GP12A-06 1455h INVITED

Contrasting Magnetic Fabrics in Sediments of Alpine and Variscan Accretionary Wedges of Central Europe

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The magnetic fabrics in sediments of the Alpine thrust sheets of the Flysch and Klippen Belts of the West Carpathians range from essentially sedimentary to mostly deformational in origin. The former magnetic fabrics are characterized by virtual parallelism of the magnetic foliations to the bedding and by close relationship of magnetic lineations to the current directions, if observable. These magnetic fabrics are typical of the thrust sheets at both margins of the Flysch Belt. The sheets were probably detached from the wedge relatively early and underwent deformations as rigid bodies (translation and perhaps rotation) without being affected by detectable ductile deformation. The latter magnetic fabrics show significant deflections of the magnetic lineations from the current directions and important deflections of magnetic foliations from the bedding evolving into girdle pattern in magnetic foliation poles. These magnetic fabrics are typical of the central thrust sheets where the magnetic fabric was relatively strongly affected by ductile deformation represented by a combination of simple shear (responsible for overthrust movements) and lateral shortening (mostly bedding-parallel), probably associated with creation and motion of the thrust sheets driven by a push from the rear side. However, the deformation was too weak to give rise to the cleavage. The Variscan thrust sheets of the Rheno-Hercynian Zone of the E Bohemian Massif show very variable magnetic fabrics and deformation fabric elements. In some areas, the achimetamorphism, ductile deformation and degree of AMS are in general weak; the magnetic fabric is oblate, the magnetic foliation is either parallel to the bedding or tends to create a partial girdle in its poles. The strata create buckle folds of long wavelength whose magnetic fabric can be unfolded geometrically. In the other areas, spaced cleavage and relatively tight buckle folds can be found. Magnetic foliation is still mostly parallel to the bedding, but the magnetic lineation is re-oriented into parallelism to the cleavage/bedding intersection lines. The magnetic fabric of the most folds can be unfolded only partially. In the other areas, cleavage folds and very well developed slaty cleavage occur. The degree of AMS is high, the magnetic foliation is parallel to the slaty cleavage and the magnetic lineation is parallel to the cleavage/bedding intersection lines. The magnetic fabric in the folds is homogeneous, the folds cannot be unfolded at all. In places, the slaty cleavage is transposed into the metamorphic schistosity. The magnetic fabric in crystalline rocks neighboring this wedge shows the same orientations as that of the wedge. This is interpreted as underplating the wedge by the detached crystalline basement.

GP12A-07 1510h

Comparing magnetic and clast fabric in gouge and breccia from the Black Mountain detachments, Death Valley, CA: Implications for the micro-mechanics and kinematics of shallow crustal shear zones.

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The Black Mountain detachments, Death Valley, CA, place Pliocene-Quaternary sediment against Miocene and older crystalline rocks. The detachments comprise sharp slip surfaces and centimeter-to-meter scale shear zones. The shear zones contain gouge and breccia that exhibit well-developed mesoscopic foliation but no evidence for deformation from crystal plasticity or penetrative pressure solution. Measurements of the anisotropy of magnetic susceptibility (AMS), partial anhysteresic remanent magnetization (pARM), and shape preferred orientation (SPO) of greater than 50 micron grains define fabric consistent with the extension direction of the faults inferred from geologic and geodetic data. Many lines of evidence including low-Temperature MS experiments, pARM, transmission and scanning electron microscopy, and optical petrography demonstrate that the magnetic carriers within the gouge and breccia are dominantly nanometer-to-micrometer scale grains that grew within the shear zones prior to the most recent deformation. In contrast, SPO was measured for populations of grains that were inherited from the wall-rock. SPO was measured on thin sections cut parallel to three orthogonal planes-of-view. Because it is not known if the SPO vectors are eigenvectors a priori the resulting SPO vectors were compared in relative length and orientation with the eigenvectors of the AMS ellipsoid. Flattened and some elongated AMS and SPO ellipsoids characterize the fabrics. The long axes of these ellipsoids are shallowly inclined to the shear plane, but in some cases are inclined out of the plane of inferred shear. The similarity of fabric defined by clasts (SPO) and matrix (AMS) is inconsistent with a plastically yielding matrix or a dispersive mode of polyphase flow. Although mechanically the gouge and breccia were/are frictional materials that deform via a complex granular flow, we find that the orientation of the SPO and AMS are best described using kinematic models rooted in Jeffery's theories for fluids. Because the magnetic carriers demonstrably grew after the larger SPO-defining clasts began rotating, we propose that the SPO records more finite strain than the AMS. This can explain most of the discrepancies between the SPO and AMS orientations.

