zones of partial melting that may delineate regions of rheological weakness. This includes the mid-crustal melt layer in southern Tibet that was imaged with both seismic reflection and MT data, and is associated with the south directed flow that has exhumed the High Himalyan leucogranites. In northern and eastern Tibet, crustal flow has been proposed to account for the observed topography and may be required to maintain a mass balance. A channel of enhanced electrical conductivity has been observed in the Tibetan crust on the INDEPTH data and also in new MT data collected in eastern Tibet. Could this feature represent one such channel of crustal flow? However, geophysical datasets must be carefully interpreted in a number of situations. Firstly, the absence of high conductivity does not exclude the possibility that deformation is occurring through other mechanisms such as creep. Secondly, other minor phases can produce a high electrical conductivity, notably electronic conduction in graphite, sulphides, iron oxides and ionic conduction in aqueous fluids. Finally, there are locations where high electrical conductivity is observed in the absence of a seismic anomalies. If carefully analyzed, and compared and contrasted with other geophysical and geoscientific data, each of these scenarios allows a broader understanding of orogenesis.

## T53D-03 1415h

### Composition, Temperature and Metamorphic Facies of the Lower Half of the Thickened Tibetan Crust From the North Kun Lun, Through Bayan Har Into the Qang Tang and Into the Himalaya-South Tibet: Insight on Their Geodynamical Evolution

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Wide angle reflection-refraction profiles of P and S-waves were obtained at the NE edge of the Tibetan Plateau of recent postcollisional active convergence tectonics, as well as into the earlier formed Himalaya-South Tibet. From the North Kun Lun through Bayan Har and into the Qang Tang block, the record-sections of six shots and their modelling evidence changes in crustal thickness, layers velocity and also image through fan profiles its internal architecture. Furthermore, recording of P-waves as well as unexpected S-waves gives insight of the lower crust physical state in the domain of block interaction in the northern edge of the Qang Tang and of the Bayan Har. Here, the quality factor Q is estimated in the lower half of the crust by accounting for the differential effect on amplitude-frequency, observed between waves of different penetrations. Attenuation values allow to exclude a significant proportion of partial melt and to estimate the homologous temperature, ratio in-situ to solidus temperatures. The latter depend on the physical conditions being dry, wet or dehydration melting, which are found different among the regions of the northern Bayan Har, northern Qang Tang and we will see also different from the Himalaya-South Tibet. Their in-situ temperatures differ also as estimated from their different Vp with similar felsic composition, highlighted by their low velocity ratio, Vp/Vs. The uncommon joint determination of several parameters: Vp, Vp/Vs, Qp and Qs reveals the composition, the mineralogy and hydration conditions of the lower half of the thickened crust of Tibet and backs up the thickening of the Tibetan crust by tectonic superposition, imbrication of originally normal thickness crusts.

## T53D-04 1430h

### Co-Anatectic Crustal Failure in the Absence of Geophysically Detectable Partial Melt

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The India-Asia collision's syntaxial terminations are loci of active deformation and vigorous exhumation. Quantitative constraints on tectonic processes operating in the syntaxes are now available from a large suite of studies conducted at the Nanga Parbat and Namche Barwa massifs by several research groups. In the western syntaxis in particular, deployment of seismic and magnetotelluric arrays at Nanga Parbat has provided an image of crustal rheologies and the distribution of fluid phases. Surface constraints from structural surveying reveal major deformation localization via two conjugate shear zones whose crustal-scale characteristics are imaged by the geophysics. Extensive geochronological constraints from multiple syndeformation shear zone granitoids indicate a prolonged history (steady-state?) of weakening and failure. In contrast to the southern-Tibet portions of the collision (where INDEPTH geophysical imaging has been interpreted to suggest crustal weakening coupled with extensive partial-melt accumulation), at Nanga Parbat no extensive partial-melt candidate is discernible in the geophysical data. Instead, these data suggest the presence of anomalously hot but dry crust beneath a region that thermochronologic and petrologic data show has experienced rapid and extensive exhumation during the Neogene. Observed shear zone-hosted granitoids result from anatexis that at any instant is volumetrically trivial for the massif as a whole. It is unclear what role geophysically "invisible" subsurface melt might play in weakening. Three-dimensional numerical experiments indicate that positive mechanical-thermal feedback associated with localized exhumation is sufficient to produce melt lozenges and that further melt-enhanced weakening is not required for "aneurysm" behavior. That the Namche Barwa massif shares a remarkably similar geologic history with Nanga Parbat despite significant differences in tectonic setting underscores the importance of vigorous exhumation in active tectonic systems.

