

# Nyainqentanglha shear zone: A late Miocene extensional detachment in the southern Tibetan Plateau

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## ABSTRACT

A major low-angle ductile shear zone containing S-C mylonites involves metamorphosed granitic rocks at the southeastern edge of the Nyainqentanglha mountain range, southern Tibet. Prominent triangular facet geomorphology is developed by valley erosion of the detachment surface, defined by the top of the southeast-dipping mylonitic shear zone. Kinematic criteria consistently indicate a top-to-southeast sense of shear. The ductile shearing deformation is inferred, from isotopic cooling ages, to have occurred during the interval 11–5 Ma (late Miocene). We interpret the shear zone as a regional extensional detachment; its development indicates when the extensional tectonics in this area started, which in turn may mark the time when the maximum sustainable surface elevation, and perhaps crustal thickness, was reached in southern Tibet.

## INTRODUCTION

Since the Indian and Asian continents began colliding at about 40–50 Ma, Tibet has been uplifted and its crust thickened, most likely by interior shortening strain induced by north-south compression (Dewey and Burke, 1973). However, the modern tectonic style in this plateau is marked by east-west-trending strike-slip struc-

tures that prevail in northern Tibet and by normal faults and grabens accommodating east-west extension that prevail in southern Tibet (e.g., Molnar and Tapponnier, 1978). The change in tectonic style is inferred to mark the time at which maximum sustainable crustal thickness was reached and the crust started to spread under gravitational stresses, perhaps ac-

companied by eastward tectonic escape movement (e.g., Mercier et al., 1987). In the Basin and Range province of the western United States (Coney and Harms, 1984; Wernicke et al., 1987), in the Variscan belt in central Europe (Ménard and Molnar, 1988), and in the Caledonian belt of western Norway (Norton, 1986; McClay et al., 1986), late orogenic crustal extension subsequent to crustal thickening in convergent or collision belts has also been explained by partial collapse of a thickened crust. In these areas, especially the Basin and Range province, large-scale low-angle ductile shear zones or detachments that show normal faulting shear sense are related to the early stage of extension (e.g., Davis and Lister, 1988; Malavieille et al., 1990). We present here observations from a mylonitic shear zone in southern Tibet, and propose that it is an exceptionally young and lofty example of this kind of low-angle ductile extensional shear zone; the timing of the shearing deformation puts a constraint on when the extension in southern Tibet began.

## SETTING

Series of Quaternary grabens and normal faults are present in the southern Tibetan Plateau (Armijo et al., 1986). The average trend of these structures is north-south, but there is considerable variation. The Yangbajian graben is part of the Gulu-Yadong rift system, the longest rift system in southern Tibet. The Nyainqentanglha Mountains bound the northwest side of the Yangbajian graben and are parallel to it (Fig. 1). The average elevation of the Nyainqentanglha Mountains is about 6000 m; the highest peak is 7162 m, in sharp contrast to the Yangbajian graben, the floor of which is about 4500 m in average elevation. The southern part of the graben is bounded to the east and west by two major faults of opposite dip, while the central and northern parts have a steep southeast-dipping master fault that developed on the southeast margin of the Nyainqentanglha Mountains (Armijo et al., 1986).

The Yangbajian graben cuts across Paleozoic to Cenozoic stratified rocks of the Lhasa block. These contain east-trending folds and thrusts, most of which predate 60–65 Ma, but there are also some south-verging thrusts that disrupted Paleogene (50–60 Ma) volcanic rocks (Coward et al., 1988). To the south and southeast of the Nyainqentanglha Mountains, the Gangdese magmatic belt, containing rocks with ages between

