initially specify rigid elements in central Greece, the South Aegean, and Anatolia. We use the GPS velocity field to identify deforming regions, rigid elements, and potential microplate boundaries. We apply an iterative approach, tentatively defining microplate boundaries, determining best-fit rigid rotations, examining misfit patterns, and revising the boundaries to achieve a better match between model and data. Short-term seismic cycle effects are minor contaminants of the data that we remove when necessary to isolate the long-term kinematics. We find that present day Aegean deformation is due to the relative motions of three microplates and straining in several isolated zones internal to them. The RMS misfit of model to data is about 2-sigma, very good when compared to the typical match between coseismic fault models and GPS data. The simplicity of the microplate description of the deformation is surprising and was not anticipated by previous work, which had suggested either many rigid elements or broad deforming zones that comprise much of the Aegean region. The isolated deforming zones are also unexpected and cannot be explained by the kinematics of the microplate motions. Focal mechanism data indicate that the Aegean stress field is dominantly extensional, driven by gravitational forces manifested in rollback of the Hellenic Trench, as originally suggested by Le Pichon and Angelier (1979). Horizontal least compressive stress axes locally make a high angle with the North Anatolian Fault in western Turkey, suggesting this plate- bounding fault is weaker than the adjacent Anatolian block. Localization of current deformation in narrow zones suggests that rheological weakness exerts a controlling influence on both the kinematics and dynamics.

T51G-03 1055h

Deformation Kinematics and Dynamics in the Philippine Sea - Eurasia Plate Collision Zone in the Taiwan Island Determined From Recent GPS Data

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The 300 km long segment of the Philippine Sea and Eurasia convergent plate boundary through the Taiwan Island involves collision, subduction, and back-arc extension tectonics. Various dynamic models have been proposed for the collision tectonics in the Taiwan Island based on geological or seismological evidence. We investigate possible dynamic processes that shape the modern tectonics in and around the Taiwan area. We first use recent GPS data to quantify the contemporary deformation kinematics in the region. A self-consistent strain rate tensor field is determined using an inversion procedure that minimizes the misfit between the model and observed GPS velocities in a common reference frame. The strain rate tensor field determined from GPS data predicts deformation styles that are in agreement with earthquake focal mechanisms and local geology, indicating that the interseismic deformation field represents the style of long-term deformation

field reasonably well. The Longitudinal Valley fault zone (LVF) has the highest strain rates with magnitude of 1-2.5x10^{-6}/yr. The strain rates in the deformation front fault zone (DFFZ), west of the Central Range in western Taiwan, are also relatively high, with magnitudes ranging from 1x10^{-7} to 2x10^{-6}/yr, increasing from north to south. The deformation style in both the LVF and DEFZ are primarily pure compression in northwest-southeast direction. In the Central Range, between LVF and DEFZ, extensional strain rates predominate. The extension regime in the Okinawa basin north of the Ryukyu subduction zone extends westward to the Ilan plain in northeast Taiwan. The rate of NS extension in the east, offshore of northeast Taiwan, could be as high as 20-40 mm/yr. West of Ilan plain, the extension rates decrease rapidly. The transition from extension to compression occurs in the northern Central Range, where strain rates are close to zero. In order to understand the dynamics driving the deformation we directly solve the force balance equations, using both a thin elastic layer and a thin viscous sheet formalism, for estimates of the styles and magnitudes of vertically averaged deviatoric stress. The observations that constrain the solutions are gravitational potential energy, inferred from topography, and the styles of strain, inferred from the kinematic solution. The solutions consist of two parts: vertically averaged deviatoric stresses associated with internal body forces (gravitational potential energy), and stress boundary conditions. The stress boundary conditions are sought such that the styles of total deviatoric stress match the styles of deformation inferred from the interseismic deformation field. Vertically averaged stress levels are approximately 100 bars in northern Taiwan, and are smaller in the southern Taiwan with stress levels ranging from 10-50 bars. Both the elastic and viscous solutions yield extensional deviatoric stresses over high topography, consistent with gravitationally driven extension. Although full solutions will require the treatment of basal tractions, the presence of extension over high topography is consistent with crustal scale, thin-skinned, type models where there is significant coupling between the elastic upper crust and a deeper viscous layer.

