T32A-9 1330h POSTER

Seismically Active Strike-slip Faults as Generators of Modern Pull-apart Basins in Northeast Asia

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A system of Cenozoic basins crosses northeast Russia from the Laptev Sea to the Sea of Okhotsk. It was previously believed that these basins and the regional seismicity were related to the Pliocene Moma rift zone. However, recent studies show that there is a large system of northwest striking strike-slip faults in this region. The faults form *en-echelon* segments with Late Pleistocene to Holocene pull-apart basins at releasing bends. The pull-aparts are located near the larger basins of the Moma rift which made them appear to be genetically related. Instead, the pull-apart basins are the result of strike-slip motion along faults in a compressional setting due to the convergence of Eurasia and North America. As a result, the "old" extensional basins of the Moma rift are now "closing" and "new" pull-apart basins are forming; the sides of the "old" basins are now thrusts. The "old" basins are marked by a low level of seismicity, while that of the pull-aparts is high. The pull-apart basins are rhombic and bounded by two strike-slip faults and two young, low-amplitude normal faults that displace the thin conglomerates of the basins; these features are best seen in the Chai-Yureya fault zone. Cenozoic volcanism of basaltic composition is found in the Upper Nera basin and the focal mechanism for the M=4.7 June 24, 1985, event in the Bugchan pull-apart basin indicates normal faulting. Thus, modern strike-slip motions in northeast Asia due to transpression between North America and Eurasia have led to the formation of young pull-apart basins. Similar processes take place along the San Andreas fault in California, the Anatolian strike-slip fault system in Turkey, and in the Xanxi grabens in east-central China.

T32A-10 1330h POSTER

Preliminary Gravity Models Around the Kolyma Structural Loop, Sakha Republic, Russia

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The Kolyma Structural Loop (KSL) is a triangular shaped Mesozoic collision-related orogenic belt located in Northeast Asia. The loop can be divided into three distinct segments based on structural trends: the east-west trending Selennyakh segment in the north, the northwest-southeast trending Main segment in the west, and the north-south trending Pri-Kolyma segment in the east. Several gravity models of profiles digitized from Russian gravity maps cross these segments. The gravity values are displayed relative to zero, and not the absolute values. On a regional scale, it can be shown that the three segments are underlain by different types (thickness, composition) of crust. The Main segment appears to be underlain by a 'normal' thickened continental crust. The Selennyakh segment is underlain by either a more mafic upper crust which is near the surface, or a thinner crust with an elevated Moho. The gradient between these two types of crust probably marks the subsurface extension of the Siberian Craton, and the actual collision boundary as suggested by Norton, et al.(in press). It also coincides with the modern North-American/Asian plate boundary. The Kolyma segment may straddle the boundary between the continental crust of the Siberian Craton and the continental crust of the Omolon Cratonal terrane. The different types of crust have profound impacts on the possible mechanisms of emplacement and deformation of each of the three segments of the loop. On a more local scale, major gravity lows are associated with the Zyranka basin and the plutonic rocks of the KSL. There are few independent constraints to help guide the modeling process. Surficial geology, and reasonable density values were the only guides. We hope to combine these data with seismologic studies now in progress and with magnetic data to form more integrated and better constrained models.

