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Geodynamics of the Nanga Parbat Massif, Pakistan Himalaya

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Within the great syntaxial bends of the India-Asia collision, the Himalaya terminate abruptly in a pair of active metamorphic massifs. Nanga Parbat in the west and Namche Barwa in the east are antiformal domes which expose Quaternary metamorphic rocks and granites, and are loci of ferocious denudation where they are transected by major Himalayan rivers (Indus and Tsangpo). Comprehensive geophysical and geological data we have collected at Nanga Parbat support a model in which these metamorphic massifs owe their origin to erosionally induced deformation of the crust near deep gorges cut by the Indus and Tsangpo as these rivers turn sharply towards the foreland and exit their syntaxes. Primarily, the intense metamorphic and structural reworking of crustal lithosphere seen at the terminations of the Himalayan arc owes its origin to mesoscale feedbacks between erosion and tectonics.

Widely taken as the type example of a collisional mountain belt, the Himalaya have seen increasing use as a natural laboratory in which to examine a variety of collisional processes. Over the past four years, an approximately 5,000 km^2 area of the central Nanga Parbat massif of the northwestern Himalaya has been the focus of our Nanga Parbat Continental Dynamics Project, a multidisciplinary study aimed at understanding how the continental lithosphere comes to be pervasively reworked during continental collision. Nanga Parbat exposes extremely young metamorphic and igneous rocks and is an ideal place to examine the specific processes involved in crustal reworking, particularly erosion, which has come to be recognized of late as a critical control on the mechanical and petrological evolution of mountain belts. The Nanga Parbat project involved the coordinated effort of numerous investigators, working in a broad range of disciplines, including the areas of geochronology, structural geology, geomorphology, seismology, remote sensing geomorphology, dynamical modeling, geochemistry, magnetotellurics and neotectonics. Together with petrologic and geomorphic studies carried out by other groups, we now have an excellent understanding of the evolution and state of the crustal lithosphere at Nanga Parbat.

The Nanga Parbat-Haramosh Massif exposes polymetamorphic Indian-plate gneisses which have been undergoing an episode of pronounced crustal reworking; this has involved pervasive deformation, young metamorphism and melting, widespread fluid flow, rapid and pronounced exhumation, and sculpting of the crust into spectacular, steep topography. Within the core of the Nanga Parbat massif, there is a bull's-eye coincidence between the massif's most extreme topography and high-temperature granulite-grade migmatites, a young and active antiformal pop-up structure, young 1-2 Ma granitoids, abundant seismicity with sharp bottom and lateral cut-offs, pronounced hydrothermal activity, steep near-surface thermal gradients, and rapid denudation documented across a wide range of timescales. These coincident features beg a simple, shared explanation.

Erosionally concentrated strain attributable to large-magnitude incision by the Indus River focuses Indian Plate material from the south into the developing Nanga Parbat massif. Advection elevates isotherms beneath the massif, creating a relatively high-temperature/low-pressure region where sillimanite and dry melt are stable that coincides with a zone of anomalously low electrical conductivity. At approximately 12 km depth these relatively dry rocks interact with highly-exchanged meteoric or metamorphic water and generate vapor-present, cordierite-bearing granitic veins. The hot rock packet then passes toward the northwest, advecting isotherms, elevating the position of the brittle-ductile transition, and generating a vigorous hydrothermal system. The base of the predicted rheological transition coincides with a cutoff in observed microseismicity.

Work by J. Burg and colleagues and mapping by Chinese geologists suggests that the Namche Barwa massif in the eastern Himalayan syntaxis shares a very similar geological and tectonic setting with Nanga Parbat. We suggest that such hyperactive metamorphic massifs may be signature features of syntaxial regions, where large orogen-scale rivers such as the Indus and Tsangpo are diverted towards the foreland, rapidly cutting deep gorges as they make their steep exit from the hinterland.

Local, sub-orogen scale erosional exhumation at Nanga Parbat (and, we suspect, at Namche Barwa), far from being overrated, is in fact of first-order importance in controlling the metamorphic, topographic, and structural evolution of the cores of the Himalayan syntaxes. Such pervasive structural and metamorphic overprinting of old basement rocks is a fundamental geodynamic process in its own right. Ultimately, the dynamics of syntaxial metamorphic massifs may be reconciled with broader orogen-scale collision processes through the feedbacks between deformation, topographic evolution, and erosion that lead to the channeling of major river systems through the syntaxes. Our results contribute to the growing appreciation of the importance that surficial processes and crustal rheological variations have on controlling the shape, dynamics, and evolution of mountain belts, at many scales.

Research on the seismological features of the 1997 Jiashi strong earthquake swarm of western China

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Over 7,000 earthquakes including 7 with Ms=6.0 occurred in Jiashi county of Xinjiang province of China during January to November 1997. Because of few stations and little knowledge about the local crustal velocity structure around the Jiashi swarm, it is very difficult to precisely locate the earthquakes of the swarm by traditional absolute location methods. In order to obtain the spacial distribution pattern of the swarm, study the evolution procession of the swarm and infer the underground tectonic features of the earthquake focal zone, precisely relocating the swarm is necessary. In this paper, the "master event" method has been used for the relocation of the swarm.

