Tectonics of Nanga Parbat, western Himalaya: Synkinematic plutonism within the doubly vergent shear zones of a crustal-scale pop-up structure

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ABSTRACT

Detailed mapping and geochronologic investigations from the eastern, southern, and western Nanga Parbat–Haramosh massif reveal two thrust-displacement shear zones that have a spatial and temporal link with granite plutonism from ca. 10 to 1 Ma. The shear zones define a crustal-scale antiformal pop-up structure, with dominant west-northwest–vergent and subordinate east-southeast–vergent thrusting. This is substantially different than the surrounding area where the main exposed Himalayan structures are oriented parallel to the orogenic trend and are early to middle Miocene or older. Structures mapped throughout Nanga Parbat demonstrate that its rapid and young exhumation is not due to orogen-scale structural unroofing, and that sustained high erosion rates are required. The observed west-northwest–directed shortening is proposed to be a result of differential arc-parallel motion accommodated at the syntaxial bend of the northwest Himalaya.

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INTRODUCTION

The western Himalaya syntaxis includes the Nanga Parbat–Haramosh massif (Fig. 1), a now-exposed section of largely Proterozoic Indian plate crust, initially overthrusted by Cretaceous island arc rocks along the Main Mantle thrust. Nanga Parbat is an area of extreme relief that has undergone rapid exhumation since 10 Ma (e.g., Zeitler, 1985), exposing migmatites and granulite-grade rocks at the core of the massif (Smith et al., 1992). There is a general association of southward-younging plutonism and cooling (ca. 10–1 Ma; e.g., Winslow et al., 1996; Schneider et al., 1997, 1999a) coupled with active deformation. Hitherto, the southeast, south, and southwest regions were undocumented, and only one full cross section (the Indus River gorge) had been examined (e.g., Madin et al., 1989). The short section of the Raikhot thrust fault near the Astor confluence (Fig. 1) was the only structure previously identified for accommodation of significant rapid uplift at Nanga Parbat. In order to (1) address these issues, (2) provide a geologic framework for the massif within the western syntaxis, and (3) discern the nature of tectonic activity (e.g., spatial and temporal distribution of deformation, magmatism, and cooling), we concentrated our efforts over three field seasons at Nanga Parbat south of the Indus-Astor River confluence. Our investigations form part of the larger interdisciplinary Nanga Parbat project, which also includes structural mapping in the northern portions of the massif (Pêcher and Le Fort, 1999).

ASTOR GORGE AND EASTERN NANGA PARBAT

The overall structure of Nanga Parbat has been described as a north-plunging antiform with an active western margin responsible for the uplift