T32A-11 1330h POSTER

Seismic Structure and Tectonics of the Shillong Plateau, Northeast India

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Northeast India is bounded by the Himalayan arc to the north and the Burmese arc to the east. The seismicity in this area is explained by the relative movement of the Indian plate with respect to the Eurasian plate. Previous researchers have suggested that the lithospheric subduction at the Himalayan belt ceased during Pliocene time, and the shallow seismicity is the effect of continental - continental collision, whereas subduction is still continuing at the Burmese arc, which is evidenced by intermediate to deep focus earthquakes in this region. Three microearthquake surveys have been performed in the Shillong Plateau region from 1982 to 1985. We have applied a tomographic method to 2742 high-quality P and S wave arrival times from 364 local earthquakes recorded by 22 seismic stations acquired during the surveys to determine 3-D velocity structure of the crust and upper mantle in this area. The result reveals significant lateral heterogeneities in the study area. At shallow depth (2 km), two low velocity zones (LVZ) in N-S direction are revealed; one is parallel to the Dudhnoi Fault and the other is parallel to a N-S photoimagery lineament in Shillong area. The Dudhnoi Fault was developed by the 1897 Great Earthquake (M 8.7). Another LVZ in NE-SW direction is observed in Nowgaon area. This LVZ is parallel to the photoimagery lineament as well as to the alignment of seismicity. At 10 km depth the LVZ along the Dudhnoi fault continue, and another LVZ is observed along the Kopili Lineament in the NE-SW direction. At this depth some high velocity zones (HVZ) are also observed in Shillong and Nowgaon areas. At the lower crust, the NE-SW LVZ is prominent in Nowgaon-Kopili area and another LVZ in NW-SE direction is observed in the west Garo Hills area. Both of the LVZs are parallel to the seismicity pattern as well as to the photoimagery lineaments in the area. The mantle velocity (35-47 km) is found to be high in Shillong area with a LVZ along Kopili lineament. The tomographic images are compatible with the tectonic features, active faults and seismicity trends, which have provided us a better understanding of the seismogenic faults and earthquake generating process in this region.

T32A-12 1330h POSTER

Quaternary Deformation in the Eastern Pamirs, Tadzhikistan and Kyrgyzstan

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This study examines evidence for active deformation within and around the Pamir Mountains, based on seismicity, analysis of satellite imagery, and field structural and geomorphic observations. Young deformation in the eastern Pamirs is concentrated in three areas: (1) the Trans-Alai mountain front along the northern perimeter of the orogen, (2) the Lake Karakul depression in the Central Pamirs, and (3) a zone of dextral strike-slip faulting in the Rushan-Pshart zone in the south. At the *Trans-Alai mountain front* thrusting has been active throughout the Cenozoic, documented by uplifted and deformed Quaternary pediments, now at >500m above the mountain front. This area is also characterized by intense seismicity, dominated by thrust faulting and dextral strike-slip faulting with N-S to NW-SE oriented P-axes. In contrast, the interior of the orogen is dominated by normal faulting events documenting E-W oriented tension. The *Karakul depression* is bounded by approximately N-S striking active normal faults with sinistral components of movement. The normal faults define an asymmetric graben with a master fault along the western basin margin. A minimum of 1200m of displacement is inferred. In the *southern Pamirs*, the Karasu Fault, which defines the central part of the Aksu-Murgab strike-slip duplex zone, displays up to 135m horizontal and 10m vertical total displacement. Dextral offsets of up to 7m and thrust-related vertical offsets of 8m in Late Pleistocene sediments underscore the recency of deformation in this region. These features and interpretation of fault-slip data suggest a transpressive tectonic remine with dsplacement rates of <1mm/a. The concentration of neotectonic features associated with thrusting along the Trans Alai, the northward migration of thrusting,, and the scarcity of other large-scale shortening features within the Pamirs suggest that this orogen moves northward *en bloc*, and causes the progressive annihilation of the intermontane Alai Valley. A minor portion of the total convergence between India and Eurasia is accommodated within the Pamirs by the splays of dextral strike-slip faults. Widespread dextral shear is observed in the Pamirs to the south and north of the extensional Karakul depression, as well as combined dextral strike-slip and normal faulting in the Muji-Tashgorgan graben of the Chinese Pamirs; these features are interpreted as localized space-accommodation phenomena, formed during progressive transfer of compressional deformation along a dextral strike-slip deformation zone with tensional stepovers.

T32B MC: Hall D Wed 1330h
International Deep Profiling of Tibet and the Himalayas II Posters *(joint with S)*

Presiding: **K Nelson,** Syracuse Univ; **Y Makovsky,** Stanford Univ

T32B-1 1330h INVITED POSTER

The 20 km Deep Yangbajain Reflection of INDEPTH II: Collisional Decollement, Extensional Detachment or Magma?

