T22C-4 1415h

Crustal Thickening in Eastern Tibet without Surface Shortening: A Natural Result of Flow within a Weak Lower Crust

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Estimates of crustal shortening along the eastern margin of the Tibetan plateau from surface structures are far too small to explain the thick crust and high topography observed for the eastern part of the plateau. In addition, the topographic boundary along the eastern edge of the plateau is poorly defined and does not parallel geologic structures in many places. This suggests that crustal thickening and creation of high topography along the eastern margin of the plateau have occurred without comparable amounts of surface shortening, and may instead reflect thickening within the middle and lower portions of the crust. This hypothesis is consistent with the results of three-dimensional modeling of large-scale crustal deformation above a "plate-like" mantle provided that the lower crust beneath the high portions of the plateau is very weak compared to the upper crust of the plateau and to the upper and lower crust beneath the margins of the plateau. As convergence continues, the lower crust is evacuated from beneath the plateau by channelized flow in the lower crust, and becomes greatly thickened beneath the eastern plateau (east of the eastern syntaxis). Within the eastern part of the plateau, lower crustal thickening is accompanied by little to no surface shortening, and the uppermost crust may even undergo net thinning. Thickening of the crust occurs in this manner occurs for approximately 500 km east of the eastern syntaxis. This explains the lack of Tertiary foreland basins along the eastern margin of the plateau, because this style of deformation does not cause loading of the foreland in the style normally observed in orogenic systems. In addition, the geometry of the topographically high region east and south of the eastern syntaxis (in Yunnan) and the observed clockwise rotation of crustal fragments in the same area indicate significant southward-directed subduction of Asian lithosphere beneath central part of the Tibetan plateau.

T22C-5 1430h

Mapping the Decent of Indian and Eurasian Plates Beneath the Tibetan Plateau from Gravity Anomalies

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The collision of India with Asia has produced a complicated continental-continental plate boundary involving north-south-directed folding and faulting and east-west-directed strike-slip and normal faulting within and along the margins of the Tibetan plateau. However, numerous lines of evidence, including the development of two scales of folding in Tibet, suggest that the lowermost crust is behaving in a ductile fashion. Thus the fundamental plate-tectonic motions in the uppermost mantle may be quite different from the complex pattern revealed by surface faulting. In this study, we use Bouguer gravity anomalies to map out the geometry of Indian and Eurasian plate interactions in the mantle beneath the plateau based on both the inferred geometry of the Moho and lateral variations in lithospheric strength determined from mechanical modeling. In our preferred model, the lithosphere beneath Tibet consists of two distinct units: (1) the underthrust (to the north) Indian plate, which sutures with the Eurasian plate in the upper mantle below the Yarlung-Zangpo Suture or the Gandise igneous arc, 200-400 km north of the Main Boundary Thrust, and (2) the underthrust (to the south) Eurasian plate. A subducting slab of Indian upper mantle extends about 200 km into the asthenosphere north from the mantle suture and exerts a bending moment of about 5×10^{17}N on the Indian plate. Thus the mantle lithosphere appears to be behaving in the simple fashion of converging oceanic plates, while the more buoyant continental crust deforms under gravitational forces in a complex pattern controlled by its lateral and vertical strength heterogeneity.

T22C-6 1445h

Development of Intracontinental Orogens: The Tien Shan

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Most of the world's great mountain belts formed at plate boundaries where the crust thickens as material is transferred from the downgoing plate to the overriding plate. Subduction provides a sink for continental mantle lithosphere. In the case of intracontinental orogens, it is less clear how mass balance is achieved. Since there is no plate boundary subduction, does the mantle lithosphere thicken along with the crust? Or do intracrustal detachments relay crust to areas of crustal thickening from either areas of crustal thinning or subduction zones?

The Tien Shan, a distant response to the collision of India with Asia, provide an excellent opportunity to examine how and why intracontinental orogens form far from active plate boundaries. In this study, we use gravity and topography data from China and the former USSR to understand the ongoing process of crustal thickening.