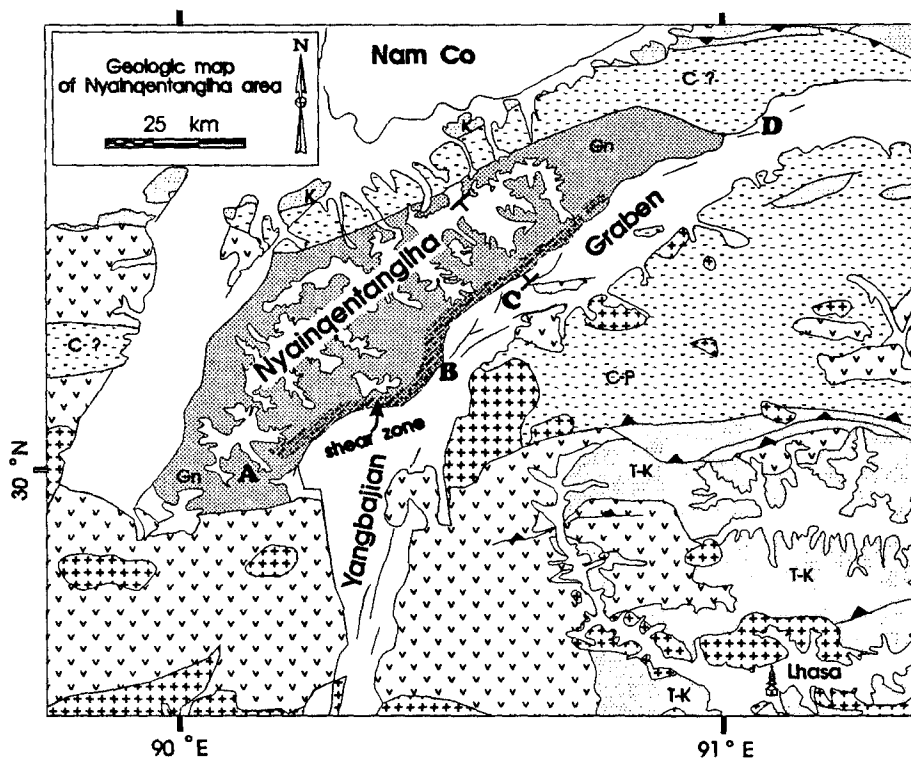


Figure 1. Geologic map (after Kidd et al., 1988) of Nyainqentanglha area, southern Tibet. Plus pattern = Gangdese batholiths, v pattern = Cenozoic volcanic rocks, Gn = orthogneiss, C? = possible Carboniferous sedimentary strata, C-P = Carboniferous-Permian sedimentary strata, T-K = Triassic-Cretaceous sedimentary strata. Lines with teeth are thrusts. Darker band on southeast boundary of area of orthogneiss represents Nyainqentanglha shear zone. Blank areas are either Quaternary sediments or ice cover in Nyainqentanglha Range. A, B, C, D are field locations visited.





>350 °C to ~100 °C between 8 and 3 Ma, and were above 300 °C prior to about 5 Ma, based on data from Copeland (1990) and Pan et al. (1991), the details of which are expected to be published in full elsewhere. Cooling histories of sheared rocks from location B and C are remarkably consistent with each other in the temperature range 350–100 °C (Fig. 6). Because the isotopic system records the latest time at a specific temperature, the deformation, which occurred at temperatures above 300 °C, must have started at  $\geq 5$  Ma. A leucocratic vein contained by a calc-silicate xenolith does not penetrate into the sheared rocks and therefore must have formed prior to mylonitization. Two analyses of sphene from this vein yield identical  $^{206}\text{Pb}/^{238}\text{U}$  ages of ~11 Ma (P. Copeland et al., unpublished). We conclude that the shear zone as a ductile structure was active to ~5 Ma, and started at or later than 11 Ma.

## DISCUSSION AND CONCLUSIONS

The Nyainqentanglha shear zone could be (1) a low-angle extensional shear zone that is analogous to the ductile detachment zones in the Basin and Range province and elsewhere in the world, or (2) a rotated low-angle ductile thrust fault. We strongly favor the first possibility, for the following reasons. The Nyainqentanglha Range is the footwall of the shear zone. Tectonic denudation of the footwall of a low-angle extensional fault provides a mechanism for the very young and rapid cooling recorded by the isotopic data. There is a remarkable parallelism between the shear zone and the graben which suggests that they are genetically related; otherwise it would be a curious coincidence, particularly because older shortening structures on the southeast side of the graben are strongly oblique to it (Fig. 1; see Kidd et al., 1988). Tectonics from the shear zone show no evidence of static recovery as would be the case if the zone was a thrust that was unroofed and cooled much later than the deformation. If the shear zone were a thrust fault, a root for the structure should be present on the northwest side of the Nyainqentanglha Range, and the thrust should come out at the surface to the southeast. There is no evidence that indicates the existence of an appropriately large, northeast-trending thrust zone in this general region.

We think that this ductile shear zone can be best explained as a major extensional detachment bounding the Nyainqentanglha Range, whose high-grade rocks represent an associated metamorphic core complex. The shallow-dipping triangular facets on the top of the shear zone prominent in the geomorphology of the southeast margin of the Nyainqentanglha Range are interpreted as the remnants of the tectonically exhumed surface of a detachment. The shearing deformation represents the earliest stage of extension in this region. If this exten-

sional structure is representative, extension began in southern Tibet in the late Miocene ( $8 \pm 3$  Ma). This occurred when the maximum sustainable surface elevation and, perhaps, crustal thickness, was achieved at this location. The timing is consistent with (1) the oldest sediment fill in the Thakkola graben, north of Annapurna, which is late Miocene (Mercier et al., 1987), and (2) the intensification of the monsoon in the late Miocene (Quade et al., 1989), indicating that the plateau was a large feature at high elevation by that time (Prell and Kutzbach, 1991), which is a precondition of graben formation.

## ACKNOWLEDGMENTS

Supported by National Science Foundation grant EAR 87-21026 to Kidd. We thank P. Copeland and T. M. Harrison for discussions; B. Zhu, Y. Zhang, and Y. Xie for making the field work possible; W. D. Means for helpful comments on quartz c-axis fabrics; and B. C. Burchfiel and P. J. Treloar for constructive reviews.

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Manuscript received December 27, 1991  
 Revised manuscript received June 5, 1992  
 Manuscript accepted June 17, 1992