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The most prominent feature of INDEPTH II's seismic reflection profiling north of the Indus-Tsangpo suture is a persistent band of reflections at travel times of 6 s to 8 s (18 to 24 km depth). Near Yangbajain the 6 s reflector is a narrow sub-horizontal band which exhibits anomalously high amplitudes near the Yangbajain geothermal field. In the southernmost Yangbajain graben the event appears to be offset by nearly 2 s (6 km) down to the south. A sub-parallel profile displaced to the west within the same graben suggests a duplex structure involving the 6 s event. To the north of Yangbajain, in the Ningzen graben, the 6 s reflection appears to cap and be offset by a relatively thick, southwest-dipping en echelon sequence of dipping reflections. Farther north, it again appears as a relatively sub-horizontal narrow band. The en echelon character is also apparent in the southwest portion of the Domxung graben. Cross lines show that the 6 s event is nearly horizontal in the NW-SE direction. We suggest several possible interpretations: 1) The amplitude anomaly, or bright spot, character as well as general depth is similar to magma bodies interpreted from reflection data in other young rift zones. 2) Its apparent spatial correlation with the rift could be evidence of its role as a zone of extensional detachment. 3) The reflection may correlate with a reflection of similar depth south of the Tsangpo River, suggesting the possibility of a regional detachment that underlies and decapitates the Indus-Tsangpo suture.

T32B-2 1330h INVITED POSTER

Deep Seismic Reflection Profiling During INDEPTH II: Technical Overview

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INDEPTH II collected approximately 200 km of deep seismic reflection profile spanning some 300 km south to north across the Yarlung Zangbo suture. The 6 core surveys and 3 cross lines were acquired by the Fourth Geophysical Brigade of the Ministry of Geology and Mineral Resources (MGMR), with drilling support from the Fifth Brigade. Selection of acquisition parameters was guided by experience with INDEPTH I in 1992. A 240 channel telemetry system (WAVE 3) recorded a 6 km spread comprised of 27 geophones (10 Hz) in a linear array with a group spacing of 25 m. The relatively short group spacing and corresponding array lengths were chosen to improve upper crustal imaging; deep velocity control was relegated to the complementary fixed station (REFTEK) program. The primary CMP source was a 50 kg seismic explosive placed in drillholes spaced 200 m apart. In addition, a 200 kg charge was interleaved every 3 km to augment near-vertical penetration and to aid the wide-angle REFTEK recording. Use of high quality explosives and blasting caps allowed charges to be "slept" for several days, making it possible to shoot to a fixed time window (8 am to 2 pm) each day, avoiding wind noise and easing maintenance of the fixed stations. Still, WAVE 3 and other vehicle noise proved a constant irritant. In addition, several extra-large shots (500 - 1000 kg) were recorded by both WAVE 3 and REFTEKs. Drilling conditions were highly variable and especially difficult in coarse alluvia. Most shots were placed in single holes, although multiple shallow holes were occasionally necessary. Extensive scouting was necessary for effective placement of both the recording spread and shot points. Except for southernmost Gabo Valley, most of the shots were placed below the water table by at least 10 m, often at depths of 30 m or more. Cross line proved essential for identifying sideswipe in the rift valleys used for access. Field computing provided critical guidance for timely modifications in the field program. Many reflections are apparent in the upper crust, and isolated deep events are visible on shot records down to 20 - 25 s.

T32B-3 1330h INVITED POSTER

Nature of the Nyainchentangla Shear Zone at Depth from INDEPTH Seismic Experiments

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The Nyainqentangla Shear Zone (NSZ) is a low-angle, ductile shear zone exposed along the western flank of the Yangbajain Graben of the Yadong- Gulu Rift System in southern Tibet. Pan and Kidd (1992) interpret the shear zone as representative of extension analogous to the ductile detachments observed in the Basin and Range province. The shear zone is truncated by a high-angle normal fault which bounds the west side of the graben. As part of its seismic traverse of the southern Tibetan Plateau, INDEPTH collected a series of reflection profiles and complementary wide angle and three component seismic data above the presumptive subsurface extension of the NSZ. A shallow east-dipping reflector at 1 - 1 1/2 s (ca. 3 km) and a prominent, listric shaped, east-dipping reflector at 2 -3 s (ca. 6 - 9 km) are interpreted to correspond to the NSZ and the western bounding normal fault respectively. Projection of these reflectors westward to the surface suggests 2 km of offset of the NSZ by the bounding fault. A steep, west-dipping reflector observed on the east side of the graben probably relates to the eastern

bounding normal fault. Although the NSZ is underlain by a umber of sub-parallel reflectors, they do not appear to define a prominent lamination as has been argued from seismic profiles over core complexes elsewhere. The western bounding fault appears to sole out at 3 1/2 s (ca. 10 km), but underlying east-dipping events that parallel this reflector extend to nearly 5 s (ca. 15 km) where they appear to be truncated by sub-horizontal reflectors that culminate in a prominent regional band of events at 6 s (ca. 18 km).

