Crustal and uppermost mantle structures are constrained by the records of these 3 events recorded at PASSCAL stations which form a natural NS profile across the plateau. In order to resolve deep structure, we use events in the western Tibet and Pamir-Hindu Kush region that give paths purely within the plateau. Broadband P, SV and SH triplications are especially clear for deep events (120 to 200 km deep) in both the direct and surface reflected phases. Although some lateral variation is evident beneath the north-central plateau, the basic upper mantle structure is shield-like and isotropic.

T21B-5 0830h POSTER

Restoration of Fault Configuration, Lithospheric Structure, Paleo-heatflow and Paleo-topography for the Indo-Asian Collision Using Step-by-Step Numerical Backward Modeling

X Kong, A Yin, P Bird, and T M Harrison (Dept. of Earth & Space Sciences & IGPP, UCLA, Los Angeles, CA 90095; xkong@ucla.edu)

The evolution of tectonic deformation is a function of fault geometry, rheology (or paleo-heatflow, since rheology depends on temperature), lithospheric structure, topography, and boundary conditions. Before we can fully understand the tectonic evolution of an orogeny (such as the collision between India and Asia), we have to determine these variables as a function of time since the onset of deformation. A numerical method was developed based on our faulted spherical finite element method to restore these variables. Starting with present tectonic deformation (because we know present values of these variables better than those at any past time), we can calculate these variables backward by small time increments, in theory until the beginning of orogeny. For each time step, tectonic deformation is simulated using these variables as input parameters. The modeling results of each time step is then used to restore these variables to the previous time step assuming that deformation within any step is steady. We have produced a variety of models, each with different assumptions regarding these parameters. Each model supports different topography with different crustal and lithospheric thickness, heat flow, fault geometry and boundary conditions. We have restored these variables in each model from the calculated deformation in small time steps for 50 m.y. using several dynamic hypotheses regarding the Indo-Asian collision. The simple patterns resulting from these experiments can be used as references to evaluate tectonic inferences gathered from geologic and geochemical evidence as well as assess the plausibility of regional tectonic hypotheses.

T21B-6 0830h POSTER

Tectonic modelling of the Late Cenozoic thick-skinned crustal deformation in central Asia.

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Topographic and gravimetric data reveal the existence of constant wavelength topographic undulations in Central Asia. Three dominant wavelengths (5-10 km, 50-60 km and 350 km), superimposed on each other, can be distinguished. The long- wavelength folding north of the Himalayan collision belt is very similar to folding of oceanic lithosphere in the Indian Ocean south of the Himalayas. This "symmetry" strongly suggests a common origin, which is most likely associated with regionally high compressive intraplate stresses induced by the collision of the Indo-Australian and Eurasian plate. We present results from 2-dimensional, plain-strain Finite Element modelling of the (thermo-)mechanical response of a continental lithosphere with a complex multi-layered rheology to compressive loading. A correct first-order order dominant wavelength is reproduced only by folding of plate models with a thermal age of less than 100 Myr. This is in agreement with geological data suggesting Cenozoic thermal rejuvenation of Central Asia. The second and third order dominant wavelengths most likely reflect the mechanical responses of a decoupled crust and upper crust, resp. Due to the strong influence of temperature on the yield strength, the thermally rejuvenated lithosphere of Central Asia is mechanically weaker than the surrounding areas. Our models show that this regional weakening can explain the spatially restricted occurrence of folding to Central Asia.

T21B-7 0830h POSTER

An Upwardly-Mobile Indentor? The Nanga Parbat Haramosh Massif viewed as a Crustal-Scale Pop-up Structure.

M. A. Edwards, W. S. F. Kidd, (both at: Department of Geological Sciences, University at Albany, Albany, NY 12222; me7685@csc.albany.edu); L. Seeber, (LDEO, Palisades, NY 10964); A. Pêcher, P. Le Fort, (both at: Institute Dolomieu, Grenoble, France); M. Riaz Lehigh University, Bethlehem, PA 18015); M. Asif Khan (Peshawar University, Pakistan)

