imentation history appears to support a plateau building mechanism resulting from the combination of two geologicallly common processes : crustal scale thrusting and sedimentary basin infilling. The time needed to completely fill the Qaidam basin and make its catchment a plateau closely resembling that of the highest part of Tibet (Qangtang) is on the order of 9 Myrs. The mechanism now at work north of the Kunlun, which involves rapid infilling of broad, flat areas separated by relatively narrow mountain ranges, has thus probably been important in producing the high, smooth topography that characterizes much of the central Tibet.

T72H-05 1430h

The Relationship Between Leucogranites and the STDS in the Rongbuk Valley, Southern Tibet

Michael Murphy[1] (1-310-794-5385; michael_a_murphy@amoco.com)
T. M. Harrison[1] (1-310-825-3880)

[1]UCLA, Department of Earth and Space Sciences, Los Angeles, CA 90095-1567, United States

The Southern Tibet Detachment System (STDS) consists of a series of gently N-dipping normal faults that can be traced along much of the length of the Himalaya. In Rongbuk Valley, immediately north of Mt. Everest, the STDS is represented by the Qomolangma detachment. Considerable attention has focused upon leucogranites exposed in the Qomolangma footwall along the eastern wall of the Rongbuk Valley because of the potential significance their emplacement ages have for the slip history of the STDS. The map relationship between the leucogranites and the upper trace of the detachment fault has been variously portrayed as 1) sills that are entirely subparallel to the STDS (Burg, 1983), 2) sills as in (1) and the discordant Rongbuk granite that does not cut the trace of the detachment (Burchfiel et al., 1992), and 3) sills as in (1) and emplacement of the Rongbuk granite across the detachment into the overlying Tethyan metasediments (Hodges et al., 1998). Previous U-Pb dating of Rongbuk area sills that were sampled in situ yielded crystallization ages between 17-14 Ma (Scharer et al., 1986; Hodges et al., 1998) whereas a detached block collected near Rongbuk village yielded a crystallization age of 22 Ma (Harrison et al., 1995). In order to select between these interpretations and better understand the timing of leucogranite intrusion, we mapped a 10 km^2 region adjacent to Rongbuk village. Here, the footwall of the Qomolangma detachment consists of a >800-m-thick zone of mylonitic schists, calc-silicates, marbles and leucogranite sills and dikes. No leucogranite bodies cut the upper trace of the detachment fault in the mapped area and no discordant granite pluton was observed. Two generations of leucogranites are recognized based on crosscutting relationships and their degree of deformation. At lower structural levels, mylonitized sills are cut by undeformed leucogranite sheets while at higher levels, the younger leucogranites become parallel to the shear zone foliation. Immediately beneath the detachment, the younger generation of sills are cut by discrete, planar, ductile shear zones. Preliminary Th-Pb ion microprobe dating of monazite extracted from both the older and younger leucogranites yield statistically indistinguishable ages between 17-16 Ma. The age results and field observations are consistent with map relationships along other segments of the STDS and indicate that the Qomolangma detachment remained active while at conditions appropriate for ductile deformation following the emplacement of the leucogranite sheets.

T72H-06 1445h

Preliminary results from INDEPTH III surface geology investigations: retrodeformed cross sections from portions of the Lhasa and Qiantang terranes.

M A Edwards[1] (00-49-931-312696; edwards@geologie.uni-wuerzburg.de)
M Staiger[1]; L Ratschbacher[1]; S Bi[2]; Z Wu[2]; Y Li[2]; E Gnos[3]; B Hacker[4]; J Li[5]; WSF Kidd[6]; P Blisnuik and Kuchel, O[7]

[1]Institut fuer Geologie Universtitaet Wuerzburg, Wuerzburg D-97070, Germany
[2]CAGS, BEIJING 1000931, China
[3]Mineralogisch-petrographisches Institut, Bern CH-3012, Switzerland
[4]Dept. Geological Sciences, UCSB, Santa Barbara, CA 93106, United States
[5]University of Syracuse, Syracuse, NY, United States
[6]Dept. Earth and Atmospheric Sci. SUNY, Albany, NY 12222, United States
[7]Geologisches Inst., Potsdam 97070, Germany