## T53D-05 1445h

### Syntectonic Melt Distribution in Deep Crust Inferred From Residual Granulites: Implications for the Rheology of Orogenic Crust

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Anatectic systems are heterogeneous, nonlinear and characterized by multiphase flow. Each process contributing to melt extraction has a characteristic length and time scale, and it is the nonlinear interactions and feedback among them that give rise to the patterning observed in lower crust. Melting and melt ascent and emplacement modify the physical properties of the crust and generate viscosity contrasts, which lead to a heterogeneous response and localization. The characteristic length scale of deformation is important, since reducing the length scale for the same velocity of deformation increases the strain rate (e.g. whole crust to orogenic channel to shear zone). Whether patterns of localization are stable with increasing strain and what effect localization has on rheology are poorly understood. Geophysical imaging suggests 6-20 vol.% interconnected melt in the crust of active orogens, numerical modeling of the transition from coupled doubly-vergent wedge structure to plateaux formation requires a viscosity drop of up to 4 orders of magnitude, and deformation experiments on rock undergoing melting indicate a 4-10-fold drop in strength due to wetting of most grain boundaries as melt volume approaches 10%. The magnitude of weakening accompanying melting suggests deformation dominantly by melt-assisted diffusion creep with melt segregation and extraction rather than magma behavior (i.e. bulk rheology of anatectic crust is solid-dominated rather than melt-dominated). However, fertile rocks generate 10-50 vol.% melt (at 1 GPa, 1,173K), which suggests melt is extracted to maintain a solid-dominated rheology. Melting occurs at multiphase grain boundaries around hydrate phases, whereas plutons represent 1,000-10,000 km3 of crystallized magma; this requires focusing the flow of segregated melt to channels that allow ascent through subsolidus crust. Studies of residual granulites suggest that melt has migrated from grain boundaries to networks of (leucosome-filled) structures to ascent conduits (now steeply-inclined rod or tabular granites). However, the common assumption that leucosome vol. equals melt vol. is precluded by the mineralogy and chemistry of leucosomes, which indicates both cumulate (early-crystallized solids) and fractionated (late-crystallized residual liquids) varieties. At the grain scale, location of melt is controlled by fabric and strain. At outcrop in residual granulites leucosome occurs in fabric parallel and transverse stromata, along foliation planes and in dilation/shear bands, forming networks analogous to ideal deformation band networks. Leucosome networks commonly are elongate parallel to lineation, so melt flow is inferred to have been primarily in the plane of the foliation and along the lineation to developing dilatant structures, and through the network of structures to ascent conduits (commonly dikes). Dike emplacement occurs along a preferred direction independent of anisotropy, suggesting stress control, which with the macroscopic fracture-like discontinuities characterizes the process of formation as a fracture phenomenon. Petrographic continuity of leucosome with granite in dikes suggests a once continuous melt-bearing network, and indicates that material in leucosomes and dikes underwent final crystallization at the same time. Blunt dike tips and zigzag propagation paths point to ductile fracture as the mode of formation, probably by pore growth and coalescence of melt pockets. The coupling between fracture formation and mass transfer appears to be significant for fracturing in crustal environments above the solidus, where a large amount of plastic strain may accumulate before fracture and where dislocation-mediated ductile fracture may be expected.

## T53D-06 1500h

### Non-uniform Extensional Processes Influenced by Fluid and Melt Distributions Below the Great Basin-Colorado Plateau Transition Zone, Utah, Revealed Through Electrical Conductivity Structure

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Electrical conductivity provides independent understanding of deep hydration, thermal regime, fluidization/melting, lithospheric-scale fabric and faulting, and economic resource controls. Since the early 1970's, regional conductivity surveys have shown a first-order partitioning of current activity in the Great Basin province, with the eastern and western margins being more anomalous w.r.t. a relatively quiescent Great Basin interior, in keeping with other indicators. The lower crust throughout the region is electrically conductive corresponding to a small fraction (less than 0.5