URL: http://www.ess.washington.edu/~cowan/

GP12A-08 1525h

Rotation of Uniaxial Ellipsoidal Particles During Simple Shear Revisited: Implications for the Interpretation of AMS Measurements.

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The rotation of uniaxial ellipsoidal particles has provided the base for many studies of shape preferred orientations (SPOs) of mineral grains, including those concerned with the anisotropy of magnetic susceptibility (AMS) of a large variety of rocks. In most AMS studies, it has been customary to assume that a stable orientation is achieved irrespective either of the elongation ratio of the particle, or of the amount of shear experienced by the rock. In contrast, fabric studies other than AMS commonly have made much emphasis in the cyclic movement of the particles, concluding that no stable orientation can be achieved in simple shear. In this work we studied the evolution of a multiparticle system as a function of 1) the elongation ratio of the particles, 2) the initial particle distribution and 3) the amount of shear experienced by the rock. Our model reveals that all of these factors are important in controlling the acquisition of a stable orientation upon deformation, and can be used to establish adequate threshold values depending of the conditions of interest. The more elongated particles (r = short / long semiaxis < 0.2) will define a stable fabric in almost any situation of geological interest. Less elongated particles ($r > 0.5$) can also be considered to have achieved a stable orientation if deformation remains low ($\gamma < 3$). Consequently, it is necessary to distinguish between rocks in which the SPO is suspected to have been achieved under solid deformation and those in which the SPO may have been acquired upon magmatic deformationand for which shear can be much larger ($\gamma \sim 80$). Of particular relevance for AMS studies is the finding that it is possible to observe some systems with less elongated particles in which the mean orientations are perpendicular to the direction of shear. This implies that many "abnormal" fabrics may have been the result of the natural evolution of a simple multiparticle system, and not to turbulence or post-emplacement alteration effects. Our model results also suggest that a systematic study of samples collected at various controlled positions within the same rock can provide enough information to evaluate whether the mean SPO of the minerals (and hence the associated AMS) is parallel to the direction of shear.

GP12B MCC: 2006 Monday 1600h

Conductivity From Crust to Core II
(joint with T)

Presiding: **S Constable,** Scripps Institution of Oceanography**; S K Park,** Institute of Geophysics and Planetary Physics, University of California, Los Angeles

GP12B-01 1600h

Three-dimensional inversion of marine magnetotelluric data

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In this paper we present the results of the feasibility study of the sea-bottom array MT observations for petroleum exploration. We consider a model of an offshore sea-bottom petroleum reservoir. The resistivity of petroleum reservoir and of salt structures is usually on an order greater than those of surrounding sea-bottom sediments. That is why these structures can be considered easily detectable targets for marine MT methods. However, the interpretation of the sea-bottom MT data was based, as a rule, on 1-D or 2-D modeling. Recently, we have developed a powerful 3-D MT inversion method, which can be applied for both the ground and sea-bottom observations. This method is based on an application of the quasi-analytical (QA) approximation in the initial stage of the iterative process to speed up the inversion. However, in the final stage of the inversion we use the rigorous forward modeling to generate more accurate result. We examine several models, which represent a petroleum reservoir in the presence of a salt dome of a complex shape. The inversion results show that even in the case of complex sea-bottom geological structures, where the reservoir response is strongly distorted by the salt dome effect, the inversion generates a clear image of the reservoir. These results demonstrate that the sea-bottom MT survey can be a powerful tool for offshore petroleum exploration.

GP12B-02 1615h

Electrical Conductivity and Anisotropy in Pacific Lithosphere: CSEM Results from APPLE

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Strain associated with plate formation at mid-ocean ridge spreading centers may influence electrical conductivity at various depths in the lithosphere, and may leave an anisotropic fabric frozen in place. By measuring lithospheric electrical conductivity and anisotropy, insight may be gained regarding the formation and evolution of oceanic crust and mantle. Controlled-source electromagnetic (CSEM) sounding of 35 Ma Pacific lithosphere was undertaken as part of the Anisotropy and Physics of the Pacific Lithosphere Experiment (APPLE), carried out approximately 1000 km west of San Diego. The transmitter (DASI), with a 100 m horizontal electric dipole antenna, was deep-towed in a 30 km radius circle around an array of receivers. A radial tow to 70 km total range and a 15 km radius semicircular tow supplemented the geometry of the main tow. DASI transmitted a 4 Hz square wave throughout the CSEM phase of the experiment. Smooth (and layered) inversions of short-offset (2-20 km) data, using 1-D isotropic modeling, generate models with upper-crustal resistivities $\sim$1 Ωm, varying by about an order of magnitude across the survey area. Lower crustal resistivities are on the order of 10^3 Ωm. Smooth inversion of the long radial tow data indicates upper mantle resistivities of $\sim 10^4$ Ωm, with an increase in conductivity below 20 km depth. This may be due to thermally-activated olivine conduction, indicating that the base

