

slip. This reconstruction is in a good agreement with that deduced from the seismic study.

Recently, five creepmeters were installed with data on a daily basis across the Chihshang fault in 1998. Three years data on creepmeters indicate that the surface ruptures of the Chihshang fault not only continuously moved in more or less steady rate of about 2 cm/yr but also show a clear seasonal variation. The fault moved in a high rate during the wet season and almost stopped to move during the dry season. Study on seismicity in the area shows also a more frequent seismicity during the wet season. It appears that the active Chihshang fault, the major plate suture boundary fault, can divide into (1) a creep zone in the upper 10-15 km, (2) a seismogenic zone (brittle-ductile transition zone) at about 15-25 km deep, and (3) ductile deformation zone below 25-30 km deep. We propose that the rapid creeping and high seismic activity during the wet season are due to decoupling on the Chihshang fault surface, when water goes into the fault zone acts as a lubricant.

T41F MC: 309 Thursday 1020h

Initiation of Subduction: Constraints From the Field and From Modeling I (joint with OS)

Presiding: J Encarnacion, Saint Louis University; M A House, California Institute of Technology

T41F-01 1020h INVITED

Towards the Dynamics of Subduction Initiation within an Historical Context

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Little progress was made on understanding the dynamics of subduction initiation following the establishment of plate tectonics. Modelers quickly established that subduction initiation would be difficult if a homogeneous, unbroken lithosphere underwent convective instability. Modelers focused on attempting to establish the means by which an Atlantic-type margin could founder, creating a theory for an idealized 'Wilson-cycle'. On the other hand, considerable progress was made at finding places where subduction nucleated in the past. Subduction zones often tend to form in close proximity to other subduction zones and/or near pre-existing zones of weakness within the lithosphere, such as old plate margins. Only recently have we attempted to understand the dynamics of subduction initiation with realistic initial conditions.

Associated with major plate reorganizations, there may be two types of subduction initiation: spontaneous nucleation and forced; both may occur on old plate margins. The Eocene reorganization of the Pacific plate provides the context for this theory. As shown by Uyeda and Hilde the Izu-Bonin-Mariana subduction zone may have formed along the Palau Kyushu Ridge, potentially a transform margin; Stern has assembled evidence suggesting that the IBM formed by spontaneous nucleation. Much further to the south, the Tonga-Kermadec subduction zone may have simultaneously formed by thrusting leading to the preserved New Caledonia ophiolite. The IBM subduction may have caused the change in Pacific plate motion at 43 Ma, while other subduction zones, such as Tonga-Kermadec, may have resulted from the change in plate motion. Unfortunately, the geological record within subducting plate boundaries becomes deformed and buried so that the ability to test dynamic models is limited.

Seeking a better preserved record, recent work has focused on the Macquarie Ridge complex, the Australia-Pacific plate boundary south of New Zealand where subduction has been nucleating during the last approx 10 Myr. We formulate models to exploit the tectonic record of the nascent subduction zone along the northern portion of the MRC, the Puysegur ridge and the Fiordland block of the South Island of New Zealand. This boundary is currently transpressional but formerly was an Eocene to Oligocene spreading center. Earlier models of subduction showed that initiation should be associated with rapid uplift of the over-riding plate; as plate convergence continues, this uplift can be followed by subsidence of the previously uplifted ridge. We show that this history is consistent with the inferred morphologic evolution of the Puysegur ridge. Although potentially different in character, the northern extension of the Puysegur subduction zone, Fiordland, may hold the ability to better constrain the history of uplift using thermochronology, as described in the presentation by House and colleagues.

T41F-02 1035h INVITED

Subduction Initiation Along the Macquarie Ridge Complex?