Surface geology investigations were undertaken in conjuction with the subsurface geophysical investigations of INDEPTH III traverse across the northern Lhasa and Qiangtang terranes of south central Tibet. Detailed profiles were measured in both terranes in order to unravel the amount of Tertiary shortening across the plateau and preliminary examples of magnitudes and styles of shortening are presented. A key section for the Lhasa terrane is located between 30o53'N and 31o15'N at approximately 90o15'E. The section includes limestones and red sand-, silt-, and mudstones of Cretaceous and perhaps younger age that have been shortened almost wholly through folding (both open and tight) with minor internal predominantly N-vergent thrusting. Total shortening is 60-75% along bulk NNE axis, and is unevenly distributed. The Cretaceous rocks apparently overthrust the Jurassic Bangoin (Ban-gue) Granite at the northern terminus of the section. The Cretaceous rocks are clearly overthrust by Permian rocks at the southen end of the section. The best studied section of the Qiantang terrane is located between 32o40'N and 32o55'N at approximately 89o'E. The section includes Triassic-Jurassic carbonates, a suite of massive and bedded limestones with dolomitic shale and fluviatile clastic deposits containing plant relicts. Conglomeratic redbeds with predominantly limestone pebbles unconformably overlie the Mesozoic carbonates. Shortening amounts are between 40% 60% along bulk NNE axis. Of this shortening, <20% appears to have been accommodated by open folding prior to the deposition of the conglomeratic redbeds. Folding is only tight near to thrust surfaces or thrust tips, where layers are steep or overturned. Preliminary results from palaeomagnmetic analyses of both sections will be presented.

T72H-07 1520h INVITED

Xenoliths from the North-Central Tibetan Plateau

Bradley R Hacker[1] (805 893 7952; hacker@geology.ucsb.edu)
Edwin Gnos[2]
Wendy Bohrson[1]
INDEPTH III Geologic Team[3]

[1]University of California, Santa Barbara, CA 93106, United States
[2]University of Bern, Bern CH-3012, Switzerland
[3]

During a geologic transect across the Qiangtang terrane, INDEPTH III geologists discovered xenoliths, the first reported from the Tibetan plateau, at three separate localities in the area of 34° 24'N, 89°14'E. The host rocks are moderately porphyritic felsic lava flows interlayered with basaltic lava flows. The relatively fresh trachyandesite to trachyte host rocks are characterized by high K_2O (K_2O/Na_2O=1.5-2.0) and therefore belong to the shoshonitic series. Phenocrysts include An_{30} plagioclase, $An_{05}Or_{56}Ab_{36}$ sanidine, quartz, pargasite, and abundant phlogopite, monazite and apatite; the holocrystalline groundmass is dominated by sanidine, phlogopite, ilmenite, titaniferous magnetite, and apatite.

Whereas the basalts contain only extremely rare xenoliths, the more evolved flows contain readily visible mm- to cm-size xenoliths and xenocrysts. The xenocrysts are chiefly sanidine, garnet, and quartz. The most abundant xenoliths are granulite-facies rocks with garnet + enstatite + plagioclase + phlogopite + apatite + hercynite + monazite. Less common are phlogopite websterite, phlogopite gabbronorite, garnet + plagioclase + tourmaline + quartz granulite, and augite + pargasite + plagioclase + monazite + apatite amphibolite.

Partitioning of Fe and Mg between coexisting augite and enstatite indicates xenolith equilibration temperatures of c. 1000°C, and Al partitioning between garnet and enstatite indicates pressures of 1.3-1.5 GPa, equivalent to extraction depths of c. 40-55 km. These calculated PT conditions are compatible with the presence of kyanite inclusions in garnet, which requires pressures >1.4 GPa at 1000°C. Textural evidence of the decompression reaction, garnet ($alm_{57}prp_{36}grs_{05}sps_{03}$) + opx (4.8% Al_2O_3) + Na-cpx → *opx*(7.6%Al_2O_3) + hercynite + magnetite + oligoclase, is widespread.