T32B-4 1330h INVITED POSTER

Analysis and Interpretation of INDEPTH I CMP Profile With Ties to INDEPTH II

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INDEPTH-1 was a 100 km long test of deep seismic reflection profiling through the Tethyan Himalaya of southern Tibet. Beyond being a pilot project, its primary purpose was to image the active continent-continent collision between India and Asia which gives rise to the Himalayan Mountains and Tibetan Plateau. The initial result was a clear reflection image of the downgoing Indian slab, separated from Tibetan crust on top by the Main Himalayan Thrust (MHT), and from the mantle below by the Moho. Subsequent processing, analysis, and acquisition has expanded upon this basic result and added details about the nature and three-dimensional structure of key reflectors, as summarized here:

1) Loss of coherence in Moho reflections from south to north across the profile may or may not be caused by changes in the nature of the Moho reflector. Acquisition-related fluctuations in S/N are responsible for 1st-order variations in coherence, overprinting any geologic signature.

2) A bright spot appearing at 25 s echo time on the unmigrated section originates offline from at or near the base of the crust, based upon 3-D migration. It has been modeled as a buried focus caused by undulatory topography on the Moho, and alternatively as a diffraction.

3) A north-dipping reflection fabric, argued to originate within the mantle, has been identified. It may evidence a collision-related shear fabric, or an inherited fabric from shortening and rifting of the Indian continental margin.

4) A weak but laterally coherent north-dipping reflection within the Indian crust terminates in a ramp of the MHT. It may demarcate the edge of a pre-collisional rift basin, and was possibly reactivated as a thrust during collision.

5) The MHT reflector is characterized by ramp and flat geometry, made especially clear when the profile is translated into a dip section and modeled in 3-D. At least one ramp appears to take advantage of pre-existing structure.

6) Recently, INDEPTH-II extended north the INDEPTH-I line by continuing acquisition in Gabo Valley some 40 km east. Although tentative at this early stage of processing, the MHT reflector appears to continue 60 km farther north than on INDEPTH-I. If it continues its northward dip from its maximum depth of 45-50 km on the INDEPTH-II profile, the MHT projects to intersect the Moho in the vicinity of the Indus-Tsangpo suture.

T32B-5 1330h POSTER

Wide-angle three-component recording during INDEPTH-2: new data on the crustal structure of southern Tibet

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Three-component seismic data were recorded using 30 Refteks at offsets ranging from 0 to 350 km during the INDEPTH-2 project in southern Tibet from May to August 1994. Arrivals from 50 kg dynamite shots are clearly observed to offsets of more than 200 km, probably corresponding to rays refracting at depths of 40 to 60 km beneath the Yarlung suture zone. Arrivals from two one-tonne dynamite shots are resolvable to the maximum offset recorded, 350 km, and probably correspond to Pn refracting at depths of around 80 km, within the upper mantle of southern Tibet. We attribute the exceptional propagation to careful placement of seismometers in deep holes on or close to bedrock, to low cultural noise in Tibet, and to our use of broadband Guralp and 1-Hz L-4 seismometers, in addition to more conventional 4.5 Hz "refraction" seismometers.

Temporary deployments were employed for specific purposes, for example to provide broadside and off-line control for CMP cross-lines within the Yangbajain graben near the north end of the CMP profile. Extra shots were placed to provide near-offset control across gaps between the CMP profile segments, especially across the Yarlung River, the surface exposure of the Yarlung-Tsanpo suture, an area of rugged topography and hard rocks resistant to dense drilling for CMP shooting. Special effort was put into bridging this gap by wide-angle undershooting, and firing an additional 22 shots into a densified Reftek array.