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The Macquarie Ridge Complex (MRC) extends for ca. 1500 km between New Zealand's South Island and the Indian-Antarctic-Pacific triple junction, and comprises the boundary between the Australian (Indian) and Pacific plates. Motion along this boundary has changed from divergence to dominantly strike slip, with areas of transpression and transtension, since ca. 10 Ma. The arcuate MRC displays unique bathymetry among submarine ridges worldwide, with four distinct segments (from north to south, Puysegur, McDougall, Macquarie, and Hjort) characterized by alternating ridge-trough polarity. A major fault zone on the crest or flank of the bathymetric ridge is continuous along the entire length of the MRC. Intermediate depth earthquakes, compressional focal mechanisms, and a single, small calc-alkaline volcano (Solander Island) suggest that subduction may be initiating in southernmost New Zealand (Fiordland) and the Puysegur region. Marine geophysical data show one or more major thrust faults along the Puysegur trough in addition to the strike slip fault along the Puysegur ridge, implying strain partitioning. The McDougall and Macquarie segments are characterized by shallow focus earthquakes and strike slip focal mechanisms; the ridges and troughs may be explained by past thrust faulting, but any evidence for subduction or initiation thereof is absent. In the Hjort region, a well-developed trench complements the crestal fault zone, again implying strain partitioning, although all earthquakes appear to be shallow. Unsampled seamounts paralleling the Hjort trench and ridge may be related to subduction, or may have been produced by hotspot activity. The morphology of the MRC integrates the changes in relative motion between the Australian (Indian) and Pacific plates since ca. 10 Ma, and the MRC presents a case study for possible models of subduction initiation.

T41F-03 1050h

Initiation of Subduction in a Complex Transpressional Regime, Fiordland, New Zealand

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Transpressional tectonic environments are often invoked as favorable locations to initiate subduction. The plate boundary between the Australian and Pacific plates through the South Island of New Zealand exhibits both transpressional kinematics and a nascent subduction zone in the Puysegur-Fiordland region. However along this plate boundary subduction has not been the primary response to transpression, rather crustal and lithospheric thickening produced the lithospheric structure of the Southern Alps. We propose that the localized subduction beneath Fiordland developed in response to interaction between an underthrust segment of the Australian plate and the lithospheric root of the Southern Alps, which acts as a buttress. Localized underthrusting of Australia beneath Fiordland was produced by an offset in the plate boundary, and it is only in the region of the pre-existing underthrust lithosphere that subduction began. The down-bending of the Australian plate was driven by a combination of vertical (crustal thickening) and horizontal (S. Alps buttress) forces. Thus the initiation of subduction was driven by transpression, but indirectly. The present day lithospheric geometry (as determined from seismicity patterns and focal mechanisms) shows a highly bent Australian plate adjacent to the root of the Southern

Alps. Gravity and topography analyses support the interpretation of a strongly bent plate, and 3-D mechanical modeling of this plate boundary indicates that the subducted plate is a relatively narrow sliver of Australia, bounded on the west by a tear in the Australian plate. The evolution of this localized subduction zone may not necessarily lead to a regionally extensive, long-lived subduction zone, since the propagation of the tear within the Australian plate may effectively decouple the Fiordland slab from Australia.

T41F-04 1105h

Thermochronologic limits on Late Cenozoic denudation of Fiordland, southwestern New Zealand: implications for subduction initiation

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New (U-Th)/He and fission track ages in apatites from Fiordland, southwestern New Zealand, provide insight into the spatial and temporal patterns of crustal uplift and exhumation that accompanied the transition between subduction and transform motion across this section of the Pacific plate boundary during Late Cenozoic times. Preliminary helium and fission track ages in apatites (AHE and AFT, respectively) indicate that much of the Fiordland region cooled through temperatures of ~110-70 C during Late Miocene-Early Pliocene times. Early Pliocene AFT and AHE ages from a constant elevation transect collected at sea level along Doubtful Sound are similar to AFT and AHE ages from a lake-level transect along the shores of Lake Te Anau. Another sea-level transect collected in southwesternmost Fiordland along Dusky Sound yielded Middle and Late Miocene AFT and AHE ages. AHE and AFT ages from two vertical profiles (one in western Doubtful Sound and one at Lake Hauroko in southeastern Fiordland) have similar slopes, corresponding to exhumation rates of 0.2-0.3 km/my. However, the profiles are offset slightly so that cooling ages from western Doubtful Sound are approx 5 m.y. younger than those from Lake Hauroko. Oligocene and older AFT and AHE ages from several localities in eastern Fiordland serve to delimit the extent of recent crustal uplift and exhumation to regions to the west of the Moonlight, Hollyford and Hauroko fault zones.