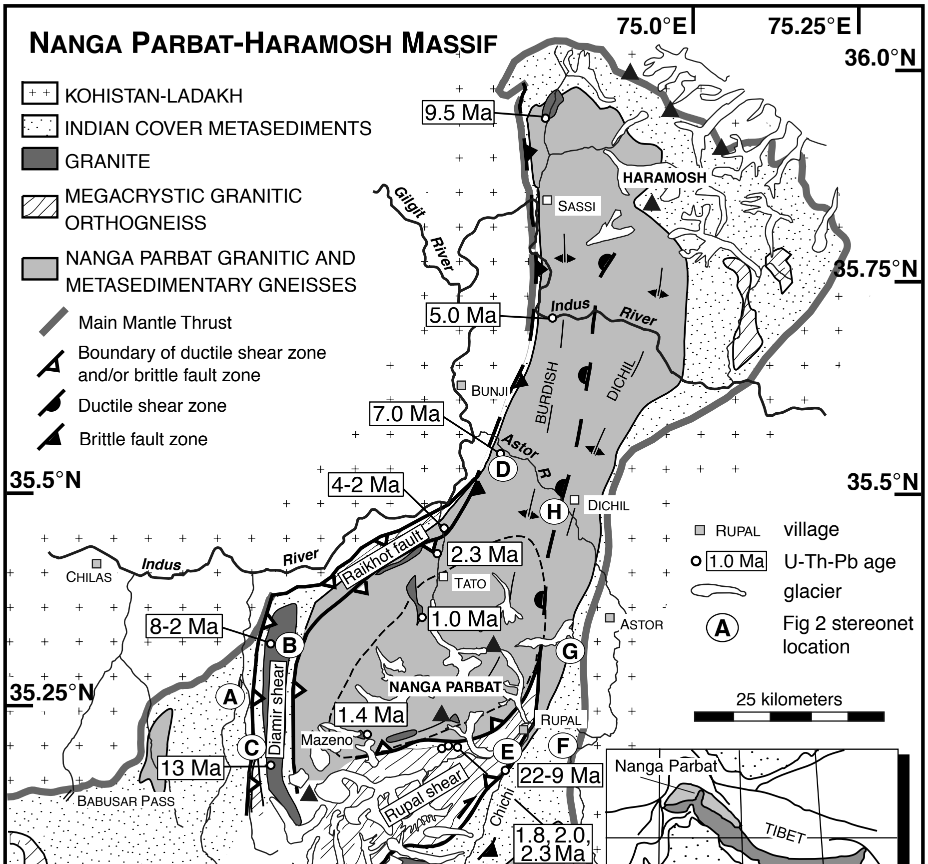

Figure 1. Geologic map of Nanga Parbat–Haramosh massif showing major lithotectonic units and tectonic boundaries (compiled by W. Kidd based on mapping by M. Edwards, W. Kidd, M. Asif Khan, and D. Schneider, and information from Butler et al., 1992, and Lemenicier et al., 1996). U-Th-Pb ages are from Zeitler and Chamberlain (1991), Zeitler et al. (1993), and Schneider et al. (1998, 1999a, 1999b). Dashed line encircling summit region is cordierite-sillimanite isograd. Patterns for inset differ from main map.

of the massif (Main Mantle thrust faulted away by the Raikhot fault system; e.g., Madin et al., 1989). Although the northern part of this fault trace coincides with a morphological right step of ~15 km in the otherwise west-east Indus River gorge (Fig. 1), we did not observe structural evidence there, or elsewhere, for significant massif-related strike-slip movement on the western margin. Along the Astor River gorge, the massif is dominated by two antiforms with approximately north-northeast–trending axial traces (Fig. 1), structurally similar to the Indus gorge to the north (e.g., Treloar et al., 1991; Butler et al., 1992). Foliation in migmatitic orthogneiss defines the tight western (Burdish) antiform, which continues to the south following the summit ridge of Nanga Parbat. Gneisses and schists form the eastern (Dichil) antiform and these are steadily north-south trending, vertical to steeply dipping, and have lineations that typically plunge gently north (H in Fig. 2). The sequence of gneisses and schists that forms the outer limb of the eastern antiform have been divided into several units, including the Kohistan-Ladakh arc rocks at the contact (Edwards, 1998), and are mappable from the Indus gorge southward. Unlike the western margin (e.g., Madin et al., 1989), the eastern contact (the Main Mantle thrust) is not significantly modified by brittle, margin-parallel faults. From Dichil to south of Rupal (and in the Indus gorge section), all significant ductile kinematic features near the contact are attributable to the Main Mantle thrust (shown by the shallowly plunging stretching lineation; F and G in Fig. 2). The eastern contact sequence dips 40°–80°E north of Astor village, and to the south it is overturned and dips 40°–80°W (F and G in Fig. 2).