T32B-6 1330h INVITED POSTER

Surface Geology of the Indepth I and II Seismic Profiles, Southern Tibet

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A composite surface geological profile, from near Yadong in the crystalline Himalaya north to near Gulu in the Lhasa block, will be presented for comparison with the INDEPTH I and II CMP seismic reflection profiles. Major ductile fault structures crossed by the surface profile which may correspond to some of the higher reflectors on the seismic lines include the Southern Tibetan Detachment [STD], the Kangmar Detachment [KD], the Gangdese Thrust [GT], and the Nyainqentanglha detachment(s). South of Pumo Tso, the earlier ductile mylonites of the STD and associated leucogranite of Kula Kangri are domed and truncated by the later gently north-dipping capping fault of the detachment. This detachment is cut here by a significant E-W steeply N-dipping normal fault, in part of post-glacial age. Significant offset of the ductile STD by these two structures is inferred. We have identified an extension to the KD east of the Nieru [Jiabu] valley; early movement may have been northward like the KD. The hypothesis that the STD and the KD were once the same movement surface is permitted by our observations, although very different basement is exposed by each, and the cover sequences are of different facies. Disappearance of the Southern Tethyan sedimentary sequence eastward across the Yadong-Gala graben corresponds to the western limit of the E-W steep normal fault, and the appearance on its south side of a thick section of carbonate mylonites, at the southern end of the Jiabu valley, which we presume to be the attenuated equivalent of the S Tethyan sequence.

T32B-7 1330h INVITED POSTER

Strain Rates and Instantaneous Relative Motions Within Central and East Asia.

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Using rigid plate constraints we investigate the characteristics of the complete strain field in Asia that accommodates plate motions. Our strain rate solutions are analogous to the response of a Newtonian thin viscous sheet in which the rate of work done by the straining medium in accommodating the velocity boundary conditions is a minimum. In these solutions the Euler pole for India relative to Eurasia is constrained (NUVEL-1a [DeMets et al, 1994]), but the Euler pole for south China is determined in the inversion while the VLBI velocity at Shanghai, China [Heki et al., 1994] is matched. A solution that both fits the velocity at Shanghai, China and yields a strain rate field consistent with the earthquake mechanisms in Asia is one where the south China block has a motion relative to Siberia described by the pole at (51°N, 131°E, 0.31°/my).

We use the spatial distribution of moment tensors of earthquakes in this century to estimate the velocity field in Asia within a Eurasian reference frame. In a least-squares inversion, strain rates on the surface of the Earth are matched with continuous spline functions to recover the velocity gradient tensor associated with the seismic moment release in Asia. Earthquakes account for 50 -60% of the expected motion of India relative to Eurasia with the missing component of strain equivalent to about 20 mm/yr of N-S shortening between Siberia and India. In this solution the south China block rotates counterclockwise and moves eastward relative to Siberia. Earthquake moment release rates in this century within Mongolia are about a factor of four larger than the long term rate. Within Gansu -Ningxia the moment rates have been about a factor of two higher than the long-term rate.

Strike-slip faulting within Mongolia, Gansu-Ningxia, western Sichuan and Yunnan is possibly a direct result of velocity boundary conditions imposed on the south China block by forces unrelated to continental collision, such as forces associated with subduction dynamics. Verification of this requires a better understanding of the role of pre-existing zones of weakness within the Asian continental lithosphere.

T32B-8 1330h POSTER

Variation of Flexural Strength of the Lithosphere and Mechanisms of Isostatic Compensation in Central Asia