We speculate that the abundance of Middle Miocene and younger cooling ages from Fiordland reflects regional uplift and exhumation resulting from changing plate motion and subduction initiation to the south. A Late Cenozoic geothermal gradient of 30 C/km and a surface temperature of 5 C imply that AFT and AHE ages correspond to the removal of approx 3.5 km and 2.2 km of material, respectively. This age and magnitude of denudation is consistent with estimates of Fiordland uplift based on provenance studies in the Halfway Formation to the north, as well as independent estimates for the timing of Fiordland uplift based on the analysis of sedimentary basins along the eastern margins of Fiordland. The small shift in ages seen across the Dusky fault suggests that this structure may have been re-activated with a small component of Late Cenozoic throw as convergent plate motion increased in this region. Similarly, re-activation of structures like the Hauroko and Hollyford fault may have played an important role in accommodating increased Pliocene and younger convergence across this portion of the Pacific Plate boundary.

T41F-05 1120h

Initiation of Subduction Beneath the Pamirs: Results from Flexural and Gravity Modeling in the Tien Shan, Central Asia

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Subduction is conventionally thought of as the underthrusting of dense, negatively buoyant oceanic crust beneath continental crust. However, in a small number of areas around the world, evidence suggests that continental crust has or is being subducted. The Pamir-Hindu Kush region is one area in which there is geophysical evidence for continental subduction occurring today. It is one of the most active areas of intracontinental intermediate-depth earthquakes in the world.

We use topography and gravity anomaly data gridded at 5' x 5' to create flexural and gravity models of the Tien Shan and surrounding regions. The continental lithosphere is treated as an elastic plate and its flexure is modeled using a finite difference method. Bouguer gravity anomalies are calculated in the wavenumber domain.

East of the Talas-Ferghana fault isostatic anomalies beneath the Tien Shan are zero to slightly positive. Observed Bouguer anomalies can be well fit by a continuous plate with $T_e < 35$ km such that the mountains are regionally supported by the elastic flexure of the lithosphere and the broad crustal root thus created. In contrast, negative isostatic gravity anomalies beneath the Pamir indicate these mountains are overcompensated with respect to Airy isostasy. Previous work shows that flexure of a continuous elastic plate cannot explain the pattern and amplitude of the gravity anomalies, whereas invoking a broken plate with an applied bending moment does provide a reasonable fit to the observed Bouguer anomalies. Our interpretation of the data is that over-thickening and sinking of the crust and mantle lithosphere may be occurring in the western Tien Shan and Pamirs. The variation in style in isostatic compensation between the eastern and western Tien Shan suggests that an east-to-west transect along the chain can provide a time history of the initiation of intracontinental subduction.