From east to west, the Tien Shan demonstrate the sequential development of an intracontinetal mountain belt. In the east, the mountain belt is relatively low in elevation, but isostatic gravity anomalies are positively correlated with the topography. Even Bouguer gravity and topography are positively correlated at two distinct wavelength bands centered near 100 and 200 km, as would be predicted for folding and faulting of the crust into basement-cored uplifts with intracrustal detachments. At this early stage of orogeny, the mountains are being supported by the strength of the Asian lithosphere, and minor crustal thickening leads to a situation of undercompensation, similar to the situation for the Laramide orogeny in the western US. In the central regions of the Tien Shan where crustal shortening is more advanced, the isostatic gravity anomalies are reduced to zero, indicating an Airy-type balance between topography and crustal thickening. In the western Tien Shan, the mountains reach their highest elevation, and there is a negative correlation between isostatic gravity and topography. This overcompensation could signal the initiation of mantle downwelling, in the manner of the Transverse Ranges along the bend in the San Andreas.

We propose that the crust is the first to respond to intraplate compression, transferring mass along detachment surfaces to concentrate compression at ancient zones of weakness. As shortening continues, intraplate compression concentrates strain within the already flexed mantle, weakening it to the point that the whole mantle lithosphere participates in intraplate shortening.

T22C-7 1500h

Active Medial Miocene Detachment in the High Himalaya of the Tibet-Bhutan Frontier: a Young Crystallisation age for the Khula Kangri Leucogranite Pluton

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The Southern Tibet Detachment System (STDS) consists of north-dipping, low-angle normal faults which outcrop on the north flank of the High Himalaya juxtaposing Tethyan sedimentary rocks against High Himalayan crystalline rock (HHC). Leucogranite plutons involved in STDS mylonites along the Nepal-Tibet Himalaya are early Miocene in age. The youngest age for STDS mylonite reported to date is ~17 Ma (Burchfiel et al., 1992). The first observation of an unambiguous STDS-type detachment east of the Yadong Cross Structure (YCS, a >70km map view offset of the Himalayan chain) was in Gonto La (north) valley, to the west of Khula Kangri (Edwards et al., 1995). Here, a major, low-angle (~5°N) detachment, extending several tens of kilometres along strike, juxtaposes Tethyan rocks over a >10km long section of the Khula Kangri pluton. Top-to-north S-C fabric is found in a ~300m thick horizon where the granite is cut by the detachment zone. The southern margin of the pluton intrudes gneisses below a sequence of south-dipping, high-strain, mylonitic augen gneisses whose foliation largely parallels the curved pluton margin. The anomalous southern dip of the mylonites, that are otherwise characteristic of STDS hanging wall lithologies, has been interpreted to be a result of deformation of an early (ductile), north-dipping STDS horizon (possibly early Miocene) by upwarping associated with rise of the Khula Kangri (KK) pluton. Later STDS N-S extension resulted in the north-dipping, pluton-truncating detachment. We report here Th-Pb crystallisation ages from monazite grains from the KK pluton in Gonto La valley. Twentynine measured ages on 16 grains of monazite yield a mean age of 12.5 +/- 0.3 Ma. Inheritance in portions of a few single grains was noted and these give an age range of 30-40 Ma. This first report of a crystallisation age for a leucogranite of the Tibet-Bhutan High Himalaya is markedly younger than those for corresponding large plutons to the west. It shows that N-S extension on the STDS continued here into the late medial Miocene. If the STDS detachments were caused by a sufficent topographic gradient (Burchfiel and Royden, 1985) then relative uplift occured here well after that in the Nepal-Tibet Himalaya, and there is a significant difference in timing of Himalayan events of the Bhutan-Tibet Himalaya, after initial MCT and consequent STDS movement. The Kakhtang thrust documented by Gansser in Bhutan has not been recognised west of the YCS and we suggest the movement on this fault may be connected with the development of the observed diachroneity. The 30-40 Ma inheritance age could be related to an early Barrovian event in the MCT hanging wall.

T22C-8 1515h

Transtension Along the Left-Slip Altyn Tagh and Kunlun Faults as a Mechanism for the Occurrence of Late Cenozoic Volcanism in the Northern Tibetan Plateau

