Tectonic and geochronologic observations in Central and Southern Nanga Parbat-Haramosh Massif arising from the Nanga Parbat Continental Dynamics Project

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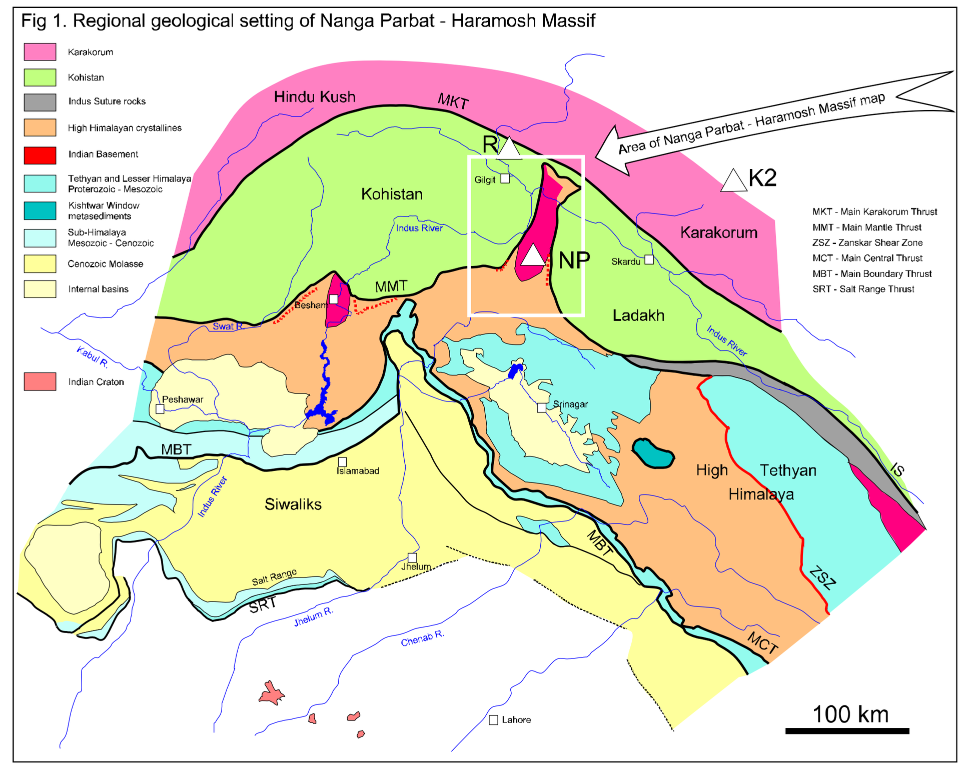
Introduction

The Main Mantle Thrust (MMT [1]) is the regional contact (Fig. 1) between collider India and the overthrust Kohistan-Ladakh fossil island arc in the Pakistan Himalaya [2]. The Nanga Parbat-Haramosh massif (NPHM), Pakistan [NW Himalaya syntaxial region] is a tectonic half window of partly re-worked, largely Proterozoic, Indian plate rocks that have been exhumed from beneath Kohistan-Ladakh [3]. Early Himalayan age, general MMT thrust displacement is modified by very young (e.g. 1.4 Ma leucogranite Th-Pb ages [4]) tectonism at Nanga Parbat Haramosh Massif (NPHM). Our investigations in southern NPHM reveal a complex interplay of features related to (1) MMT-convergence, and (2) subsequent NPHM general uplift and tectonism. We present a new geological map of the N PHM (Fig. 2) incorporating our work and that of previous investigations [13,14,15,16,17]

Fig 1. Regional geological setting of Nanga Parbat - Haramosh Massif



Truncation of cover sequence

In the area that is encompassed by the N-S trending Bunar valley, and NW trending Diamir valley (Fig. 3), the main fabrics trend mostly N to NNE. In this area, the Indian "cover" passive margin rocks that form the original MMT footwall include sequences of carbon ates and amphibolites (probably the Permian "Panjal Traps") interlayered with metapelites. In Diamir Valley, these are not more than a few 100's metres thick. Here, the regionally NW-dipping cover sequences and MMT hanging wall (Kamila amphibolite) are o verturned to become SE-dipping (Fig. 4). These overturned layers are traceable to a newly recognised recumbent open fold (the Gashit fold) in Airl Gah near the village of Gashit, where they form the upper (overturned) limb. The hinge line and axial plane of the fold plunge gently N. South of this fold, the lower limb is exposed, thus sequences are not overturned and are observed to dip moderately to steeply west. The thickness of the cover sequence increases markedly to the south; carbonates, amphibolites and metapelites of seve ral km of structural thickness (see Figs 3 and 4) are present in the W-E Airl-Nashkin section, 10 km to the south of Diamir valley .