T41F-06 1135h

Active tectonics of the South Caspian Basin

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We use observations of surface faulting, well-constrained earthquake focal mechanisms and centroid depths, and velocity structure determined by surface wave propagation and teleseismic receiver functions to investigate the present-day deformation and kinematics in and around the South Caspian Basin. The lack of earthquakes within the basin itself indicates that it behaves as a rigid block, though its sedimentary cover is deformed by numerous folds that are decoupled from its rigid basement by overpressured mud. The basin contains a sedimentary sequence almost 20 km thick above a relatively high-velocity basement that is thinner within the basin than on its margins. The basement beneath the basin could be either unusually thick oceanic crust or thinned, but relatively high-velocity, continental crust. The South Caspian Basin is surrounded by active earthquake belts on all sides. No earthquakes deeper than 30 km can be confirmed in the Kopeh Dag, Alborz and Talesh, which bound the NE, S and W sides of the basin. By contrast, earthquakes occur to depths of at least 80 km on the Apsheron-Balkhan sill, which bounds the N side of the basin and where no earthquakes can be confirmed that are shallower than 30 km. We interpret these deeper earthquakes to indicate the onset of subduction of the South Caspian Basin beneath the central Caspian, a process which appears to occur aseismically at shallow levels. Although oblique shortening is partitioned into pure strike-slip and pure thrust in many areas, conjugate right-lateral and left-lateral components in the Kopeh Dag and eastern Alborz suggest that the South Caspian Basin has a westward component of motion relative to both Eurasia and Iran. This motion enhances westward underthrusting of the basin beneath the Talesh mountains of Iran and Azerbaijan. We estimate the present motions of the South Caspian Basin to be about 13-17 mm/yr to the SW relative to Iran (a maximum value) and about 8-10 mm/yr to the NW or NNW relative to Eurasia. We suspect that these motions are all relatively recent, and may have begun only in the Pliocene (3-5 Ma ago). The South Caspian Basin will

ultimately be destroyed by subduction or underthrusting and its present situation may represent an intermediate stage between that of the eastern Mediterranean and that of the seismically active slab beneath the Hindu Kush.

T42A MC: Hall D Thursday 1330h

Multidisciplinary Insights From Seismic Tomography, Mantle Dynamics, Geological Origins, and Evolution I (joint with S, V, DI, MR)

Presiding: F Dubuffet, Minnesota Supercomputer Institute

T42A-0908 1330h POSTER

Sensitivity Simulation of Magnetic Field Induction Associated with Mantle Electrical Conductivity Anomalies

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Recent laboratory experiments measured *in situ* electrical conductivities of mantle materials, and suggest that the contrast of conductivities due to the temperature anomaly in a hot plume (σ_p) and in the surrounding mantle (σ) can be as large as an order of magnitude, i.e., if the temperature difference is ~ 500 K, σ_p/σ is ~ 5.7 for pyrolyte and ~ 10.2 for eclogite composition in the transition zone depths (410 to 660 km), ~ 15 for upper mantle (200 to 410 km), and ~ 2.5 for lower mantle (800 to 900 km), respectively. Using the conductivity anomalies thus estimated, we carried out computer simulations to test if the anomalous plume-like distribution is observable in the induced magnetic fields. We used a fully parallelized, time-domain 3-D finite difference code (Chou et al., 2000) that is particularly suitable for simulating transient responses such as those due to magnetic substorms whose prominent frequency band is typically from 0.00001 to 0.00005. Skin depths of this frequency band fall around the mantle transition zone. We tested EM responses for a variety of conductivity anomalies that are in a plume tail with a diameter of 100 to 400 km and an overlying broader layer ($\sim 1000 \times 1000 \text{ km}^2$) in the mantle, given a plane electric field (or a vector potential \mathbf{A} differentiated by time) that oscillates with a period of ~ 13 hours to 1 day in the x -direction. After sufficient computation time (~ 3 to 5 times the oscillation period of the external field), the induced field at the surface was evaluated. Results show notable differences of EM responses (B_y) to the 3-D mantle conductivity anomalies. B_z (induction in the z -direction) is also induced by the anomalies.