of the lithosphere has been detected. The integrated resistivity-thickness product for the top 100 km of our model is 1.1 x 10^9 Ωm^2. The electric field is characterized in terms of the polarization ellipse parameters. During the circular tow, the maximum axis varies by a factor of two, while the minimum axis varies by a factor of 5. Forward calculations were run on models with a uniaxially anisotropic layer sandwiched between two isotropic layers. Simulated data from models with increased conductivity perpendicular to the paleo-spreading direction in the anisotropic layer (with a ratio of 10) match the actual data well. In addition, the anisotropy appears to be in the lithospheric upper mantle; an anisotropic sheeted dike complex alone does not replicate the variation in the data.

GP12B-03 1630h

Conductivity Structure of the San Andreas Fault, Parkfield, Revisited

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Laboratory measurements of samples of sedimentary rocks from the Parkfield syncline reveal resistivities as low as 1 ohm m when saturated with fluids comparable to those found in nearby wells. The syncline lies on the North American side of the San Andreas fault at Parkfield and plunges northwestward into the fault zone. A previous interpretation of a high resolution magnetotelluric profile across the San Andreas fault at Parkfield identified an anomalously conductive (1-3 ohm m) region just west of the fault and extending to depths of 3 km. These low resistivity rocks were inferred to be crushed rock in the fault zone that was saturated with brines. As an alternative to this interpretation, we suggest that this anomalous region is actually the Parkfield syncline and that the current trace of the San Andreas fault at Middle Mountain does not form the boundary between the Salinian block and the North American plate. Instead, that boundary is approximately 1 km west and collocated with current seismicity. This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract W-7405-ENG-48 and supported specifically by the Office of Basic Energy Science. Additional support was provided by the U.S. Geological Survey (USGS), Department of the Interior, under USGS Award number 03HQGR0041. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

GP12B-04 1645h

Constraints on the surface conductance map by 3-D EM induction modeling using ground-based and satellite Sq data

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The long-term topic of our research is to determine continental-scale 3-D electrical conductivity variations in Earth's lithosphere and mantle using constraints imposed by ground observatory and satellite-borne magnetometer time series. Recently we have created a database consisting of hourly means of geomagnetic field components observed on quiet days in years 2001 and 2002 at roughly 75 ground observatories and Ørsted satellite measurements covering the same time intervals. Forward 3-D time-domain EM global induction modeling of the observations is performed using a spherical harmonic-finite element approach in spherical coordinates. A previously published heterogeneous surface conductance map which reflects the contrast between the resistive continents, intermediate shelves and the highly conductive oceans is an important constituent of the model. The forward code is run with an external excitation that consists of the superposition of several Sq spatiotemporal harmonic functions, thereby simulating induction in the Earth in response to ionospheric Sq current vortices. The 3-D forward calculations produce considerable improvement in the fit of both ground-based and satellite time series compared to that of the optimal 1-D conductivity model derived from daily geomagnetic variations observed at ground stations. This highlights the important role of the oceans and continents in shaping the global Sq response and suggests that the spatial distribution of electrical conductivity in the continental interiors may be resolvable by geomagnetic induction methods. A full 3-D inversion of ground and satellite data, the preliminary results of which are discussed here, is necessary to advance our understanding of the global-scale electrical conductance distribution of the continents and shelves.