Volcanic rocks nearby have yielded ages of c. 1 and 8 Ma (Turner et al., 1997), suggesting that the xenolith-bearing flows were erupted since the Late Miocene. Teleseismic P waves recorded in Tibet indicate that the crust of the Qiangtang terrane is c. 65 km thick (Owens and Zandt, 1997), implying that these xenoliths are samples of the lower crust.

T72H-08 1535h

Metamorphism and Exhumation of Mesozoic Melange in North-Central Tibet

C. E. Manning[1] (1-310-825-3880; manning@ess.ucla.edu)
P. Kapp[1]; A. Yin[1]; M. Murphy[1]; T. M. Harrison[1]; M. Spurlin[2]; Din Ling[3]; Deng Xi-Guang[3]

[1]UCLA, Department of Earth and Space Sciences, Los Angeles, CA 90095-1567, United States
[2]University of Arizona, Department of Geoscience, Tucson, AZ 85721, United States
[3]Institute of Geology, Chinese Academy of Sciences, Beijing, China

Blueschist facies metabasites and ultramafic rocks have long been recognized in the Qiantang region of north-central Tibet; however, their origin and metamorphic evolution remain poorly understood. Our recent studies in the eastern (Shuang Hu) and western (Gangma Co) regions of a 400-km-long metamorphic belt in Qiangtang reveal the presence of tectonic windows containing ultramafic rocks as well as blueschist, greenschist, epidote amphibolite, and amphibolite facies mafic lithologies. The metamorphic rocks occur in tectonic mélange with quartzofeldspathic to pelitic matrix containing musc+alb+qz ± gnt, bio, chl, epd, graph, and hem. Mafic and ultramafic blocks of all metamorphic grades may occur as meter- to km-scale blocks within the mélange matrix. Completely altered ultramafic lithologies are characterized by antig+talc+graph. Blueschist facies metabasites contain blue amph (glauc to mg-rieb), epd, alb, sph, oxide, ± Na-cpx and white mica. In both localities, blueschist-facies assemblages may be strongly overprinted by greenschist facies minerals; unretrograded blueschists were found only at Gangma Co. Associated calcic amphiboles show little increase in Al# with increasing Na#. This distribution of compositions is characteristic of amphiboles from high-P/T terranes which formed in paleosubduction zones, and implies that metamorphism of the metabasites occurred under similar metamorphic conditions. Higher grade epidote amphibolites (hbd+epd+plag+qz+sph) and amphibolite gneisses (hbd+plag+qtz+ru±gnt) are also found at both localities. Their presence in the mélange implies steep thermal gradients within the subduction complex.

Existing geologic evidence suggests that the mélange was underplated beneath the Qiangtang margin during the Early Mesozoic and subsequently exhumed by Early Jurassic detachment faults, which juxtapose the metamorphic rocks against greenschist-facies Paleozoic-Mesozoic strata. This style of exhumation may be similar to that which exposed the Rand/Pelona/Orocopia schists of southern California. Further exhumation occurred by S-directed Tertiary thrusting and Late-Cenozoic high-angle normal faulting. Central Qiangtang metamorphism predates Indo-Asian collision and is a result of subduction and subsequent exhumation of tectonic mélange, probably including crust and mantle of Paleo-Tethyan affinity.

T72H-09 1550h

Initial Results of INDEPTH-III Magnetotelluric Survey

Martyn J Unsworth[1] (206- 543-4980; unsworth@geophys.washington.edu)
Shengui Li[1]; Paul Bedrosian[1]; John Booker[1]; Alan G Jones[2,3] (613-992-4968; jones@cg.nrcan.gc.ca); Juanjo Ledo[2]; Brian Roberts[2]; Kurt Solon[3]

[1]Geophysics Program, Box 351650, University of Washington, Seattle, WA 98195, United States
[2]Geological Survey of Canada 615 Booth St., Room 218, Ottawa, ON K1A 0E9, Canada
[3]Department of Earth Sciences Syracuse University, Syracuse, NY, United States

In July and August 1998 Long Period magnetotelluric (MT) data were collected as part of the INDEPTH-III survey in Central Tibet. Long period MT data were collected at 26 sites on a 400 km profile extending from Nam Tso to Longwei Tso with the goal of imaging crustal and mantle structure. Broadband MT data were also collected to image shallow structure by the China University of Geosciences.