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The occurrence of volcanism younger than 13 Ma along the northwestern margin of the Tibetan plateau has been attributed to delamination of the mantle lithosphere due to thickening caused by the Indo-Asia collision. This hypothesis was based on a weak correlation between the location of a low seismic-velocity zone in the upper mantle and volcanism in the northern region of the plateau. There are two problems with this hypothesis. (1) The delamination mechanism requires that volcanism occurred in a large region of Tibet regardless of local structural settings. However, examination of late Cenozoic geologic structures adjacent to the volcanics suggests that their occurrence in general was spatially related to two major active left-slip faults along the northern margin of the Tibetan plateau: the Kunlun fault that separates the Tibetan plateau to the south and the Qiadam basin to the north, and the Altyn Tagh fault that bounds the Tibetan plateau to the southeast and the Tarim basin to the northwest. (2) There is no spatial correlation between the low-velocity region and the occurrence of late Cenozoic volcanism in Tibet. Where the upper mantle seismic velocity is relatively high, such as at the western end of the Altyn Tagh fault system, late Cenozoic volcanics are also present. Volcanism was occurring at different locations on the plateau during the Oligo-Miocene and is not restricted to ≤13 Ma as previously suggested. Although clearly a left-slip fault in the late Cenozoic, recent geologic investigations along the Altyn Tagh fault suggest that it is transpressional along its eastern segment east of Qieme (~38°N, 86°E), and transtensional along its western segment, west of Qieme. North of the eastern segment, there are numerous thrusts and folds, involving Quaternary sediments, are developed parallel to the Altyn Tagh fault. In the western segment near Hotan (~37°N, 80°E), active normal faults are developed subparallel to the Altyn Tagh fault. In addition, the western segment consists of a series of en echelon faults and associated pull-apart basins where Quaternary volcanic rocks are present. We propose that it is the transtensional tectonic setting along the western segment of the Altyn Tagh fault in general, and the pull-apart basins in particular, that have controlled the occurrence of the late Cenozoic volcanism in the northwestern Tibetan plateau. Examination of the structural setting of the late Cenozoic volcanics along the Kunlun fault suggests a similar conclusion - that formation of pull-apart basins was the cause for the volcanism. The variation of transtension to transpression along the Altyn Tagh fault from west to east implies that the Tarim basin in the late Cenozoic has been rotated clockwise with respect to the Tibetan plateau. Such a sense of rotation is consistent with both a decrease of late Cenozoic shortening from west to east in the Tian Shan region and the suggested clockwise rotation of Tarim in the Cenozoic based on paleomagnetic analysis. Emplacement of the abundant late Cenozoic volcanics along the western Altyn Tagh fault may have been aided by the great crustal-thickness gradient (~70 to 35-km thickness over <100-km distance) from the Tibetan plateau to the Tarim basin. Thus, the plateau may have acted as a "pump" that pushed lithospheric mantle magma both sideways and up through pull-apart related structures.

T22C-9 1530h

Thermal Evolution of Collisional Orogens: Effects of Accretion and Erosion

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The thermal evolution of collisional orogens is strongly controlled by the location of radioactive material within the upper plate. The evolution of the size and shape of the "radioactive wedge" in the upper plate is controlled by the rates of accretion from below and erosion from above in addition to the dip and velocity of the subducting plate. In order to maintain radioactive material in the upper plate, the accretion rate must exceed the erosion rate.

Results of two-dimensional numerical modeling indicate that, during early stages of collision, temperatures in the upper plate decrease and are controlled by the temperature of the subducting plate. Subsequently, temperatures in the upper plate increase and are controlled primarily by accretion of radioactive material from below and surface erosion. High accretion rates produce a rapid increase in temperatures and result in high steady-state temperatures. Erosion and lower accretion rates produce an overturned geotherm within the upper and lower plates. At higher subduction rates, isotherms within the upper plate become closed contours in cross-section, with temperatures decreasing in all directions. For example, given an 18 km thick radioactive layer with heat production of 2.5 mW/m^3, a dip of 11°, subduction rate of 20 km/my, horizontal accretion rate of 9 km/my, and erosion rates from 1-2 km/my, overturned geotherms develop at mid-crustal depths in the upper plate within less than 20 my following initiation of collision. After 30 my, closed isotherms develop, enclosing 100's km^2 in cross-section with temperatures of > 600°C.

Modeled thermal evolutions compare favorably with data from the central Himalayas, where since 45 Ma continental crust from the subducting plate has been accreted to the upper plate and subsequently exhumed via erosion and tectonic denudation. Present-day exposures of midcrustal rocks directly above the Miocene subduction zone display an apparent steep-to-overturned thermal gradient associated with anatectic plutons. Thus, the modeled thermal regime and time scale are consistent with Himalayan observations, and provide a geologically reasonable scenario for development of the enigmatic apparent overturned thermal gradient and anatexis.