GP12B-05 1700h

Geomagnetic induction modelling based on CHAMP magnetic vector data

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The first results of modelling geomagnetic induction signals induced by equatorial ring currents in the magnetosphere recorded at satellite altitudes, are presented. The input of the model consists of the X-component of the magnetic induction vector measured by the CHAMP vector magnetometer along individual night-time satellite tracks. The magnetic induction signals measured along day-time tracks and above polar regions are not considered because they are disturbed by signals with sources different from ring currents. Thus, only mid-latitudes are considered. Only periods during magnetic storms with time scales of the order of days are analysed because the induced signal is most intense. Forward modelling of magnetic induction is implemented in the time domain using the spectral-finite element method developed by Martinec et al. (2003) and recently modified for satellite data. The output is the Z-component of the magnetic induction vector at satellite altitudes. We test the sensitivity of the computed Z-component using an electrical conductivity model for the Earth's mantle. We then compare the output with CHAMP magnetic data and evaluate the acceptability of the electrical conductivity model adopted. We show that a spherically symmetric model of electrical conductivity is too restrictive to adjust to the Z-component of the CHAMP magnetic data for all night-time, mid-latitude satellite tracks over a magnetic storm. For near-future considerations, this implies the necessity to introduce a more complex conductivity structure of the Earth's mantle when interpreting the CHAMP magnetic induction data. Martinec, Z., M. E. Everett and J. Velímský, 2003. Time-domain, spectral-finite element approach to transient two-dimensional geomagnetic induction in a spherical heterogeneous earth, *Geophys. J. Int.*, (in press).

GP12B-06 1715h

Deep MT Sounding Across the Yellowstone-Snake River Hotspot Track

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The Snake River Plain (SRP) in Idaho marks the path of an active hotspot with a terminus under Yellowstone National Park in Wyoming. The trace of the hotspot is marked by a series of volcanic caldera ranging in age from 16 million years in southeastern Oregon and northern Nevada to several thousand years to the northeast. The motion of the North American plate over this feature has resulted in an apparent northeastward progression of the focus of the volcanism. In previous studies, a narrow, deep, low velocity zone below the SRP has been imaged using teleseismic P-wave residuals. This past summer, we collected magnetotelluric (MT) data along a transect across the SRP to map the conductivity structure of this region. The objective is to detect features associated with the Yellowstone hotspot, and ultimately, to place limits on the temperature and melt fraction of these features. To this end, we collected long period electrical and magnetic data at 19 sites using the NIMS equipment from the EMSOC instrument pool, and broadband field data at 2 sites using SIO's MT equipment. The sites were located along a northwest-southeast line stretching from near Challis to the southeast corner of Idaho, at an average spacing of 20 km. The results of our first summer of fieldwork are presented here.

GP12B-07 1730h

The 1998 M5.0 Main Shock Region in Sendai, Japan, Imaged by magnetotellurics

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We imaged the resistivity structure of the 1998 M5.0 Earthquake Sendai which was located at 10–12km depth at the deep extension of the active Nagamachi-Rifu Fault. We had 63 magnetotelluric stations mostly along three profiles perpendicular to the fault trace. The magnetotelluric data showed strong two-dimensionality in the period range between 1s to 1000s. The estimated regional strike is consistent with the tectonic stress field and the surface trace of the fault. We used tensor–decomposed apparent resistivity and phase in two modes and projected magnetic transfer functions for two-dimensional inversions in 1s-1000s period. The final models showed the main shock regions as a resistive gap in between the mid–crustal conductors. One of the conductors is located at the deep extension of the fault, which is also characterized by the seismic low velocity and high Vp/Vs ratio. This implies the distribution of fluids at the root of the active fault, which may help accommodate the quasi–stationary preslip before the main shock.

GP12B-08 1745h

Magnetotelluric constraints on the the nature of lower-crustal shear zones

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While recent geophysical studies have shed light on the nature of upper-crustal (brittle) transform faults, little is known about the ductile roots of these shear zones. Models have been suggested encompassing varying degrees of strain localization, vertical coupling, and connectivity with upper-crustal faults. The lack of seismicity makes it especially difficult to discern the structure and geometry of such ductile shear zones. Magnetotellurics (MT), sensitive to zones of anomalous conductivity, is one of a handful of geophysical methods capable of imaging earth structure at such depths. Previous MT studies along the San Andreas (SAF) show strong indications that structural changes occur in the lower crust. Geo-electric strike, skew, and inductions vectors all suffer marked changes at a frequency of approximately 0.01 Hz, corresponding to depths of 10-15 km. A range of 3D and 2D anisotropic forward models have been examined in order to understand the changes in the observed MT data as well as the sensitivity of MT data to lower-crustal structure. The resistivity contrast across the fault provides the dominant MT signature and in some cases may mask the response of deeper structure. Assuming a conductive shear zone, the degree of localization is discernable from MT data. Furthermore, an anisotropic shear zone gives rise to a distinct response in the induction vectors, similar to that observed in data across the SAF.

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