In this paper we will present initial results based on the long period data, since the broadband and long period data have yet to be merged. Preliminary inversions of the long period MT data show the following features.

(1) In the south of the profile a strong conductor is observed at a depth of 15 km. This is at a similar depth to the conductor observed beneath the Yangbaijin graben during INDEPTH-II in 1995. This conductor terminates 50 km north of the Bangong suture.

(2) Further north, where the shallow conductor is absent, a deeper conductor is imaged at a depth of 50-60 km. This conductor continues to the northern end of the profile and is at the same depth as the low velocity zone imaged by seismic observations. It may represent the asthenosphere beneath a 50-60 km crust.

T72H-10 1605h

Structure of the Altyn Tagh and Chang Ma Fault Zones in Gansu Province, China from Magnetotelluric Measurements.

Paul A Bedrosian[1] ((206)-543-9661; bedros@geophys.washington)
Martyn J Unsworth[1] ((206)-543-4980; unsworth@geophys.washington.edu)
Fei Wang[2] (86-10-64213413; wf1026@163.net)

[1]Geophysics Program, AK-50, University of Washington, Seattle, WA 98195, United States
[2]Beijing Research Institute of Uranium Geology (BRIUG) , Beijing 100029, China

The Altyn Tagh fault is a major left-lateral, strike-slip fault associated with the eastern movement of the Tibetan plateau relative to the Tarim basin to the north. East of 98 degrees E, the trace of the eastern segment terminates and deformation is characterized by thrusting in the Qi Lian Shan. The crustal structure of this area has been investigated using commercial magnetotelluric data collected in 1995-6. Broadband magnetotelluric data (100 Hz - 200 s) was collected on 13 lines with a site spacing of 3 km. Several fault-crossing profiles have been analyzed and the resulting electrical conductivity sections show the following dominant features.

T72G-11 1620h

Correlation between fracture permeability and in situ stress to 7 km depth in the KTB scientific drillhole

Takatoshi Ito[1] (+81-22-217-5234; ito@ifs.tohoku.ac.jp)
Mark D Zoback[2] (+1-650-725-9295; zoback@pangea.stanford.edu)

[1]Institute of Fluid Science Tohoku University, Sendai 980-8577, Japan
[2]Department of Geophysics Stanford University, Stanford, CA 94305, United States

To better understand the mechanisms that control hydraulic conductivity at depth in the brittle crust, we have examined the relationship between fracture permeability and in situ stress in the German continental deep drillhole (KTB). The KTB main hole reached a final depth of 9.1 km at the end of 1994. Among the data collected were a number of high resolution temperature profiles, the strike and dip of fractures and faults (as detected by FMS/FMI and BHTV measurements) and the state of in situ stress (Brudy et al., 1997). In the present analysis, we analyze data collected from 3 - 7 km where data quality was uniformly high. We identified thermal anomalies as regions where the amplitude of ΔT exceeded 0.5°C (ΔT is the difference between the measured temperature and the average temperature within a moving window taken over 100 m of depth). The thermal anomalies are associated with fluid flow in and out of the wellbore along relatively permeable fractures (Hess, 1986; Cornet, 1989). We defined fractures and faults within +/- 5m of the thermal anomalies as permeable fractures. The effective normal stress and shear stress acting upon these permeable fractures were computed and plotted in 3D Mohr diagrams. The results show that the fractures associated with the thermal anomalies lie close to the Coulomb failure line for a coefficient of friction $\mu = 0.6$ over the entire depth range (i.e., 3 - 7 km). Conversely, non-critically stressed fractures and faults do not appear to be permeable as they are not associated with identifiable thermal anomalies. These results demonstrate that bulk permeability of the mid crust appears to be controlled by critically - stressed (or optimally - oriented) fractures and faults as previously reported by Barton et al. (1995). Finally, a major Mesozoic age thrust fault penetrated by the KTB main hole at about 7 km also appears to be quite permeable. It is noteworthy that this fault is being reactivated as a strike - slip fault in the current stress field.