## T53D-07 1515h

### Crustal flow in the India-Asia collision constrained by earthquakes

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Continent-continent collision is one of the fundamental processes in the plate tectonic cycle and is critical to understanding crustal evolution. The India-Asia collision provides the opportunity to investigate the mechanics of continent-continent collision in a modern setting avoiding many of the uncertainties inherent in studying ancient mountain belts. A fundamental problem in understanding the India-Asia collision is what drives deformation in the Tibetan Plateau. Seismic activity provides one of the best constraints on the stresses responsible for mountain building and how that stress is distributed. We have examined earthquakes distributed throughout the Indian foreland, the Greater Himalaya and the Tibetan Plateau. We focus on earthquakes with well-controlled depths, and use the Harvard Centroid Moment Tensor (CMT) catalog to map

States: Good Friday earthquake of March 1964, Mammoth Lake seismic swarm of May 1980, Hector Mine earthquake of 1999, and recent San Simeon earthquake of December 2003. The data of topside sounders of Alouette and Intercosmos-19 satellites are used, as well as GPS total electron content measurements. The physical mechanism of the seismo-ionospheric coupling is discussed together with possible application techniques for the ionospheric precursors identification.

### T53C-05 1440h

## Geosynchronous Weather Satellite Thermal IR Measurements Prior to Earthquakes

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Thermal anomalies prior to earthquakes have been a controversial topic for some time. Previous investigations of three earthquake events by the authors showed thermal changes, and as a result a more systematic analysis of fourteen events, representing a range of magnitudes and epicenter depths was undertaken. Earthquakes associated with plate movement (strike-slip and thrust faulting), rather than volcanism, were to be considered. It was the purpose of this study to determine if thermal anomalies could be found in association with known earthquakes by systematically co-registering geosynchronous weather satellite images at the sub-pixel level and then determining if statistically significant responses had occurred prior to an event. The automatic co-registration procedures used for this task to accommodate all properties particular to weather satellite observations taken at night. Spacecraft and sensor ephemeris and the horizontal displacement due to elevation were all factored in, and final adjustment for minor satellite deviations (related to roll, pitch, and yaw) were made by using image-to-image tie-point correlations. Reliance upon visual clues in an image (frequently the subject of debate in the past) is not required. The technique relies on the general condition where ground cools after sunset. The technique applies best to the use of the geosynchronous weather satellites (GOES,and Meteosat), where images are taken every thirty minutes. Use of the geosynchronous satellites also reduces the potential for miscalculation of trends due to weather front movement or local cloud/fog formation. The data analyzed for each earthquake includes 10 days prior to each event and 5 days after the event as well as the day of the event. The data are for every half hour from sunset to dawn, thermal IR bands. We also obtained the same Julian dates of the data for the three previous years to use as a baseline. The data sets were used to systematically measure the observance of thermal anomalies in two key contexts. First is the degree any thermal anomaly just prior to an event can be demonstrated to deviate from a baseline thermal profile derived from the previous three years and recorded weather history. Second is the possibility to compare the earthquake epicenter with nearby regions having similar or different geology using the same imagery but no history of seismic activity. This experimental design will help address questions regarding the "uniqueness" of thermal anomalies observed by us and others previously, and help characterize the observed thermal responses under a variety of magnitude, depth, and geologic conditions.

### T53C-06 1455h

## TIR Satellite Techniques for monitoring the Earthquake active regions:review of the limits, achievements and perspectives.

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Space-time fluctuations of Earth's emitted Thermal Infrared (TIR) radiation observed from satellite, months to weeks before earthquakes occurrence, have been, by several authors interpreted as pre-seismic signals. Despite the increasing number of such observations and some claimed success in earthquake prediction a general consensus of the scientific community regarding methods, models and results of such studies is still far from being achieved. Main problems regard data analysis (how distinguish normal from anomalous TIR signal fluctuations?) and interpretation (which statistical significance have the space-time correlation observed/suggested between TIR signal transient and earthquake occurrence?) often done without a convincing validation/confutation approach. On the other hand, several physical models have been proposed that in principle could explain not only such a correlation but also justify the occurrence of other (geochemical, geo-electrical etc.) precursory phenomena. In this context the potential of satellite techniques using Earth's thermally emitted radiation to monitor seismically active areas will be presented considering: a) recent progresses obtained (on several earthquakes occurred in Europe, Africa and America) from the analysis of several years of satellite observations; b) shared knowledge and still open problems; c) actual perspective of research in this field.