RUPAL SHEAR ZONE AND SOUTHEASTERN NANGA PARBAT

Along the Astor gorge section, both main antiforms are asymmetric and are separated by a tight synform dominated by highly strained pelitic gneisses and schists (the Dashkin synform). Overturning of both antiforms, and asymmetry of parasitic folds on a range of scales, indicates west-over-east displacement localized in the Dashkin synform, although lineation has not been transposed. The prominent displacement horizon of the synform can be followed southward to where the width of the zone increases and the strain fabric markedly intensifies in a broad shear zone that is widespread in the Rupal-Chichi area (the Rupal shear) in the southern portions of the massif (Fig. 1). The Rupal shear is a several-kilometer-wide belt of northwest-dipping noncoaxially sheared granitic orthogneiss with a southwest-plunging stretching lineation (E in Fig. 2). Well-developed augen asymmetry and S-C relationships demonstrate pervasive northwest side up, with dextral shear, consistent with the southeast part of the massif moving up and northeast relative to the eastern margin. Thermochronologic results (multigrain, laser total-fusion $^{40}Ar/^{39}Ar$ biotite cooling ages) from the southeast area of Nanga Parbat, in the footwall of the Rupal shear, indicate a suite of ages older than 10 Ma, markedly different than the younger hanging-wall and shear-zone cooling ages (ca. 4 Ma or younger) to the north and west (Fig. 3; Schneider et al., 1997, 1999b).

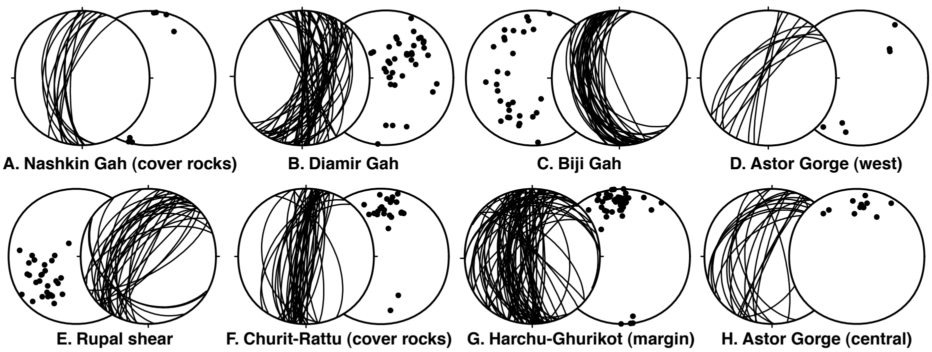

Figure 2. Lower hemisphere equal-angle projections of gneissic foliation and ductile stretching lineation from Nanga Parbat. Letters correspond to locations in Figure 1.

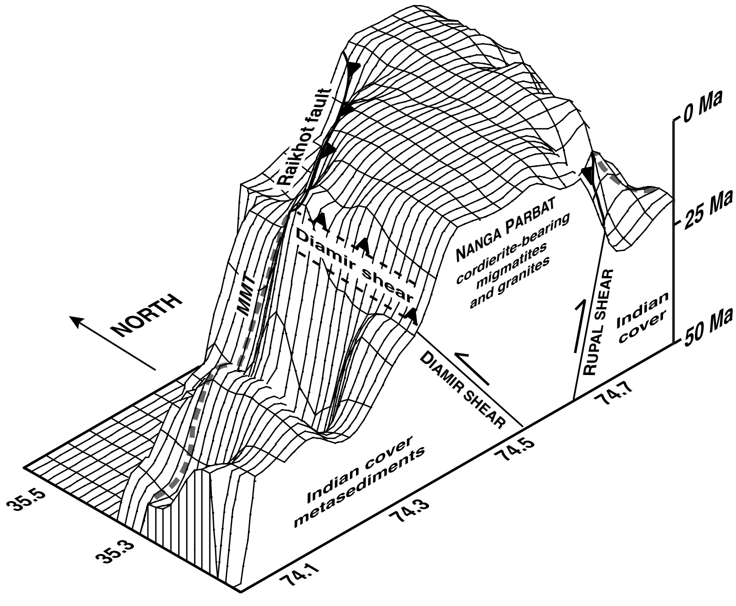

Figure 3. Three-dimensional perspective of ~200 contoured Ar-Ar biotite cooling ages from southern Nanga Parbat (Winslow et al., 1996; Schneider et al., 1997, 1999a, 1999c). Map extent is from Babusar Pass in west to Astor River gorge in east and Indus-Astor River confluence in north to southern Chichi valley in south. Dashed line is location of Main Mantle thrust (MMT).