T42A-0909 1330h POSTER

The Influence of the Temperature-Dependence of Phonon Lifetimes in Lattice Thermal Conductivity on Mantle Convection

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The conventional temperature dependence of lattice thermal conductivity goes like $1/T$ and was derived by solid-state physicists for simple ionic crystal structures, like sodium chlorides, and has been used extensively in the geophysical literature for over the last 30 years for both thermal modelling in both the crust and mantle. Recently Hofmeister (1999) has developed a semi-empirical model for mantle thermal conductivity, based on infra-red spectroscopic constraints, such as phonon lifetimes. This formulation has been shown to be applicable to a wide suite of crystal structures with more complicated bonding and coordination number. The applicability of this formulation is broad and includes minerals such as oxides, silicates, spinels, and garnets. This formulation for lattice conductivity differs from the former $1/T$ dependence in that it is now split into two multiplicative terms $A(T)^a B(T)$, where $A(T) = (298/T)^a$ and $B(T)$ is an exponential function of T , which describes the change of frequency and volume with temperature, where a is a parameter which measures the sensitivity of the temperature dependence of the principal phonon lifetimes. The argument inside $B(T)$ have the average Grüneisen parameter and also an integral of the variable thermal expansivity over the temperature interval. Previous studies on the influence of lattice conductivity on mantle dynamics have fixed the values of a , like 0.3 and 0.9. We have conducted both 2-D and 3-D numerical simulations to show that there is a great sensitivity in the dynamics to variations of this parameter a , as the temperature-dependence of the phonon lifetimes is reduced for smaller values like 0.1. We have found that there is as much, if not, greater dynamical difference in the solutions between $a=0.3$ and 0.1 than between $a=0.9$ and 0.3, very similar to the development of a threshold effect. From the standpoint of mineral physics, there is no reason not to expect values of a smaller than 0.3, especially for garnet-bearing minerals. Smaller values of the power-law index a , such as 0.1, promote the development of large plumes and more vigorous convection. There is a nonlinear coupling between internal heating and the decrease in the parameter a . We see an analogy in the dynamical sensitivity of the value of a in thermal conductivity and the power-law index n in nonlinear aspects of mantle rheology.

T42A-0910 1330h POSTER

A Stabilizing Dynamical Influence in the Deep Mantle due to the Radiative Thermal Conductivity and a high temperature at the Core-Mantle Boundary

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The thermal conductivity of mantle materials has two components, the lattice component k_{lat} from phonons and the radiative component k_{rad} due to photons. The temperature (T) derivatives of these mechanisms have different signs, with $d k_{lat}/d T$ negative and $d k_{rad}/d T$ positive. This attribute of a positive temperature derivative on the part of k_{rad} offers the possibilities for the actual temperature at the core-mantle boundary (CMB) to be a stabilizing factor on boundary layer instabilities at the D" layer. We have parameterized the weight factor between k_{rad} and k_{lat} with a dimensionless number f , where $f=1$ corresponds to the reference conductivity model given by Hofmeister (1999). For this thermal conductivity model ($f=1$) we have found that by increasing the temperature at the CMB, T_{cmb} , from 3000 to 4200 K, the boundary layer instabilities are quenched more and become more stabilized for surface Rayleigh numbers between 10^6 and 5×10^6 in an aspect-ratio 6 box. For purely basal heating situations the time-dependent chaotic flows at $T_{cmb} = 3000$ K become stabilized for values of f between 1.5 and 2. As we increase the T_{cmb} to 4000 K the critical value of f , f_c , needed for flow stabilization is correspondingly reduced. For T_{cmb} greater than 4200 K, f_c becomes less than 1. Our results, obtained from a detailed parametric study, would argue for the important role played by the T_{cmb} in controlling the stability of the D" layer in the presence of any sort of radiative thermal conductivity. Greater contribution of k_{rad} together with a high T_{cmb} , greater than 3500 K, would act to stabilize D" thermal instabilities. On the other hand, a lower T_{cmb} would greatly promote secondary instabilities in the D" layer. These results argue for the possible constraints on T_{cmb} from the presence of radiative thermal conductivity in the deep mantle and the development of secondary instabilities on the CMB. Too high a T_{cmb} would quench instabilities.