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Newly-merged Bouguer gravity data over Central Asia from China and Russia (60°-96°E and 38°-48°N) fail to display the high correlation between topography and gravity as predicted for local isostatic equilibrium. The observed coherence shows that surface and subsurface loads are supported by a plate with an effective elastic thickness of approximately 30 km in the Tarim Basin, 20 km in the Junggar Basin, 30 km in the Turfan Basin, 35 km in the Kasakstan shield, and 25 km in the Tienshan. There seems to be a bias toward low flexural rigidities due to no surface loading in the basins relative to the tectonically active Tienshan. When we increase f (as is reasonable for basins with no surface topography but large Bouguer anomalies), the best-fitting Te is higher. The model indicates that loads with wavelength greater than 1100 km are locally compensated, loads with wavelengths in the range 110-1100 km are partially supported by the strength of the lithosphere, and loads with wavelength less than 110 km are almost completely supported by lithospheric strength. We examine the phase angle between Bouguer gravity and topography to distinguish those features resulting from vertical loads (Bouguer lows corresponding to topographic highs) versus horizontal loads (Bouguer highs corresponding to topographic highs in a "folding" mode). High energy for vertically-directed loads (anti-phase) appears at wavelengths of 220-270 km in the eastern Tienshan (east of 80°E) and 550 km in the western Tienshan (west of 80°E). High energy for horizontally-directed loads (in-phase) comes out at wavelengths of 180-220 km in the eastern Tienshan (east of 80°E) and 45-85 km in the western Tienshan (west of 80°E). The positive transfer function between topography and gravity in Junggar Basin implies that there is folding due to horizontal transpressional stresses in Central Asia induced by the collision with the Indian plate and a rigid Tarim block. The northwest-trending linear isostatic anomalies in Kasakstan correspond to faults plotted on geological map, indicating the Tienshan not only separate the geological features in a north-south direction, but also in an east-west direction.

T32B-9 1330h POSTER

Thermal Evolution of the Gangdese Thrust

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The 'suture zone' separating southeastern Tibet from the Indian subcontinent is generally marked by the Renbu-Zedong thrust (RZT), a south-dipping fault active between ~18-8 Ma that juxtaposes Tethyan shelf rocks directly atop the Andean-type Gangdese batholith. West of Zedong (29°10'N/92°00'E), however, the RZT splays to the south creating a ~100 km long window through which the Gangdese thrust (GT) is exposed. The GT is a south-directed thrust estimated from thermochronometry to have been active between 27-23 Ma with a total displacement of 50-80 km. West of Lhasa, the GT juxtaposes the Late Cretaceous Xigaze Group over Tethyan sedimentary rocks. There, a lower age bound for the GT of 18.3±0.5 Ma is given by crosscutting relationships. Near Zedong, 150 km ESE of Lhasa, the trace of the RZT does not obscure that of the GT, and the hanging wall of the GT is marked by a ~200-m-thick mylonitic shear zone that consists of deformed granite and metasedimentary rocks. The intervening assemblage is comprised of what we interpret to be a Tertiary conglomerate unconformably overlying a "collisional melange" comprised of radiolarian cherts, syenite, mafic volcanics and intrusives, gneisses, and discordant serpentinites emplaced along thrust imbricates of the RZT.

The interplay between erosional denudation and refrigeration of the hanging wall during thrusting produces two distinctive thermal regimes within the GT hanging wall; (1) a zone immediately above the thrust surface whose thickness is a function of the conductive time constant for the duration of thrusting, and (2) a region far above the thrust surface in which cooling is dominated by erosional denudation in response to thrust-related crustal thickening. Because thickening is diachronous, mid-crustal rocks in the south will tend to be uplifted and denuded before rocks in the north. Near the thrust surface (regime 1) we see evidence for rapid cooling beginning at 27 Ma that we interpret to result from refrigeration by the cold Teihyan sediments. This event is also observed at Samye and Quxu, 60 and 120 km further west along strike, respectively. Note that the observed pattern of cooling in the Gangdese batholith is the opposite of what would occur if the RZT had been the dominant structural control. Within regime 2, the northward younging of cooling ages is interpreted to reflect the propagation of the tip of the footwall ramp. To further constrain the timing and duration of thrusting, we have collected samples along a number of 1-1½ km vertical elevation traverses in the hanging wall directly above the GT for $^{40}Ar/^{39}Ar$ measurements.

T32B-10 1330h POSTER

Strike-slip driven growth of the Tibet Plateau and other SE Asian reliefs.