The western Himalaya syntaxis includes the Indian-plate Nanga Parbat Haramosh Massif (NPHM). The contact between collider India & the overthrust Kohistan-Ladakh series (KLS) is regionally termed the Main Mantle Thrust (MMT). It forms a plan-view, "oxbow" shape around NPHM, yet NPHM is not a relict promontory of India that has acted as a horizontal indenter and "bowed out" the visible MMT. This is recognised by the absence of appropriate deformation of the northern margin of the KLS. Pervasive lineation in NPHM is ~N-S, and sense of shear on the eastern margin is often dextral where recognised. Although this agrees with horizontal indentor model predictions, the broadly antiformal nature of NPHM allows the steep N-S foliation near the margins to be the result of rotation of the original, ~E-W, gently north-dipping MMT system about an axis ~parallel to the pervasive lineation. Therefore, the eastern margin and dextral shear sense, respectively, can be restored and recognised as top-to-south, MMT zone Himalayan thrust structures, largely unaltered. Observations now extending to seven main valleys confirm that there is no large brittle fault defining the eastern NPHM-KLS contact; the contact is essentially unmodified MMT. The antiformal nature of the massif is illustrated by the degree of apparent exhumation. Within NPHM, exhumation of the central portions of the massif (e.g. Nanga Parbat) has formed a complete window through Indian plate cover sequence schist and gneiss (garnet-staurolite grade) into basement gneiss (sillimanite grade ±granulite facies, cordierite-bearing anatectic segregations). This exhumation has been accommodated in part by large ductile and brittle shear zones within SE NPHM. The Rupal Shear Zone is a wide belt of ~N-S trending orthogneiss showing a pervasive, west side up with dextral shear S-C fabric and overprinting lineation. Closer to the eastern margin, the Churit Fault in lower Tarshing valley juxtaposes sillimanite (?) grade orthogneiss in the west over staurolite grade metapelites in the east, but lacks significant ductile overprinting of regional N-S lineation. Near Raikot, the original MMT contact of the western margin is largely obscured by east-over-west thrusting with some overprinting the regional ~N-S lineation. Qualitative changes in the relative development of some fault and shear zone features may indicate diminishing strain to the north. Within NPHM and in Kohistan, late, NW-vergent structures dominate (young pegmatitic dyke sets, fault propagation folds, antithetic faults) and are suggestive of an asymmetric pop-up or flower structure. The NW-vergence in NPHM late brittle structures is consistent with the direction of axes of maximum compression derived from brittle fault kinematics in both crystalline and Quaternary rocks near and west of the Raikot fault. Our evidence confirms and strengthens the view that NPHM is an asymmetrical antiformal structure, verging NW.

T21B-8 0830h POSTER

Tectonics of the Himalaya-Karakorum Boundary: Dextral Shearing and Shortening Parallel to the Suture

Arnaud Pecher; Patrick Le Fort (both at UJF, Laboratoire de Geologie, CNRS, LGCA, 38031 - Grenoble, France) and Leonardo Seeber (Lamont-Doherty Earth Observatory, Palisades, NY 10964, USA)

Our recent mapping and structural analysis in the Northern part of the Nanga-Parbat - Haramosh massif and of the south-facing Karakorum margin improves constraints on the tectonic evolution of this key area of the Himalaya. After successive collisions between the Ladakh-Kohistan Arc and Karakorum along the Main Karakorum thrust (MKT) (≈100 Ma) and between the arc and the Himalaya along the Main Mantle thrust (MMT) (≈55 Ma), this entire collision zone was affected by late Miocene - early Pliocene ductile deformation. In the Karakorum, it is mainly flattening and shortening perpendicular to the belt. No inflection of the strain trajectories is detected in front of the Himalayan Haramosh spur. Close to the MKT, the syn-metamorphic Mio-Pliocene folds display steeply plunging axis, suggesting right lateral shear parallel to strike. In the Himalaya north of the Indus valley (Haramosh massif), recent deformation displays progressive decoupling between the Karakorum and the Himalaya through the following stages:

(i) Early suturing-related folds and shearing (such as the MMT) reflect shortening perpendicular to regional structural trend of the Karakorum boundary. Dextral north-south shearing is observed on both sides of the future Nanga-Parbat spur. It may accommodate differential north-south convergence to account for the obliquity of the Himalaya-Karakorum boundary (MKT).