### T53C-07 1510h

## Simultaneous ELF Magnetic Field Monitoring of Earthquakes from a Nano-satellite (QuakeSat) and a Ground Network

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On June 30 2004, QuakeFinder LLC, in collaboration with Stanford University and Lockheed Martin, launched a 4.5 kg nanosatellite called QuakeSat into an 840 km circular, sun-synch orbit. In addition to the student teaching goals, the satellite was a prototype for a research satellite to study whether Extremely-Low-Frequency (ELF) magnetic field disturbances occurred before or after large earthquakes. The frequency response for QuakeSat's single-axis search coil magnetometer and ELF receiver was 1-1000 Hz in 4 bands. The overall mission also had a ground component, namely a network of 35 three-axis magnetometer sensors, deployed every 30 km along major faults (e.g. San Andreas) in California. The frequency response of these ELF receivers was 0.1 to 4 Hz. and they had a 10km range. Both the space and ground-based systems were designed to record raw, time series data, and the objectives were not only to determine if earthquake-generated ELF signals exist, but to characterize them in both time and frequency and to distinguish them from the many other magnetic signals present in space and near the ground. This paper addresses a case study of the Dec. 22 2004, M6.4 San Simeon earthquake in California, and compares both space and ground ELF signatures. Preliminary results of the satellite collections showed unique signals prior to and after the San Simeon quake, as well as several other large world-wide quakes. Ground collections were inconclusive since the 4 closest of the 35 sensors were more than 60 km and 2 parallel fault traces from the epicenter.

URL: http://www.quakefinder.com

### T53C-08 1525h

## Recent Results in Geoelectrical Studies od a Seismic Area in Southern Apennine Chain (Italy).

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Since 1991 it was installed a geophysical monitoring network able to detect geoelectrical, geochemical and seismometric parameters in a seismic active area of Southern Italy. To date a very large data set of ULF electrical time series is available and the possible correlation between anomalous electrical signals and local earthquake activity can be carried out using robust filtering procedures for noise reduction and multifractal techniques for identifying extreme events. Recently the monitoring activity has been focused on Val d'Agri area representing one of the most active seismic zone of Southern Apennine chain. The Val d'Agri is a NW-SE trending intermontane basin formed after Miocene-Pliocen shortening events and controlled by high-angle trastensional and extensional active faults. In this work some recent results regarding the analysis of observational evidences of anomalous electrical signals are analysed and discussed. Finally, for better exploring the site effects governing the electrical signals we perfomed shallow and deep electrical resistivity tomographies in the investigated areas. The possibility to have extremely long period of electrical measurements, the application of novel fractal and multifractal techniques, the knowledge of resisistivity subsurface patterns close the measuring stations disclose the way to better understand the space-time dynamics of electrical signals in the study area.

# T53D MCC: 3002 Friday 1340h

## Orogenic Studies: Cutting Through the Flow I *(joint with S, V, MR)*

***Presiding:*** **C Rosenberg,** Department of Geological Sciences, Freie Universitt Berlin; **M A EDWARDS,** Structural Processes Group, Deptartment of Geological Sciences

### T53D-01 1345h INVITED

## Detailed Fluid/Melt Structure Deduced from Geophysical Field Observations

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Geophysical field observations point to the present existence of huge amount of melts in the crust below the Central Andes (e.g. Schilling & Partzsch, 2001). The Central Andes are an ideal place to study melt distributions in a continental crust due to the amount and quality of geophysical, geological, petrological, and geochemical studies within the framework of the Special Research Project 267, Deformation processes in the Andes, including seismic velocity and wave absorption studies, as well as electrical conductivity and gravity observations.
Furthermore, laboratory studies and model calculations were performed in conjunction with the field measurements to study the effect of partial melts on the physical properties of rocks. The melt distribution/melt structure were optically determined in the laboratory on quenched samples. Laboratory experiments on the electrical conductivity and elastic properties of partially molten rocks are used in combination with melt structure observations to get a detailed insight into the dependence of physical properties on the melt structure. The interrelation of different properties allows to distinguish between melt isolated in pockets (magma chambers) and interconnected melt along grain boundaries or grain edges.
The aim of this contribution is to use the interrelation of different physical properties to get a more detailed insight into the melt distribution of large areas, which have been inferred to be partially molten. The field observations are interpreted with respect to the laboratory experiments, while taking the scaling problem into account. The results deduced from the Andes will be compared to observations from the Tibetan Plateau.