T51G-04 1110h

Subduction Zone Locking and Forearc Rotation in the North Island, New Zealand From Inversion of Geodetic, Seismologic, and Geologic data

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The GPS velocity field in the North Island of New Zealand is dominated by the long-term tectonic rotation of the Hikurangi forearc (eastern North Island) and elastic strain from the Hikurangi subduction zone. We simultaneously invert horizontal GPS velocities, earthquake slip vectors, and geological fault slip rates in the North Island for poles of rotation of elastic blocks and the degree of coupling on faults bounding the blocks. This approach allows us to estimate the distribution of locking on the subduction zone interface beneath the North Island, as well as the kinematics of the forearc blocks. In agreement with previous studies, we find that the subduction zone beneath the lower North Island is strongly coupled in the interseismic period and that the degree of coupling decreases northwards along the margin. We also find a small locked patch on the subduction zone in the northeastern North Island, very close to where an aseismic deformation event occurred in October 2003. Much of the eastern half of the North Island is rotating clockwise at 2-4 degrees/Myr relative to Australia, about a pole just west of the central North Island. This forearc rotation accommodates most of the margin-parallel component of motion between the Pacific and Australian plates. The motion of the forearc with respect to the Pacific plate agrees well with seismological inferences of slip partitioning at the Hikurangi margin, although the GPS do suggest that motion on the subduction interface might become more oblique south of -41 degrees latitude. We infer that the forearc rotation is due to an along strike variation in the properties of the lower plate being subducted at the Hikurangi margin, where the buoyant Hikurangi plateau is being subducted at the southern end of the subduction zone, and oceanic crust is being subducted further north. This mechanism for rotation is similar to that seen in other locations (for example, Papua New Guinea).

T51G-05 1125h INVITED

Dynamic And Kinematic Models Of The Yellowstone Hotspot Constrained By Seismic Anisotropy, GPS Measurements And Fault Slip Rates

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The Yellowstone-Snake River Plain (YSRP) volcanic system is comprised of the Yellowstone Plateau and the eastern Snake River Plain – a region of young basalt flows overlying older silicic calderas and believed to be the track of the Yellowstone hotspot. The YSRP is characterized by an anomalous10-m geoid-high centered on Yellowstone, and a parabolic pattern of high topography and active seismicity surrounding the low topography and aseismic eastern Snake River Plain. We will discuss an integrated study of the upper-mantle flow and the structure, kinematic deformation and strength for the YSRP. Mantle flow and structure are assessed by shear-wave splitting and tomography, while lithospheric deformation is determined by GPS measurments. The stress field and strength of the lithosphere is then obtained from integrated dynamic modeling of the deformation field and the geoid. The kinematic deformation field is derived from the integration of GPS surveys of the YSRP and Basin-Range from over 200 campaign and permanent stations constrained by L. Quaternary fault-slip data. The kinematic models reveal a rotation of the velocity field from NE-SW extension of 4 mm/yr in the YSRP to E-W extension of 2 mm/yr in the eastern Basin-Range. The teleseismic data were recorded by 79 temporary PASSCAL seismographs combined with data from 5 permanent regional networks, with an additional 90 stations, centered on Yellowstone. Teleseismic shear-wave splitting indicates that the fast-polarization directions are dominantly aligned parallel to the direction of N. America Plate motion. The observed anisotropy can be explained by simple asthenospheric flow, although lithospheric deformation may be important along the SRP. Mantle tomographic images reveal a relatively shallow, < 250 km, low-velocity, 1-3%, P-wave anomaly, beneath Yellowstone and the SRP consistent with a partial melt. Overall deformation of Yellowstone and the eastern Basin-Range region makes up about 25

URL: http://www.mines.utah.edu/~rbsmith/research.html

T51G-06 1145h

Sequential Strain Maps of Continental Extension: Comparing Variations in Geologic to Geodetic Strain Rates in the Basin and Range