Locally intruding the periphery of the Rupal shear are several leucogranite bodies (a few to several hundred meters wide) as well as meter-scale dikes. One of the larger bodies, the Mazeno Pass pluton, is a notably undeformed, tourmaline-absent, fine-grained, muscovite granite that crosscuts foliation of local biotite gneiss; U-Pb zircon and Th-Pb monazite analyses (via the University of California, Los Angeles, Cameca ims1270 ion microprobe) yield a 1.4 Ma crystallization age for the granite (Schneider et al., 1999a). In the central portion of Rupal valley, predominantly muscovite-rich, tourmaline-bearing undeformed pegmatite dikes are abundant and typically trend west-east and dip north, subparallel to local gneissic fabric of the shear zone. Three Rupal dikes at the southern base of the summit region give accessory-mineral ages (zircon and monazite) between 1.2 and 2.3 Ma (Schneider et al., 1997, 1999c). The ages of the dikes, as well as the Mazeno pluton, are similar to the melt stringers (1–2 Ma) and the Tato pluton (ca. 1 Ma) on the northern side of the summit region (Zeitler et al., 1993), and all are located within the cordierite-sillimanite isograd that encompasses the summit region (Poage et al., 1998). Such leucogranites within the massif have been suggested to be the result of fluid-absent, muscovite breakdown (Butler et al., 1997) and/or decompression melting (Zeitler and Chamberlain, 1991), allowing intrusion at shallow depths.

The southern portion and margin of the Rupal shear is well exposed in Chichi nullah, subparallel to the valley and marked by a contact between the noncoaxially sheared granitic orthogneiss (continuous north to central Rupal) and extensive metapelites, amphibolites, and marbles of the local Indian plate cover sequences. The foliations of the cover rocks and the gneisses are largely parallel, and orientation changes from northwest dipping (overturned) in northern Chichi, through vertical, to southeast dipping in southern Chichi. Adjacent to the Rupal shear, intruded into the cover rocks, is the Southern Chichi granite (Fig. 1), an early Miocene, largely undeformed, fine-grained leucogranite (Schneider et al., 1999b). Close to its margin, the granite shows minor subsolidus deformation; however, we found no part of the granite that can be termed a gneiss.

In order to place timing constraints on displacement along the Rupal shear, we analyzed a small (tens of centimeters), little-deformed granite dike that discordantly cuts orthogneiss of the shear zone in northern Chichi nullah (Fig. 1). The Th-Pb analyses on monazites from this granite dike yield a scatter of ages between 9 and 22 Ma (Schneider et al., 1999b), markedly older than the 1–2 Ma granite crystallization and bedrock cooling ages along the northern section of the Rupal shear. Biotite $^{40}Ar/^{39}Ar$ cooling ages from the local Chichi orthogneiss are 9–10 Ma (Fig. 3; Schneider et al., 1999b), concordant to the younger Th-Pb monazite age of the crosscutting dike. We infer that most of the displacement along this outer portion of the Rupal shear occurred prior to 9 Ma.