T72G-12 1635h

In-Situ Stress and Fracture Permeability Along the Stillwater Fault Zone, Dixie Valley, Nevada

S H Hickman[1] (650-329-4807; hickman@usgs.gov)
C A Barton[2]
M D Zoback[2]
R Morin[3]
R Benoit[4]

[1]U.S. Geological Survey 345 Middlefield Rd., Menlo Park, CA 94025
[2]Dept. of Geophysics Stanford University, Stanford, CA 94305
[3]U.S. Geological Survey Box 25046 Denver Federal Center, Denver, CA 80225
[4]Oxbow Geothermal Corp. 9790 Gateway Dr., Reno, NV 89511

To determine tectonic controls on the permeability of a fracture-dominated geothermal reservoir at Dixie Valley, NV, we conducted an integrated study of stress and fracture permeability in wells penetrating the Stillwater fault zone at depths of 2-3 km. This fault is a major, active, range-bounding normal fault in the western Basin and Range province and comprises the main reservoir for a 62 MW geothermal electric power plant. In particular, by studying wells within the primary zone of geothermal production (transmissivitiy T~1 m^2/min and wells adjacent to the reservoir that were not commercially viable (T~ $10^{-4} m^2$/min), we were able to compare the effects of in situ stress on reservoir permeability along highly permeable and relatively impermeable segments of the fault.

Observations of drilling-induced cracks in borehole televiewer (BHTV) logs from four wells intersecting the permeable main reservoir indicate that the local orientation of the least horizontal principal stress, S_{hmin}, is nearly optimal for normal faulting on the Stillwater fault. These logs also revealed pervasive macroscopic natural fractures with a wide range of orientations. Temperature/pressure/spinner (TPS) logs conducted during fluid injection and withdrawal were used to determine the permeabilities of these fractures. The orientations of the most permeable fractures are distinct from the overall fracture population and are subparallel to the Stillwater fault. Hydraulic fracturing tests in these wells indicate that the magnitude of S_{hmin} is low enough to lead to frictional (Coulomb) failure on the Stillwater and subparallel faults, using laboratory-derived coefficients of friction of 0.6-1.0. Crack sealing would be expected along this segment of the Stillwater fault zone, given thermal and geochemical evidence for up-dip transport of silica-saturated fluids. However, the observation that highly permeable fractures are favorably aligned and critically stressed for normal faulting suggests that porosity increases due to intermittent fault slip are sufficient to counteract the expected permeability reduction.

Similar measurements were conducted in two wells penetrating a relatively impermeable segment of the Stillwater fault zone, 8 and 20 km southwest of the geothermal reservoir (wells 66-21 and 45-14, respectively). BHTV logs from these wells revealed extensive natural fracturing, with the dominant fracture set in each well being roughly parallel to the Stillwater fault. Analyses of TPS logs indicate that hydraulically conductive fractures in these wells have much lower permeabilities and are fewer in number than observed in the producing wells. Hydraulic fracturing tests and observations of stress-induced borehole breakouts show that the orientation of S_{hmin} in well 66-21 is near optimal for normal faulting on the Stillwater fault, but the magnitude of the resolved shear stress is too low to result in incipient frictional failure on either the Stillwater fault or any of the natural fractures observed in this well. In contrast, although the magnitude and orientation of S_{hmin} in well 45-14 indicate that some of the fractures seen in the BHTV log are in a state of incipient frictional failure, the Stillwater fault itself is locally rotated by about 40 from the optimal orientation for normal faulting. This misorientation, coupled with an increase in the magnitude of the greatest horizontal principal stress in going from the producing to nonproducing wells, inhibits frictional failure on the Stillwater fault near well 45-14. Taken together, these data suggest that fault zone permeability is high only when individual fractures as well as the overall Stillwater fault zone are optimally oriented and critically stressed for frictional failure.