The main principle of the "master event" method is briefly described as follow: selecting an earthquake with high-precise location as the "master event" at first, then the earthquake locations of the swarm relative to the "master event" are determined by comparing their P or S wave travel time differences between the earthquakes of the swarm and "master event" in the whole network. It is very important to select a proper earthquake with high-precise location as the "master event". Fortunately, an Ms 5.0 earthquake occurring on June 24, 1997 was recorded by the temporary mobile network consisting of 3 stations equipped with DR-200 3-component digital seismographs, which were very close to the epicenters of the swarm. We take this Ms 5.0 earthquake as the "master event". It is obvious that the "master event" location can be precisely and reliably determined by the traditional absolute location program - Block 86 . Its rms is only 0.34 second.

291 earthquakes with Ms=3.0 among the Jiashi swarm have been relocated by the "master event" method. Their average rms is only 0.29 second, much less than the previous value of 0.87 second (using the traditional absolute location program - Block 86). The horizontal location error is less than 1.2 km and the vertical location error is less than 3.0 km. After relocation, we can see a clearer and more reasonable earthquake spacial distribution pattern of the swarm. The pattern obviously shows a pair of en echelon belts striking NNW direction, implying that the NNW direction may be the main rupture direction of the Jiashi strong earthquake swarm.

According to the P-wave onset symbols and the waveform data, the focal mechanisms of 48 earthquakes with Ms=4.0 which occurred in the Jiashi-Atushi district have been inferred. The results show that the principal pressure stress direction is along NNE, which is in agreement with the regional stress field. It is remarkable that an earthquake with Ms6.9 and an earthquake with Ms6.0 occurred on March 19, 1996 and on March 19, 1998, respectively and both occurred in Atushi, only 50 - 70 km away from the Jiashi swarm; however, their focal mechanisms are quite different from the swarm's. The focal mechanisms of the two Atushi strong earthquakes occurred on the mountain-basin-boundary with strong seismicity are thrust faulting, in contrast to the focal mechanisms of the 6 strong earthquakes with Ms=6.0 of the swarm which occurred in the Tarim basin are strike-slip faulting and some of them with a little dip-slip component. We have obtained 39 medium earthquakes' (Ms 4.0 - 5.5) focal mechanisms. Among all the mechanisms we obtained, 74.6% are strike-slip faulting, 25.6% are dip-slip faulting. 78.3% normal faulting, 21.7% thrust faulting. The results show that both the compressional stress along NNE direction and the extensional stress nearly along the east-west direction play a very important role in the swarm preparation.

Tracing the evolution of the Jiashi strong swarm, we found that the earthquake frequency decay exponent, - h value (Liu exponent) - always dropped rapidly to less than 1.0 within a few days after the strong earthquakes of the swarm occurred. Such abnormally rapid attenuation

Terra Nostra, n. 2, 1999

14th
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Workshop

Abstract Volume

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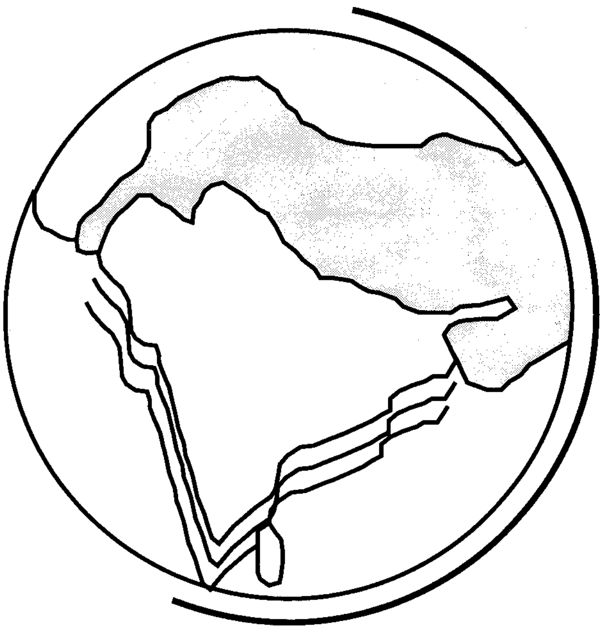
Kloster Ettal, Germany
March 24-26, 1999

TERRA NOSTRA

Schriften der Alfred-Wegener-Stiftung 99 / 2

14th
Himalaya-Karakoram-Tibet
Workshop



Kloster Ettal, Germany
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Organized by the Universities of Potsdam, Tübingen and Würzburg

Universität Potsdam (Germany)

Eberhard-Karls-Universität Tübingen (Germany)

Bayerische Julius-Maximilian-Universität Würzburg (Germany)

Impressum

Terra Nostra, 99/2: 14th Himalaya-Karakoram-Tibet Workshop, Kloster Ettal Germany

Herausgeber:
Alfred-Wegener-Striftung, Weyerstr. 34-40, 50676 Köln
Telefon: 49-(0)221-921 54190, Telefax: 49-(0)221-921 8254

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Redaktion und Layout:
Edward Sobel

Druck:
Audiovisuelles Zentrum der Universität Potsdam
Am Neuen Palais 10
14469 Potsdam

ISSN 0946-8978

Selbstverlag der Alfred-Wegener-Stiftung, Köln, (1999)
Printed in Germany