SOUTHWESTERN NANGA PARBAT

On the southwestern side of Nanga Parbat, the Indian cover sequence passes eastward into a dominantly plutonic, ~5-km-thick crystalline sequence that forms a continuous, ~30-km-long, north-south belt with vertical to steeply east or west dipping fabrics and mostly moderate to steeply plunging stretching lineations (B and C in Fig. 2). This contrasts with the Main Mantle thrust–related Himalayan fabrics preserved elsewhere that have gently plunging stretching lineations (A, D, F, G, and H in Fig. 2). The granite belt consists of a coarse- to medium-grained biotite granite (the Jalhari granite) that grades into granitic and porphyroclastic gneiss due to east-over-west shearing that occurred during and/or after plutonism. Jalhari leucogranite lenses (tens to hundreds of meters thick), showing little to no subsolidus deformation, are separated by layers of gneiss, tens to hundreds of meters thick, where deformation of the granite has been localized. These higher strain layers anastamose around the granite lenses, and mark reverse faults that climb to the west. The granitic gneiss shows significant subsolidus strain, including S-C relationships and a porphyroclastic fabric having a sense of shear that consistently indicates east side up (Nanga Parbat). We term this the Diamir shear zone (Edwards et al., 1997). Thermochronologic data (Fig. 3; Winslow et al., 1996; Schneider et al., 1997, 1999c) from within and surrounding the Diamir shear zone indicate major displacement: biotite cooling ages west of the shear zone to Babusar Pass are >20 Ma and probably represent Himalayan cooling, whereas hanging-wall rocks are ≤5 Ma and young toward the summit. The Diamir shear zone forms the mechanical continuation of the main Raikhot fault, i.e., a northwest-vergent reverse fault with Nanga Parbat in the hanging wall (Fig. 1).

Monazite Th-Pb ages from a sample of undeformed Jalhari granite suggest that the granite intruded as early as 13 Ma (Fig. 1; Schneider et al., 1998). A deformed, biotite-rich portion of the Jalhari granite near Diamroi yields monazite ages between ca. 2 and 8 Ma, suggesting that the granite was hot and mobile after initial intrusion. For the Jalhari granite–Diamir shear zone we suggest that initial intrusion of the granite occurred ca. 13 Ma, synchronous with ductile deformation. Continued high-temperature deformation, coupled with fluid flow, produced the currently juxtaposed deformed and undeformed granite portions, and the dissolution and reprecipitation of the Jalhari monazites (cf. Teufel and Heinrich, 1997), thus the resultant spread of Th-Pb ages in the gneissic layers. We suggest that final crystallization of some granite may have been as young as 3–4 Ma, consistent with biotite cooling ages of <5 Ma in the hanging wall of the Diamir shear.

DISCUSSION

Typically, the first-order observations at Nanga Parbat (e.g., rapid exhumation, migmatites adjacent to lower grade cover rocks) would suggest tectonic denudation where the active structures are normal-motion, crustal-scale detachment faults underlain by large quantities of partial melt at depth. This has prompted speculation that Nanga Parbat may be a Himalayan core complex (Hubbard et al., 1995). However, the results of this study indicate the contrary; our mapping shows that there is no evidence for any significant structure that would allow substantial tectonic denudation of the massif, and therefore erosion must be the dominant contributor to the large-magnitude, rapid exhumation demanded by the young high-grade metamorphism (Smith et al., 1994) and cooling (e.g., Zeitler, 1985). Our investigations in the previously undescribed areas throughout southern Nanga Parbat have identified two new major shear zones: the north- and west-dipping Rupal shear, and the southeast- to east-dipping Diamir shear zone (that joins the formerly recognized Raikhot fault). We note that the two shear zones represent a conjugate pair of reverse faults that defines a crustal-scale pop-up structure (Fig. 4; Edwards et al., 1996). The main folding of central Nanga Parbat (including the Burdish antiform) clearly accommodates some shortening and exhumation of the massif; however, the antiformal folding has given way to major shear-zone development. The pop-up structure thus provides a straightforward mechanism to accommodate the major upward displacement of Nanga Parbat along with very rapid cooling, young plutonism, and deeply exposed basement. Such a structure is consistent with doubly-vergent orogen models (Koons, 1990), where one of the faults is dominant and effectively fixed in position (in this case, the Raikhot-Diamir shear) and the other is secondary, migrating outward or switching structural positions. Crystallization ages on crosscutting dikes provide constraints on the inward migration of displacement on the Rupal shear, ca. 9 Ma in the outer portion (in Chichi nullah) and ca. 2 Ma in the inner portion. We note the partitioning of a noticeable dextral strike-slip component of movement onto the Rupal shear (E in Fig. 2), unlike the dominantly dip-slip movement on the Diamir-Raikhot shear zone (B in Fig. 2).