T72H MC: 121 Sunday 1330h Tectonics of the India-Eurasia Collision Zone II

Presiding: **M A Edwards**, University of Wuerzburg; **M J Unsworth**, University of Washington, Seattle

T72H-01 1330h

Reconstruction of the Deformed Zone Between India and Asia by Backward Motion of Lithospheric Blocks

Anne Replumaz[1] (33 1 44 27 24 38; replumaz@ipgp.jussieu.fr)
Paul Tapponnier[1]
Steven Bergman[2]
Robin Lacassin[1]
Philippe Herv Leloup[1]

[1]Institut de Physique du Globe de Paris, 4 Place Jussieu, Paris 75252, France
[2]ARCO, 2300 West Plano Parkway, Plano, Tex 75214, United States

The growing set of data on fault rates and finite offsets permits to envisage a step-by-step backward restoration of the intracontinental deformation between India and Asia. We here assume that the major part of the deformation is localized along a few majors faults separating less deformed lithospheric blocks. The motion of such blocks can thus be modelled by moving microplates on the sphere. To account for crustal thickening or extension at the limits of the blocks, we allow changes in the surface of these blocks. Finally, minor deformation of the blocks interiors (bending, local rotation...) permit to minimize gaps or overlaps due to motion along faults. Tectonic and geophysic data used to constrain these reconstructions are: present-day rates and finite offsets along fault (strike-slip, thrusts); amount of crustal thickening or, eventually, extension; paleomagnetic rotations; kinematics of large tectonic plates. We use Euler poles and rotation parameters determined for India (Demets et al, 1994; Patriat and Achache, 1984), Tarim (Avouac et al, 1993), Tibet and China (Peltzer and Saucier, 1996), and Indochina (Briais et al, 1993). The present reconstruction is done by steps corresponding to the timing of major changes in the active fault pattern during the collision evolution. Such changes correspond to the dextral reactivation of the Red River fault at 5 Ma, the activation of the Kunlun fault at 10 Ma, the end of the sinistral motion on the Red River fault at 17 Ma, and the end and beginning of motion along the Wang Chao and 3 Pagodas faults at 30 and 40 Ma. The recent contours of the blocks are drawn along major faults of Central Asia, whose segmented traces and junctions have been simplified. As we step back in time, the size of the area of deformation reduces itself and the block contour pattern gets simpler. At each time step we propose a global solution for the position of all the blocks of the deformation zone, in agreement with the data set available for this period. We finally obtain a synthetic evolution of the collision, up to its onset. This backward reconstruction allows us to test the validity of the assumption of quasi-rigid lithosperic blocks and permit to make kinematic and mass balances. This model confirms the importance of the extrusion mechanism that plays a role comparable to crustal thickening to absorb the plate convergence.

T72H-02 1345h

CENOZOIC SEDIMENT MASS BUDGET IN ASIA: IMPLICATIONS FOR THE INDIA ASIA COLLISION

FRANCOIS METIVIER[1] (33-1-44-27-28-21; metivier@ipgp.jussieu.fr)
YVES GAUDEMER[1]
PAUL TAPPONNIER[1]

[1]Laboratoire de Tectonique, Institut de Physique du Globe, 4 PLace Jussieu, PARIS 75252, France

We report estimates of mass accumulation rates in 18, mostly offshore, sedimentary basins of Asia since the beginning of the Cenozoic, ≈ 66 Ma. The estimates were derived from isopach maps, cross sections and drill holes or stratigraphic columns assuming regional similarity of the stratas. Average solid phase volumes and accumulation rates were calculated for nine epochs approximately corresponding to geological periods : Paleocene (≈ 66-58 Ma), Eocene (≈ 58-37 Ma), Oligocene (≈37-30 and 30-24 Ma), Miocene (≈ 24-17, 17-11 and 11-5 Ma), Pliocene (≈ 5-2 Ma) and Quaternary (≈ 2-0 Ma). These rates shed new light on the geologic history of Asia since the onset of the collision of India with Asia (≈ 50 Ma). The overall average accumulation rates curve for Asian sedimentary basins since the beginning of the Tertiary shows an exponential form with slow accumulation rates (less than 0.5 10^6 km^3/Ma) until the beginning of the Oligocene, more than 15 Myrs after the onset of the collision. From the Oligocene on rates increase quickly in an exponential manner, reaching their maximum values in the Quaternary (more than 1.5 10^6 km^3/myr). From these observations we suggest that extrusion and crustal shortening are complementary processes that have been successively dominant throughout the India-Eurasia collision history. At smaller scales one may distinguish between independant histories at the subcontinental and basin-scale. This permit comparison of the relative importance of tectonic and climatic erosion processes affecting the different mountain belts of Asia during the Cenozoic.