T22C-10 1545h

Oblique Convergence: Modeling Examples in Pakistan

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It is rare to find a convergent margin where the plates in question have a convergence direction normal to both of their margins. For this reason the way in which strain is partitioned at oblique plate margins is of broad geological interest.

Our previous modeling of oblique convergent plate margins indicated that the nature of the structures that develop to accomodate plate-boundary strain is strongly influenced by geometries and relative strengths of the margins and accreted terranes between them. The total relative plate motion vector must be resolved as discrete strain between the stable portions of the two plates.

Our model for strain partitioning allows us to account for this strain along a geometrically complex margin. Our current study is a more detailed look at the effects of plate geometry upon the Indian-Eurasian collision to the south and west of the western syntaxis of the Himalayas in the area of the Sulamian Lobe and Sulaiman Range. This area is of interest because of the close juxtaposition of varied styles of strain accomodation; north-south shortening in the Sulamian Lobe and east-west shortening in the Sulamian Range, with strike-slip faulting on the structures such as the Kingri fault in between.

We show that the northeast-striking Chaman fault zone allows Afghanistan to act as an oblique barrier to convergence and the formation of thin-skinned thrusting in Pakistan. In the presence of substantial strength contrasts, such an inital geometry inevitably leads to the formation of east- and south-facing zones of shortening analogous to the Sulaiman Lobe and Sulaiman Range in both sandbox and numerical models. The assumption that accreted materials north of the Muslimbagh ophiolite are mechanically strong and are restricted in their northward motion by the Chaman fault zone leads to an additional eastward component of motion there and in the Sulaiman Range. In this way, the north-south convergence of India and Asia is able to produce a substantial mountain belt with nearly east-west shortening.

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T22C-11 1600h

Deformation of the Iranian Plateau, Implications From a Numerical Study

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The deformation of the Iranian plateau due to convergence of the Arabian shield and Eurasian plate is studied by applying thin viscous sheet model. The lack of deformation in central Iran and the south Caspian

in brittle rocks. The model is based on the 2D displacement discontinuity method. Modifications have been made to account for Coulomb friction along closed portions of cracks, crack tip stress intensity factor calculations, statistical distributions of initial cracks, and crack coalescence. The model predicts many realistic aspects of rock deformation and failure under triaxial compression including: strain hardening due to initial microcrack growth, and strain- softening due to crack interaction and coalescence; axial splitting macroscopic failure under uniaxial loading, and macroscopic shear failure formed by the coalescence of many smaller extensile cracks under triaxial compression; volume dilatancy; size dependence; rate dependence when subcritical crack growth is used. By varying the crack and elastic properties, many different rock types have been successfully modeled including Westerly granite, Berea sandstone, Indiana limestone, and Yucca Mountain tuff.

There are several aspects of shear localization that have been investigated with the model, including characteristics of both the onset of localization and when cracks have coalesced to form a through-going shear plane. Also, the results give a clear picture of how the cracks coalesce to form a shear plane with a specific orientation.

T22B-10 1615h

Shear Zone Formation and Evolution in Porous Sandstone Under Laboratory Triaxial Compression

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We investigate the micromechanical processes involved in the formation and evolution of shear zones in porous rocks. Dry, intact, 100mm diameter sandstone cores were deformed in a large capacity stiff triaxial compression rig. Tests at increasing axial displacements (up to 23mm) were carried out at constant confining pressure (34MPa) and axial strain rate (5E-06/s). The response of the rock to loading was continuously monitored during the test by recording axial load and axial strain. Deformation structures and gouge material produced were studied by thin section, SEM and laser particle sizing analyses.

These tests generated fault zones consisting of interweaving strands of pale granulated material between which lay lenses of apparently undamaged host rock. The individual strands showed a reduction in grain size, porosity and sorting compared to the host. The number of strands in the fault zone and the fault zone width were found to be correlated to the applied axial displacement. Mean grain size in these shear strands, however, reached a steady value irrespective of applied axial strain. These features may imply a strain hardening process is active, where a limited amount of strain is accommodated on each individual strand, further strain requiring new strands to form. These laboratory induced faults strongly resemble field exposures of shear zones e.g. "granulation seams" in the Permo-Triassic sandstones of Arran, Scotland.