Our new results indicate a clear association between granites and the major Nanga Parbat shear zones. Few of the numerous granites seen within the massif are of large areal extent; we infer that there has not been a widespread melting event (cf. High Himalaya leucogranites), but rather numerous anatectic pulses since 10–13 Ma. Geophysical studies show that there is no resolvable partial melt zone directly beneath the massif at present (Park and Mackie, 1997; Meltzer et al.,

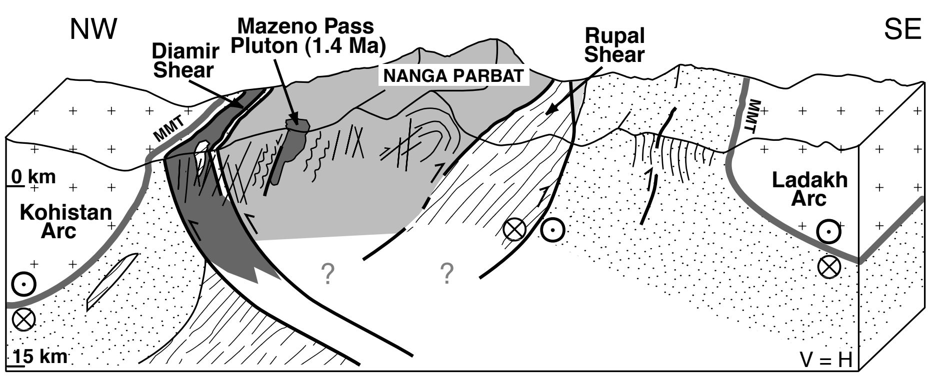

Figure 4. Northwest-southeast cross section through Nanga Parbat; section line extends along Diamir gah, through summit and south of lower Rupal valley. Lithologic patterns are in Figure 1. MMT is Main Mantle thrust.

1998), consistent with anatexis that is restricted to small volumes and/or distinct episodes. The observed location of the larger granites within the shear zones suggests to us that these anatectic episodes and shear-zone genesis are coeval in space and time. We suggest that muscovite breakdown and/or decompression melting promoted small amounts of melting and, coupled with deformation-enhanced melt extraction (e.g., Thompson and Connolly, 1995), allowed melt migration to shear zones. These shear zones then acted as sites of thermally weakened material that focused further deformation (e.g., Brown, 1994), resulting in hanging-wall uplift and subsequent cooling. This would explain the structural coincidence of the larger granites and shear zones and the chronologic coincidence of granite crystallization and bedrock cooling.

The majority of structures around Nanga Parbat indicate a northwest-southeast to west-east principal direction of shortening, a possibly counterintuitive direction in view of the northerly Indian-Asian plate convergence vector. Northwest shortening is, however, consistent with models of an orogen where arc-parallel extension (Seeber and Pêcher, 1998; McCaffrey and Nabalek, 1998) is accommodated by significant amounts of shortening at the tips of the arc (the syntaxes). This provides a simpler tectonic model than that previously proposed, which tied Nanga Parbat uplift to a local ending of the main Himalayan thrust at a pinning point (Treloar et al., 1991). We suggest that the Nanga Parbat pop-up structure initiated ca. 10 Ma on the basis of crystallization ages of granites determined in our work (e.g., Schneider et al, 1998, 1999a, 1999b), and the mica cooling ages located adjacent to the principal bounding shear zones (Schneider et al., 1997, 1999b, 1999c). This timing is consistent with the link suggested to Himalayan arc-parallel extension, the significant expression of which started ca. 8 Ma (Harrison et al., 1995).