(ii) Those structures are deformed by a series of domes, forming an east-west alignment at least 100 km long across the south Karakorum - North Himalaya corridor. These domes are cored with gneissic or plutonic rocks. The Haramosh dome is the most prominent and contains Himalayan gneisses. We found clear evidence for a compressive regime and no evidence for normal faulting associated with the domes. We tentatively interpret them as right-stepping en echelon folds linked to a buried dextral shear zone parallel to MKT;

(iii) A broad anticline forms with an axis nearly perpendicular to pre-existing northwest trends and is centered on the Haramosh dome. This antiform does not affect the South Karakorum to the north, but it overthrusts the Kohistan terrane to the northwest on the Raikot fault. The displacement increases to the south, suggesting a scissors-like movement on this fault. The epicenter of this deformation migrates south from the Haramosh to the Nanga-Parbat area where the youngest metamorphism and granite emplacement are found.

Thus, in an overall regime of meridian convergence, the deformation since Miocene in the Himalaya-Karakorum boundary area is partitioned into northeast shortening perpendicular to the belt, mainly in the Karakorum, and shortening parallel to the belt in the Himalaya.

T21B-9 0830h POSTER

Strain Partitioning along the Himalayan Arc and the Nanga Parbat Antiform

Leonardo Seeber (Lamont-Doherty Earth Observatory, Palisades, NY 10964, USA) and Arnaud Pecher (UJF Laboratoire de Geologie, 38031 - Grenoble, France)

Slip vectors of thrust mechanisms along the Himalayan arc of continental convergence are generally in the radial direction. Pure thrusting along a 60° wide arcuate thrust front requires strain partitioning and substantial "intraplate" deformation of at least one of the two interacting plates. If the footwall block (India) underthrusts undeformed the hangingwall block (Tibet) along an arc which is invariant in shape and on a flat Earth, radial velocity is Ccosq, where C is the convergence rate between India and the arc and q is the position along the arc relative to the axis where this motion is radial. Radial India-Tibet convergence along the entire arc requires Tibet to stretch along the arc such that its motion is Csinq away from the q=0 point. Numerous radial grabens in southern Tibet are symptomatic of this arc-parallel extension. Strain partitioning stops at the arc termini where "intraplate" compression is expected to compensate for the arc-parallel extension. The Nanga Parbat-Haramosh Massif (NPHM) and the western syntaxis are part of a 250-km long northeast-striking and northwest-verging antiform between the seismogenic thrust front at the northwestern end of the Himalayan arc and the South Karakoram fault (SKF). This antiform is the structural/topographic expression of a belt of arc-parallel shortening that may compensate, at least in part, for the extension along the rest of the Himalayan arc. This model predicts right-lateral motion along the SKF east of the NPHM and similar rates of convergence across the western Himalayan front and the NPHM. Himalayan radial convergence manifested by the Indus-Kohistan seismic zone continues at least 100 km west of the syntaxis. This suggests that the belt of arc-parallel shortening may be broader than the Nanga Parbat antiform and may include parts of eastern Kohistan. Arc-parallel shortening related to strain partitioning may also occur at the eastern terminus of the Himalayas, although obliquity to the plate motion is considerably less there than at the western terminus. Arc-parallel extension is found along convergence zones worldwide and Nanga Parbat-like arc-parallel convergence zones may be just as common.

T21B-10 0830h POSTER

Tectonometamorphic History of the Nanga Parbat-Haramosh Massif, Northern Pakistan

C P Chamberlain; J D Blum; C A Gazis; M A Poage (all at: Department of Earth Sciences, Dartmouth College, Hanover, NH 03755; ph. 603-646-3624; e-mail: C.P. Chamberlain@Dartmouth.EDU)

The geology of the northern margin of the Indian plate is remarkably uniform along hundreds of kilometers of strike of the Main Mantle Thrust. The Indian-plate footwall rocks consist of southward-directed thrust sheets which stack upper-amphibolite-grade upon lower-grade rocks. Metamorphism and plutonism in these thrust-slices was relatively old (50 to 45 Ma). Metamorphism and melting of the rocks within the Nanga Parbat-Haramosh Massif (NPHM), an anomalous northward extension of the Indian plate margin in northern Pakistan, however, was considerably younger (¡10 Ma) and at granulite-grade. Until now we have been unable to reconcile the along-strike variations in metamorphic style observed within Indian plate rocks of northern Pakistan. Recent field studies suggest that the metamorphic break occurs along steep thrust-faults which border the massif. The NPHM is a syn-metamorphic dome. Our studies of both the east and west margin of the NPHM, show that the granulite-grade rocks of the massif are juxtaposed against an amphibolite-grade cover sequence along steeply-dipping thrust faults. Rocks within the core of the massif consist of cordierite-sillimanite-kspar bearing gneisses and anatectic leucogranites. On the edge of the massif is a cover sequence consisting of Himalayan-age staurolite-garnet-kyanite schists. Despite the similarities between the NPHM and western North American core complexes, the NPHM did not form as a result of crustal extension.