T22B-11 1630h

Identifying Failure Through Acoustic Emission Mechanisms

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The purpose of the study is to identify stress-dependence of damage mechanisms and precursors of localization. Failure in brittle rocks is generally accompanied by localization of deformation in tensile or shear zones. The experimental technique of acoustic emission (AE) has been found to be useful in monitoring failure and in determining the micromechanisms. To study the effects of localization on distribution and sources of AE activity, rock specimens were tested under uniaxial compression and tensile bending. Hypocenters of AE events were located based on the first arrival of P-waves and mechanisms were inferred through polarities. Polarities of first motion can distiguish among tensile opening, shear sliding, and point implosion type mechanisms and also are useful in identifying focal planes. Localization in the form of spalling near the free surface was detected by the clustering of hypocenters for uniaxial compression. Source mechanisms seemed to shift from tensile opening to sliding prior to localization at around 90% of peak load and may be an indicator of failure. Four-point bending tests showed the development of a process zone prior to the limit load and tensile crack propagation in the post-peak regime. The spatial distribution of AE activity is useful in tracking localization, while the shift in mechanisms may be a predictor of failure.

T22B-12 1645h

Interaction of Microcrack Damage Inferred from Acoustic Emissions

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Fault nucleation in crystalline rock has been shown to involve cooperative interaction of flaws within the rock mass. We have considered a two-stage hierarchical model in which damage of a given size must accumulate within the rock until it reaches a sufficient density for flaws to interact. Once a critical damage concentration is achieved, local failure leads to the development of a flaw (or fault) on the next larger scale. This process will then continue to larger and larger scales. As a first step in understanding this process, we have analyzed the statistical correlations in space and time among acoustic emission (AE) events occurring in the peak stress region in laboratory deformation experiments.

A 76.2 mm-diameter sample of coarse-grained Harcourt granite was loaded to failure at 50 MPa confining pressure. Acoustic emissions were recorded during sample deformation and used to determine hypocentral locations and amplitudes of source events. In this manner, over 20,000 events were located (with approximately 3 mm accuracy) in the pre-faulting stage of the experiment. Analysis of the spatio-temporal pattern of events occurring before macroscopic fault formation shows that a small percentage of the total population of AE events were correlated in both space and time. Before fault nucleation, small amplitude events occurred throughout the sample and showed modest spatial clustering with a correlation coefficient exponent of about 2.7. This exponent is a kind of fractal dimension that expresses the degree of spatial clustering of events. For example, an exponent of 3 would result from purely random occurrence of events within the rock volume, while fault formation reduces this exponent to 2 or less. Superimposed on this background activity which occurs uniformly throughout the sample, we found that there was a 20% increased probability that a small-amplitude event would be accompanied by a second event within a distance of 8 mm and time interval of 40 sec. The same calculations performed on the large-amplitude AE events showed approximately a 250% increase in probability, relative to the background level, that smaller events would occur within 10-15 mm and 50-80 sec of a large-amplitude event. These smaller events appeared as both foreshocks and aftershocks of the main events. These observations are consistent with expectations that perturbations in the local stress field within the rock will be correlated with the magnitude and rate of microcrack activity. Since earthquake populations are known to obey similar spatial and temporal clustering rules, it may be possible to use laboratory experiments as analogs for understanding the statistics of seismicity patterns.

T22C MC: 132 Tues 1330h
Collisional Tectonics of Asia

***Presiding:* M A Edwards, SUNY Albany; A D Huerta, MIT**

T22C-1 1330h

India-Asia Suture Observed on Wide-Angle Seismic Data of Project INDEPTH

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Wide-angle seismic data recorded in 1994 as part of project INDEPTH (International Deep Profiling of Tibet and the Himalayas) are used to construct reflection sections across the surface exposure of the Indus-Yarlung-suture (IYS) in southern Tibet. A continuous, bright, 2-5s wide band of reflections was imaged crossing the IYS and will be named here the Yarlung Suture Reflection (YSR). The south end of the YSR is 40km south of the IYS with its top at 6s twt (about 17.5km). This area was imaged by the INDEPTH CMP profile and interpreted to be comprised of backthrusting structures. The north end of the YSR is 50km to the north of the IYS, where its top is at 8s (about 24km depth), and at which point it terminates against a set of steep north dipping reflections. A discontinuous band of "bright-spot" reflections, imaged by the INDEPTH CMP profile beneath the Yangbijin rift system and interpreted as a set magma bodies, appear to converge to the south with the northern end of the YSR.