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REFERENCES CITED

Brown, M., 1994, The generation, segregation, ascent and emplacement of granite magma: The migmatite-to-crustally-derived granite connection in thickened orogens: Earth-Science Reviews, v. 36, p. 83–130.

Butler, R. W. H., George, M., Harris, N. B. W., Jones, C., Prior, D. J., Treloar, P. J., and Wheeler, J., 1992, Geology of the northern part of the Nanga Parbat massif, northern Pakistan, and its implications for Himalayan tectonics: Geological Society of London Journal, v. 149, p. 557–567.

Butler, R. W. H., Harris, N. W. B., and Whittington, A. G., 1997, Interactions between deformation, magmatism, and hydrothermal activity during crustal thickening: A field example from Nanga Parbat, Pakistan Himalaya: Mineralogical Magazine, v. 61, p. 37–51.

Edwards, M. A., 1998, Examples of tectonic mechanisms for local contraction and exhumation of the leading edge of India, southern Tibet and Nanga Parbat, Pakistan [Ph.D. thesis]: Albany, State University of New York, 308 p.

Edwards, M. A., Kidd, W. S. F., Seeber, L., Pêcher, A., Le Fort, P., Riaz, M., and Khan, M. A., 1996, An upwardly mobile indentor? The Nanga Parbat–Haramosh massif viewed as a crustal scale pop-up structure: Eos (Transactions, American Geophysical Union), v. 236, p. F692.

Edwards, M. A., Kidd, W. S. F., Khan, M. A., Schneider, D. A., and Zeitler, P. K., 1997, Structural geology of the southwestern margin of Nanga Parbat: Eos (Transactions, American Geophysical Union), v. 237, p. F651.

Harrison, T. M., Copeland, P., Kidd, W. S. F., and Lovera, O., 1995, Activation of the Nyainqentanghla Shear Zone: Implications for uplift of the southern Tibetan Plateau: Tectonics, v. 14, p. 658–676.

Hubbard, M. S., Spencer, D. A., and West, D. P., 1995, Tectonic exhumation of the Nanga Parbat massif, northern Pakistan: Earth and Planetary Science Letters, v. 133, p. 213–225.

Koons, P. O., 1990, The two-sided wedge in orogeny; erosion and collision from the sand box to the Southern Alps, New Zealand: Geology, v. 18, p. 679–682.

Lemenicier, Y., Le Fort, P., Lombardo, B., Pêcher, A., and Rolfo, F., 1996, Tectonometamorphic evolution of the central Karakorum (Baltistan, northern Pakistan): Tectonophysics, v. 260, p. 119–143.

Madin, I. P., Lawrence, R. D., and Ur-Rehman, S., 1989, The northwestern Nanga Parbat massif: Evidence for crustal uplift at the northwestern corner of the Indian craton, *in* Malinconico, L. L., and Lillie, R. J., eds., Tectonics of the western Himalayas: Geological Society of America Special Paper 232, p. 169–182.

McCaffrey, R., and Nabalek, J., 1998, Role of oblique convergence in the active deformation of the Himalaya and southern Tibet plateau: Geology, v. 26, p. 691–694.

Meltzer, A. S., Sarker, G., Seeber, L., and Armbruster, J. G., 1998, Snap, crackle and pop! Seismicity and crustal structure at Nanga Parbat, Pakistan Himalaya: Eos (Transactions, American Geophysical Union), v. 79, p. F909.

Park, S. K., and Mackie, R. L., 1997, Crustal structure at Nanga Parbat, northern Pakistan, from magnetotelluric soundings: Geophysical Research Letters, v. 24, p. 2415–2418.