B. Meyer, P. Tapponnier, Y. Gaudemer, J. Van der Woerd (Institut de Physique du Globe, 4 Place Jussieu 75252 Paris Cedex 05, France)- 1913

Implicit in many models of continental collision is the view that crustal thickening is the earliest and most prominent process to absorb plate convergence after suturing. Strike-slip faulting, by contrast, is often seen as a consequence or side effect of thickening. Such faulting has even been interpreted to be coeval with post orogenic extension, hence to characterize the latest episodes of the evolution of mountains and plateaus. High-resolution satellite image analysis and field studies of large strike-

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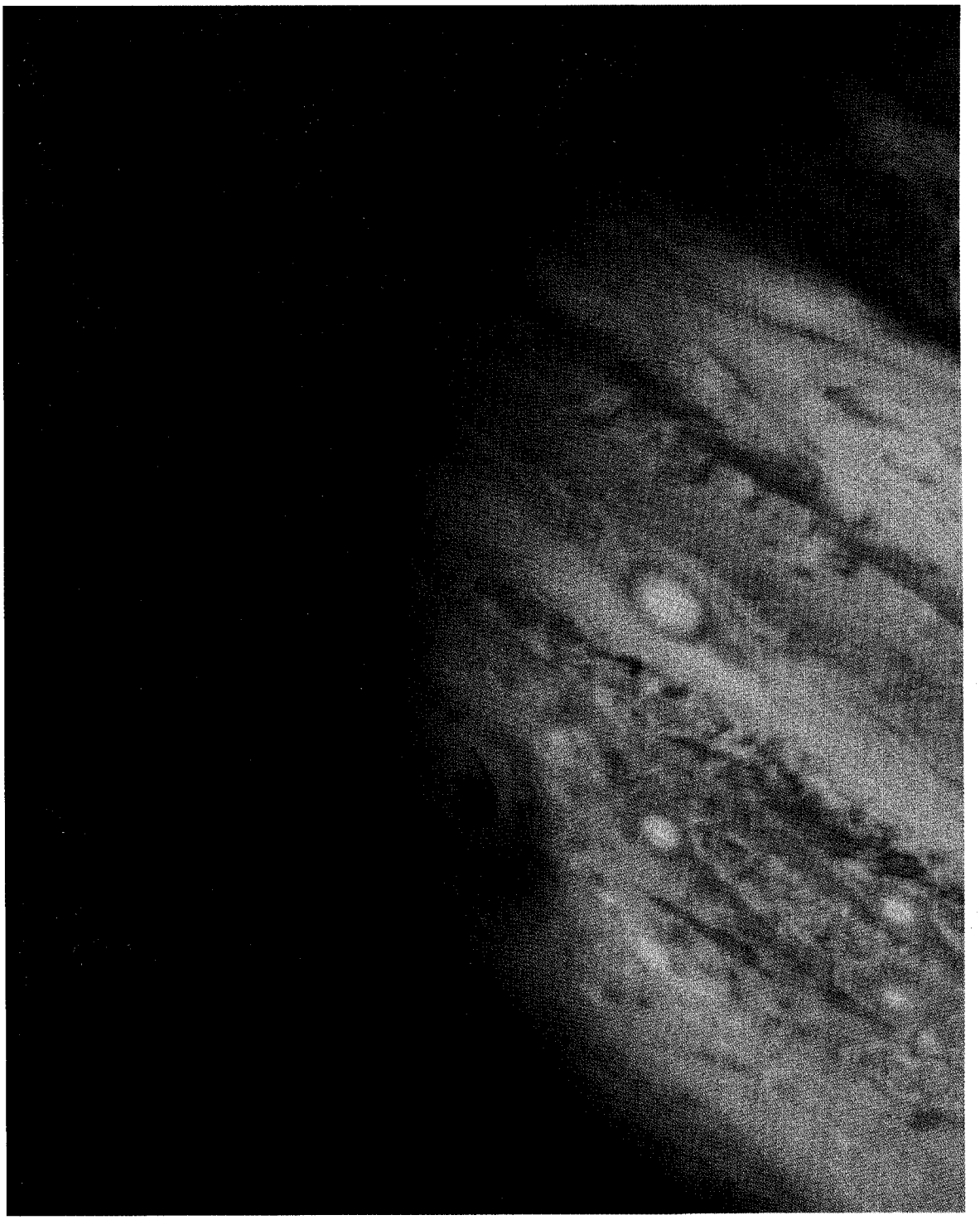

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