Interpretations proposed for this reflective band are:

1. An ophiolitic slab of the IYS that was underthrust beneath the Gangdese arc and accretionary wedge marking the suture. The acoustic contrast between the accretionary wedge and the ophiolitic basalts, possibly still fluid rich, gives rise to the strong reflections. This is our preferred interpretation.

2. The basal detachment of the post-collisional Gangdese Thrust (GT) system continuing, possibly as a blind thrust, to the south of the IYS. This inetrpretation is less likely since the YSR is much deeper than the estimated depth of the GT. In addition this interpretation does not provide a convincing explanation for the strength of the reflections.

3. Young magma bodies associated with the east-west extension similar to features observed on the INDEPTH CMP profile to the north beneath the Yangbijin rift system. The strong amplitudes of the reflections suggest the presence of magma beneath the suture, however shear-wave data recorded in this area provide no conclusive evidence to support this possibility.

The implication of our prefarred interpretation is that the IYS ophiolitic complex is not represented by the Xigatze ophiolites which are the basement of the forearc basin attached to the Lhasa Block (Asia). The ophiolitic complex of the IYS in southern Tibet was burried to a depth of about 20 km by the GT from the north and by backthrusting from the south. Ophiolitic slices brought up by backthrusts south of the Xigatze ophiolites provide geological evidence for the presence of ophiolitic material at depth south of the present outcrop trace of the IYS.

T22C-2 1345h

A Deep Crustal Seismic Section Beneath the Indus -Yarlung Suture, Tibet From Wide-Angle Seismic Data

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Records of densely spaced shots along the Sino-US reflection line INDEPTH II at offsets between 70 and 130 km parallel to the main profile provide an image of the crust straddling the Indus-Yarlung suture. The major features are prominent reflections at about 20 km depth beneath and extending out to about 20-30 km north and south of the surface exposure of the suture, and north-dipping reflectors north of the suture. Various interpretations for the reflections are possible. i) They represent a decollement, possibly of the Gangdise thrust system. In this, our preferred scenario, the surface expression of the Gangdise thrust as mapped in eastern south Tibet is a splay with the decollement continuing southwards and either ending as a blind thrust or ramping up as one of the thrusts within the northernmost Tethyan shelf sequence. ii) They represent fabrics within gneisses, partly obliterated by regional extensive intrusions reaching various levels of the crust. iii) They represent a fortuitous coincidence of different features north and south of the suture. Neither the ophiolitic suture nor the widespread backthrusts, both prominent surface features, produced clear reflections. Although it is not possible to discriminate between the suggested scenarios without additional information, the seismic mapping points to the importance of post-collisional (Oligocene-Miocene) tectonics, which reshaped the suture.

T22C-3 1400h

Active Tectonics of the Eastern Margin of the Tibetan Plateau and its Relations to the Formation of the Plateau

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Most interpretations for the formation of the Tibetan Plateau suggest at least some north-south shortening north of the India indentor, but interpretations differ, sometimes dramatically, for the region of the plateau east of the indentor. The active tectonics along the eastern margin of the Tibetan Plateau is dominated by three different tectonic regimes, from south to north 1) the left-lateral Xianshuihe-Xiaojiang fault regime, 2) the Longmen Shan right-lateral transpressive regime, and 3) the Qilian Shan-west Qinling left-lateral transfer regime. The Xianshuihe-Xiaojiang regime appears to be no older than Pliocene and has a long term shear rate of 15±5 to 10±5 mm/y, deforms the Red River fault and passes south into Indochina. It is partly decoupled from the Longmen Shan transpressive regime that appears to be date from Miocene time. The rate of oblique convergence in the Longmen Shan regime determined from preliminary 2-year GPS results is locally about 10 mm/yr, but displays considerable lateral variation. Four year and two year GPS measurements from the two regimes are currently being analyzed and will presented. Work on the Qinling-Qilian Shan is very preliminary and will not be considered.

Unlike the north and south boundaries of the Tibetan Plateau that are topographically sharply defined and parallel geological structure, the eastern margin is poorly defined and does not follow geological structure except in the Longmen Shan regime where it is locally strongly controlled by older crustal anisotropy. Additionally, estimates of crustal shortening along the east margin of the plateau appear to be far to small to create the thick crust and high plateau that adjoin it. Combining geological, geodetic and modeling studies we suggest lateral eastward flow of lower crust was an important feature in formation of the eastern part of the Tibetan plateau.

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