Pêcher, A., and Le Fort, P., 1999, Late Miocene tectonic evolution of the Karakorum–Nanga Parbat contact zone (northern Pakistan), *in* Macfarlane, A., et al., eds., Himalaya and Tibet: Mountain roots to mountain tops: Geological Society of America Special Paper 328, p. 145–158.

Poage, M. A., Chamberlain, C. P., and Craw, D., 1998, Metamorphism at Nanga Parbat: Eos (Transactions, American Geophysical Union), v. 77, p. F909.

Schneider, D. A., Zeitler, P. K., Edwards, M. A., and Kidd, W. S. F., 1997, Geochronologic constraints on the geometry and timing of anatexis and exhumation at Nanga Parbat: A progress report: Eos (Transactions, American Geophysical Union), v. 78, p. S111.

Schneider, D. A., Edwards, M. A., Kidd, W. S. F., Zeitler, P. K., and Coath, C., 1998, Synkinematic magmatism within SW Nanga Parbat, Pakistan Himalaya: Geological Society of America Abstracts with Programs, v. 30, no. 7, p. A357.

Schneider, D. A., Edwards, M. A., Zeitler, P. K., and Coath, C., 1999a, Mazeno Pass Pluton and Jutial Granite, Pakistan Himalaya: Age and implications for entrapment mechanisms of two granites in the Himalaya: Contributions to Mineralogy and Petrology (in press).

Schneider, D. A., Edwards, M. A., Kidd, W. S. F., Zeitler, P. K., and Coath, C., 1999b, Early Miocene anatexis identified in the western syntaxis, Pakistan Himalaya: Earth and Planetary Science Letters, v. 167, p. 121–129.

Schneider, D. A., Edwards, M. A., Kidd, W. S. F., and Zeitler, P. K., 1999c, Geochronologic summary and lithotectonic architecture of the Nanga Parbat–Haramosh Massif, NW Himalaya: Ettal, Germany, Himalayan-Karakorum-Tibetan Workshop Abstracts, v. 14, p. 137–138.

Seeber, L., and Pêcher, A., 1998, Strain partitioning along the Himalayan arc and the Nanga Parbat antiform: Geology, v. 26, p. 791–794.

Smith, H. A., Chamberlain, C. P., and Zeitler, P. K., 1992, Documentation of Neogene regional metamorphism in the Himalayas of Pakistan using U-Pb in monazite: Earth and Planetary Science Letters, v. 113, p. 93–105.

Teufel, S., and Heinrich, W., 1997, Partial resetting of the U-Pb isotope system in monazite through hydrothermal experiments: An SEM and U-Pb study: Chemical Geology, v. 137, p. 273–281.

Thompson, A. B., and Connelly, J. A. D., 1995, Melting of the continental crust; some thermal and petrological constraints on anatexis in continental collision zones and other tectonic settings: Journal of Geophysical Research, v. 100, p. 15,565–15,579.

Treloar, P. J., Potts, G. J., Wheeler, J., and Rex, D. C., 1991, Structural evolution and asymmetric uplift of the Nanga Parbat syntaxis, Pakistan Himalaya: Geologische Rundschau, v. 80, p. 411–428.

Winslow, D. M., Zeitler, P. K., Chamberlain, C. P., and Williams, I. S., 1996, Geochronologic constraints on syntaxial development in the NPHM, Pakistan: Tectonics, v. 15, p. 1292–1308.

Zeitler, P. K., 1985, Cooling history of the NW Himalaya, Pakistan: Tectonics, v. 4, p. 127–151.

Zeitler, P. K., and Chamberlain, C. P., 1991, Petrogenetic and tectonic significance of young leucogranites from the NW Himalaya, Pakistan: Tectonics, v. 10, p. 729–741.

Zeitler, P. K., Chamberlain, C. P., and Smith, H. A., 1993, Synchronous anatexis, metamorphism, and rapid denudation at Nanga Parbat, Pakistan Himalaya: Geology, v. 21, p. 347–350.

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