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We compare GPS (BARGEN) data to kinematic reconstructions across the Basin and Range province of western North America to show the patterns of plate boundary deformation over a wide range of temporal scales. The Basin and Range province of western North America is a classic example of large magnitude diffuse deformation. More is known about timing, amount, and spatial variations of extension within the Basin and Range province than in any other comparable region, making the western United States one of the most appealing locations to look at the driving forces behind large magnitude diffuse deformation. Even though in selected portions of the Basin and Range are rich in kinematic data, the kinematic history of the province as a whole is still not well understood. The critical body of data required to adequately compare GPS velocity data to velocity data over geologic (10^6 yr.) time scales is the detailed kinematic history of the region of interest. We compiled kinematic data (amount, timing and direction of displacement) along three transects through the northern (40°N) central (36°-37°N) and southern (34°N) Basin and Range. Extension in each of these areas was sequentially restored using the kinematic data and ArcGIS. The sequential restorations highlight misalignments, overlaps or large gaps in each incremental step, particularly in the areas between the data transects. We use the regions where the kinematics are known to constrain adjacent areas where the kinematics are not defined. For instance, strain compatibility requires that the timing and amount of northward motion of the Sierra Nevada block along the eastern California shear zone be complementary across the north-south extent of the region. The northward motion of the Sierra Nevada block must be coupled to the deformational history of the Mojave region for strain compatibility between the three transects. The sequential reconstructions provide province-scale strain maps of horizontal velocity vectors over 2 Myr to 20 Myr intervals. The reconstructions also illustrate the path of a series of points (representing individual ranges) through time. The horizontal velocity maps over 2 Myr increments can be compared to each other and to horizontal velocity maps of GPS solutions to show how different regions of western North America (Basin and Range, eastern Californian shear zone, Garlock fault, the Mojave desert) have evolved and continue to evolve through time. As an example, these maps show a progressively westward migration of strike-slip deformation associated with the eastern California shear zone from 10 Ma to present.

T51G-07 1200h

A Model with Rigid Rotations and Slip Deficits for the GPS Derived Velocity Field in Southwest Japan

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In order to determine the kinematic features of arc tectonics, we analyzed the GPS derived velocity field in southwest Japan. We consider two factors; one is the elastic deformation caused by fault dislocations (or slip deficits), and the other is rigid motions of regional tectonic blocks (or plates). Rigid motions might cause significant errors in the estimation of slip deficits if they are not properly accounted for. For example, the velocity field in southwest Japan cannot be fully explained by a model with only slip deficits. Residuals in such a model imply the westward migration of the outer arc of southwest Japan and backarc spreading along the northern extension of the Okinawa trough.

We interpret the GPS derived velocity field in southwest Japan by a superposition of the elastic deformation caused by fault interactions (slips or slip deficits) and rigid motions of tectonic blocks (or plates). Based on the strain rate field and crustal seismicity, we apply a model with 3 blocks (Inner Arc, Outer Arc, and northern Ryukyu) and slip deficits along the block boundaries.

Some characteristics of the model are found:

(1) westward motion of the outer arc relative to the Amurian plate and the inner arc,

(2) southward motion of the N-Ryukyu block relative to the Amurian plate,

(3) small right lateral slip deficits along the boundary at latitude 32° N in southern Kyushu,

(4) small left lateral slip deficits along the Median Tectonic Line and the Beppu-Shimabara Graben,

(5) slip deficit rates on the plate interface smaller than those for the case without consideration of rigid block motions,

(6) clockwise deflection of the slip deficit rate vector from that estimated for the case without consideration of rigid block motions.

T51H MCC: 3005 Friday 1020h

Structure and Dynamics of the Oceanic Upper Mantle III *(joint with OS, S, V)*

Presiding: **J Gaherty,** Georgia Institute of Technology**; S Zhong,** University of Colorado

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T51H-01 1020h INVITED

Melting Processes Beneath Mid-Ocean Ridge Spreading Centers

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The variations in major element composition of mid-ocean ridge basalts (MORB) provide significant insight