T72H-03 1400h

C and O Isotopic Evidence From Thakkhola Graben Paleosols and Fossils, Nepal: Implications for Tibetan Plateau Uplift History

Carmala N. Garzione[1] (520-621-6024; garzione@geo.arizona.edu)
Jay Quade[1] (520-792-0454; jquade@geo.arizona.edu)
David L. Dettman[1] (520-299-5220; dettman@geo.arizona.edu)
Peter G. DeCelles[1] (520-621-4910; decelles@geo.arizona.edu)

[1]Department of Geosciences, University of Arizona , Tucons, AZ 85721, United States

North-south oriented extensional grabens, such as the Thakkhola graben, located throughout the southern half of the Tibetan Plateau, are considered to have formed during gravitational collapse of the plateau following uplift. C and O isotopic results from the Thakkhola basin (which includes older Tetang Fm and younger Thakkhola Fm) provide constraints on the age of the basin fill and uplift history of the southern Tibetan plateau. The $\delta^{13}C$ values of soil carbonate from the Thakkhola Fm fall between -5.6 and +3.5 per mil (PDB), consistent with C_4-dominated vegetation. Thakkhola Fm therefore must be younger than the ~8 Ma global expansion of C_4 plants. The most negative $\delta^{13}C$ values (-5.6 and -4.1 per mil) occur lowest in the section, reflecting a larger proportion of C_3 vegetation. Higher in the section, $\delta^{13}C$ values fall between -3 and +3.5 per mil, indicating an increase in the percent of C_4 grasses, consistent with the presence of modern C_4 grasses in the basin. This shift to mostly C_4 vegetation may coincide with the shift recorded in the Neogene Siwalik Group in the Himalayan foreland basin between ~7.4 and 6 Ma. Fossil clams and gastropods of the Tetang and Thakkhola Fms and soil carbonate of the Thakkhola Fm record a shift to more negative $\delta^{18}O$ values between Tetang and Thakkhola deposition. Tetang $\delta^{18}O$ (PDB) values fall in a range of about -11 to -16 per mil, whereas Thakkhola values range between about -16 to -22 per mil. Modern Kali Ghandaki River water yields $\delta^{18}O$ = -18.2 per mil (SMOW), consistent with Thakkhola Fm carbonate values. The shift to more negative $\delta^{18}O$ values in the Thakkhola graben contrasts with a shift to more positive values from paleosol and fossil carbonates in the low elevation Siwalik Group, and may indicate an increase in local or regional elevation between Tetang and Thakkhola deposition.

T72H-04 1415h

SEDIMENTARY MASS BUDGET OF THE QAIDAM BASIN : IMPLICATIONS ON THE NORTHEASTWARD GROWTH OF TIBET

YVES GAUDEMER[1] (33-1-44-27-28-21; gaudemer@ipgp.jussieu.fr)
FRANCOIS METIVIER[1] (33-1-44-27-24-36; metivier@ipgp.jussieu.fr)
PAUL TAPPONNIER[1]
BERTRAND MEYER[1]

[1]Laboratoire de Tectonique, Institut de Physique du Globe de Paris 4 Place Jussieu, PARIS 75252, France