Schilling F.R., Partzsch G.M. (2001) Quantifying Partial Melt Portion in the Crust Beneath the Central Andes and the Tibetan Plateau, Physics and Chemistry of the Earth (A), 26, 239-246.

### T53D-02 1400h

## Magnetotelluric observations of crustal deformation and flow in Tibet

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Geophysical data are a vital source of information regarding the processes at work in active orogens. For example, seismic reflection and magnetotelluric (MT) studies of the Tibetan-Himalayan orogen have revealed

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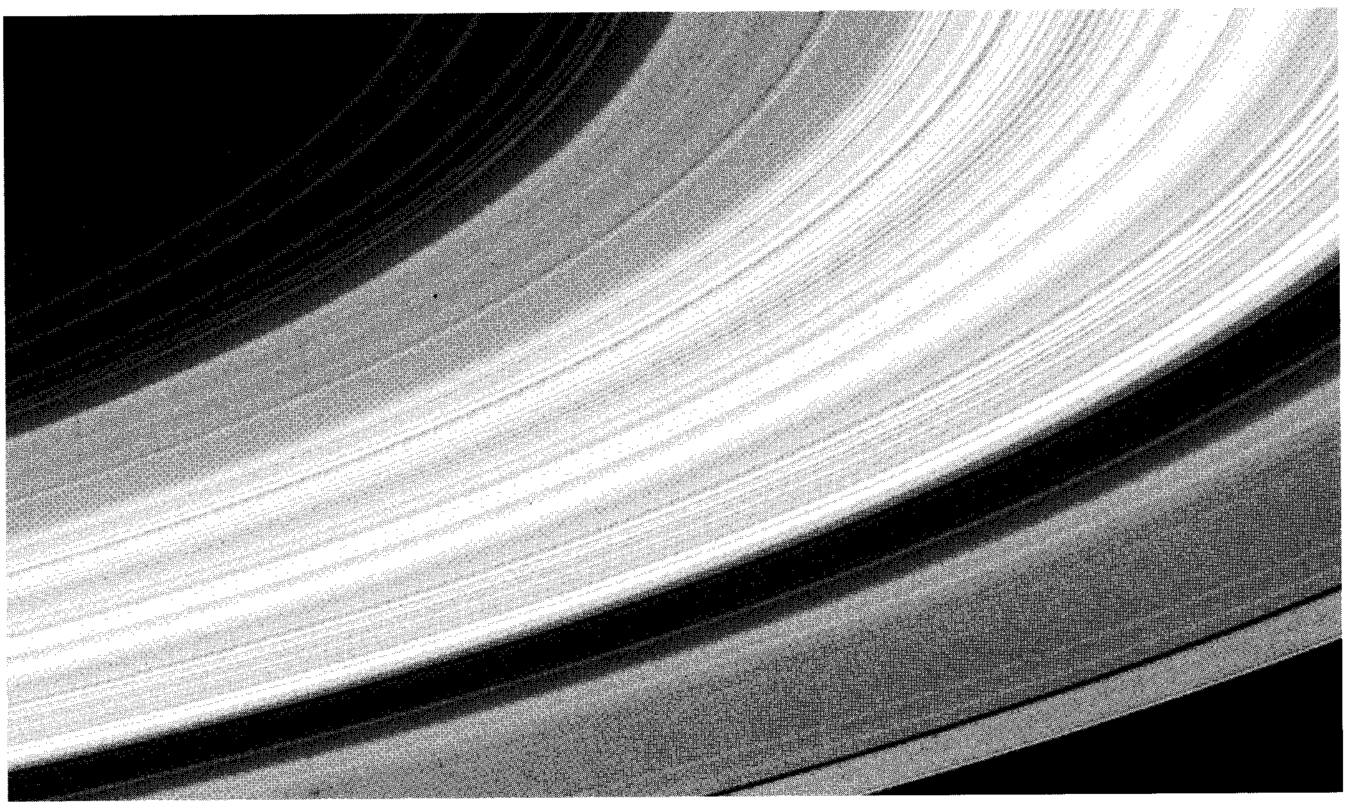

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