T21B-11 0830h POSTER

Late Pleistocene Incision Rate Patterns Confirm Long-term Differential Uplift of the Western Syntaxis of the Himalaya along the Indus River in Northern Pakistan

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Well-preserved, river-cut bedrock surfaces (straths) abandoned by progressive incision of the Indus River in northern Pakistan have been dated using *in situ* cosmogenic ^{10}Be and ^{26}Al exposure age dating. Strath exposure ages range from 0 age for actively forming straths to 65 ka for straths 150 m above the river. The data show that straths form quickly with essentially no buildup of cosmogenic nuclides prior to strath abandonment. The results also show that higher straths yield older exposure ages than lower straths as expected.

1120 h SM21D-09 *INVITED* Time Domain Structures in the Auroral Acceleration Region: **F S Mozer,** P Harvey, D Pankow, W Teitler, R Ullrich, J Vernetti, J Wygant, C T Russell

1140 h SM21D-10 *INVITED* Polar Energetic Particles (PEPs): A New Signature of the High-Latitude Magnetosphere: **H E Spence,** R B Sheldon, T A Fritz, J Chen, J B Blake, J F Fennell, D N Baker, M G Henderson, M Grande, M G Kivelson, R J Walker

1155 h SM21D-11 First Results From the Source/Loss-Cone Energetic Particle Spectrometer (SEPS) on the NASA POLAR Satellite: **H D Voss,** M Walt, W L Imhof, J Mobilia

T21A MC: HALL D Tues 0830h

Indian Ocean Spreading Centers III Posters *(joint with OG,V)*

Presiding: **P Patriat,** Inst. de Physique du Globe, Paris ; **D Scheirer,** Brown Univ

0830 h T21A-01 *POSTER* Early Tertiary Reconstructions of the Australian and Antarctic Plates: **A A Tikku,** S C Cande

0830 h T21A-02 *POSTER* Segmentation of the South-West Indian Ridge From 49°E to the Triple Junction (70°E): What Is the Mark of a Very Low Spreading Rate?: **P Patriat**

0830 h T21A-03 *POSTER* Magnetic and Kinematic Study at the Southwest Indian Ridge Between 15°E and 35°E: **C Rommevaux-Jestin,** N R Grindlay, J A Madsen, J Sclater

0830 h T21A-04 *POSTER* Morphology of Transform Faults at the Southeast Indian Ridge Between 88°E and 118°E: A Recent Change in Plate Motion: **A Shah,** C Small, J Cochran

0830 h T21A-05 *POSTER* Variations in Major Element Composition of Basalt Glasses Along the Southeast Indian Ridge in the Vicinity of the Amsterdam-Saint Paul Platform: **L M Douglas,** D W Graham, K T M Johnson, D S Scheirer, D W Forsyth

0830 h T21A-06 *POSTER* Geochemistry of Basaltic Glasses From the Very Slow Spreading Southwest Indian Ridge: **C J Robinson,** M J Bickle, R S White, T A Minshull

0830 h T21A-07 *POSTER* H_2O Contents of Basaltic Glasses From the Australia-Antarctic Discordance (AAD) and the Southeast Indian Ridge (SEIR) Immediately East From the AAD: **L V Danyushevsky,** R Batiza, D M Christie

0830 h T21A-08 *POSTER* Models of Structural Processes at Oblique Spreading Centres: **G W Tuckwell,** J M Bull, D J Sanderson, L M Parson, B J Murton

0830 h T21A-09 *POSTER* Influence of the Reunion Hotspot on the Segmentation of the Central Indian Ridge near 19°S: **D Sauter,** A Briais, H Hebert, S Merkouriev, P Patriat, J R Vanney

0830 h T21A-10 *POSTER* Asthenosphere Flow Model of Hotspot-Ridge Interactions: **M M Yale,** J P Morgan