We report volumes and masses of sediments deposited in the Qaidam and Hexi Corridor basins since ≈ 35 Myrs ago. The mass budget is based on simple geometrical assumptions such as regional similarity of the thickness ratios between strata of different ages. In the Qaidam, where our record extends back to the Oligocene, the budget shows a huge rise of the accumulation rates after the beginning of the Pliocene (5.3 Myrs). The early Pliocene seems to be the period of maximum deposition with accumulation rates in excess of 1 mma^{-1} (≈ 2.7 $kgm^{-2}a^{-1}$) of compacted rocks throughout the basin. There also seems to be a southeastwards shift of the largest depocenters between the upper Pliocene (3.4 - 1.6) and the Quaternary. In the Hexi Corridor, sedimentation is confined to small foreland flexural depressions associated with the frontal thrusts of the Qilian Shan and occurs at an average rate one order of magnitude smaller than in the Qaidam basin. The accumulation rate is maximum in the Quaternary. The sed-

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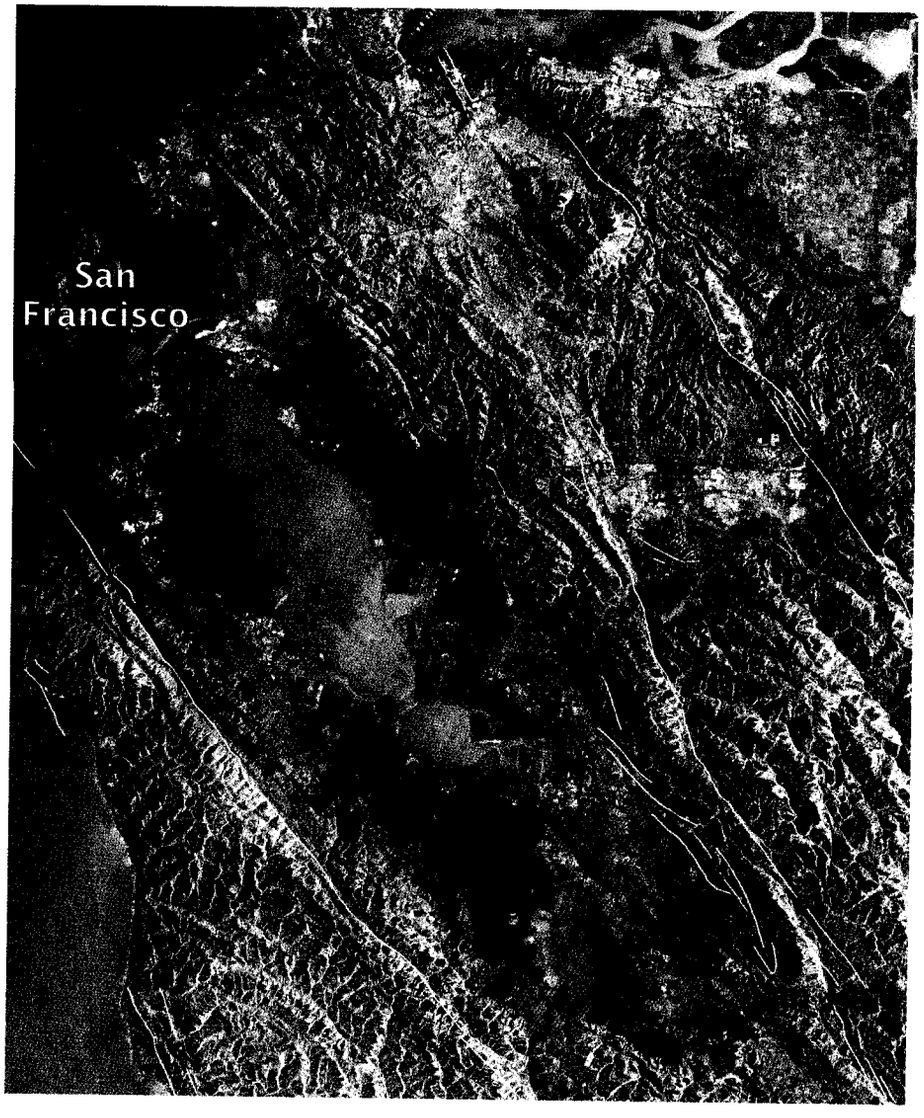

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