0830 h T21A-11 *POSTER* The Wharton Fossil Ridge: Preliminary Results of a 3-D Geophysical Survey: **C Deplus,** M Diament, J Dubois, H Hebert, P Patriat, J J Sibilla, G Bertrand, S Dominguez, J Malod, B Pontoise

0830 h T21A-12 *POSTER* Multibeam Bathymetric and Backscatter Survey of the Southwest Indian Ridge, 15-35 Degrees E: Results Using the SEA BEAM 2112 System on the R/V KNORR: **J A Madsen,** N R Grindlay, S P Miller

0830 h T21A-13 *POSTER* H_2O Contents of MORB Glasses From the Southeast Indian Ridge: **B Sylvander,** D M Christie, L V Danyushevsky

T21B MC: HALL D Tues 0830h

Structure and Evolution of the Tibetan Plateau III Posters *(joint with S)*

Presiding: **L Zhu,** Caltech; **A Rodgers,** Univ of California, Santa Cruz

0830 h T21B-01 *POSTER* Converted Shear-Wave Reflections From the Tibetan Middle Crust: Melt or Water?: **Y Makovsky,** S L Klemperer

0830 h T21B-02 *POSTER* Strong Differences of Crustal Structure North and South of the Tsangpo Suture - Evidence From Surface Waves: H A Pedersen, N Cotte, M Campillo, J F Ni, E Sandvol, W Zhao

0830 h T21B-03 *POSTER* Lateral Heterogeneity in the Upper Mantle Beneath the Tibetan Plateau and Its Surroundings From SS-S Travel Time Residuals: **I G Dricker,** S W Roecker

0830 h T21B-04 *POSTER* Lithospheric Structure Under the Tibetan Plateau From Broadband Seismic Waveforms: **L Zhu,** D V Helmberger

0830 h T21B-05 *POSTER* Restoration of Fault Configuration, Lithospheric Structure, Paleo-heatflow and Paleo-topography for the Indo-Asian Collision Using Step-by-Step Numerical Backward Modeling: **X Kong,** A Yin, P Bird, T M Harrison

0830 h T21B-06 *POSTER* Tectonic Modelling of the Late Cenozoic Thick-Skinned Crustal Deformation in Central Asia: **F Beekman,** E B Burov, S Cloetingh

0830 h T21B-07 *POSTER* An Upwardly Mobile Indentor? The Nanga Parbat Haramosh Massif Viewed as a Crustal-Scale Pop-Up Structure: **M A Edwards,** W S F Kidd, L Seeber, A Pecher, P Le Fort, M Riaz, M A Khan

0830 h T21B-08 *POSTER* Tectonics of the Himalaya-Karakorum Boundary: Dextral Shearing and Shortening Parallel to the Suture: **A Pecher,** P Le Fort, L Seeber

0830 h T21B-09 *POSTER* Strain Partitioning Along the Himalayan Arc and the Nanga Parbat Antiform: **L Seeber,** A Pecher

0830 h T21B-10 *POSTER* Tectonometamorphic History of the Nanga Parbat-Haramosh Massif, Northern Pakistan: C P Chamberlain, J D Blum, C A Gazis, M A Poage

0830 h T21B-11 *POSTER* Late Pleistocene Incision Rate Patterns Confirm Long-Term Differential Uplift of the Western Syntaxis of the Himalaya Along the Indus River in Northern Pakistan: **J F Leland,** M R Reid, D W Burbank, R C Finkel, M Caffee

0830 h T21B-12 *POSTER* Northeastward Growth of the Tibet Plateau Deduced From Balanced Reconstruction of Two Cenozoic Sedimentary Basins: The Qaidam and Hexi Corridor, China: **F Metivier,** Y Gaudemer, P Tapponnier, B Meyer

0830 h T21B-13 *POSTER* Role of Oblique Convergence in the Active Deformation of Southern Tibet: **R McCaffrey,** J Nabelek, P Zwick

0830 h T21B-14 *POSTER* Kinematics of Holocene Normal Faulting in the Northern Pamir: **P M Blisniuk,** M R Strecker

0830 h T21B-15 *POSTER* Discrete Thrust Faulting and Transfer Fault Zone Deformation Along the Northern Pamir Mountains, Kyrgyzstan (India-Eurasia Collision Zone): **J R Arrowsmith,** M Strecker

0830 h T21B-16 *POSTER* Slip Rate and Earthquake Recurrence Interval on Himalayan Plate-Boundary Megathrust: **R S Yeats**