The abrupt northward thinning (prior to NPHM uplift and faulting) of cover sequences in NPHM, also seen clearly on the eastern side, is an order of magnitude too large to be original depositional variation and there must be some type of tectonic excision. We suggest (Fig 5a) that a large-scale frontal ramp in the original MMT gave rise to a local duplex structure that imbricated slices of cover and, locally, basement. This model is consistent with mapping in Niat Gah, the next main valley to the west of NPHM, where (Figs 2, and 4) a basement slice occurring close to the MMT implies large-scale imbrication of the cover sequences, and with previous mapping farther west, south of the MMT [3,27,28]. An alternative model (Fig 5b) for the excision would require significant normal motion on the MMT after thrusting. Large amounts of STDS-type normal motion have not been reported from the MMT - only collapse folding [10], or diffuse shear type deformation [11], both occurring structurally deeper within the MMT footwall. Similarly, we have found little evidence around NPHM for substantial normal motion on the MMT zone (the normal motion seen within the cover sequence of SE NPHM in lower Rupal is unaccompanied by a large metamorphic contrast and seems unlikely to account for several km of exhumation [18].

Fig 3. Geology of Southwest Nanga Parbat Massif

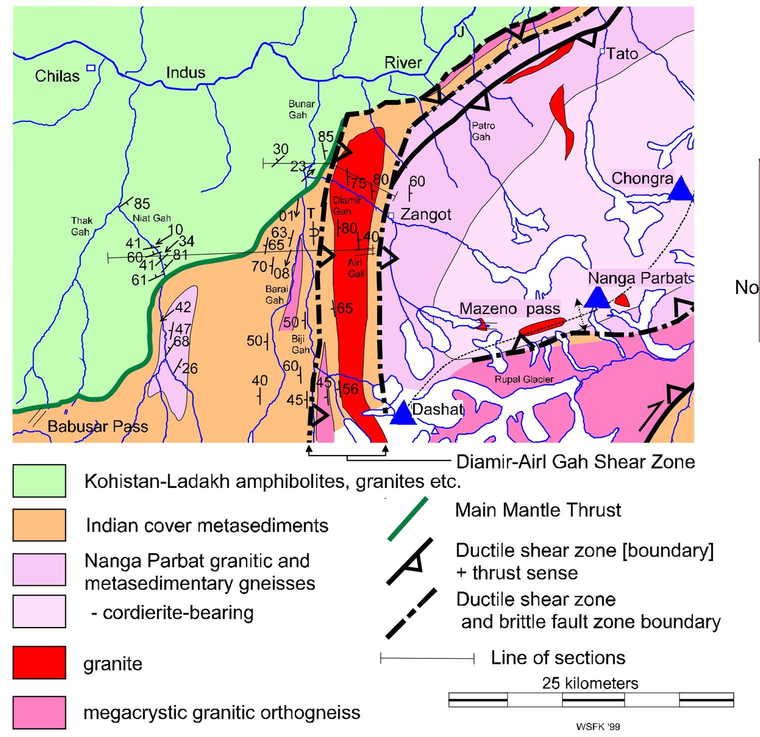


Fig 4 - Cross sections of the southwestern margin of the Nanga Parbat structure

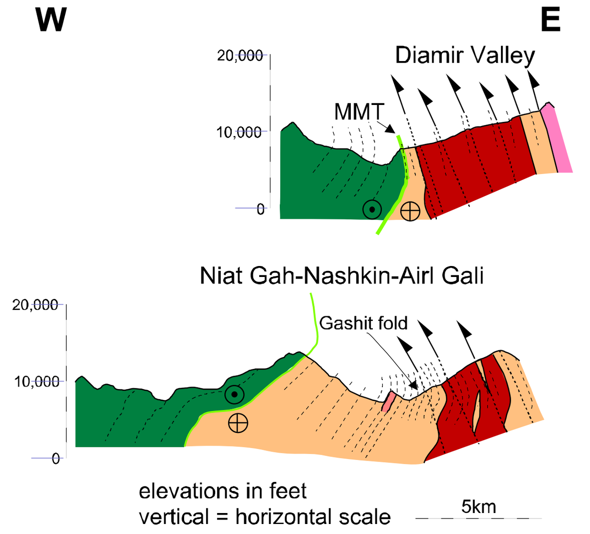
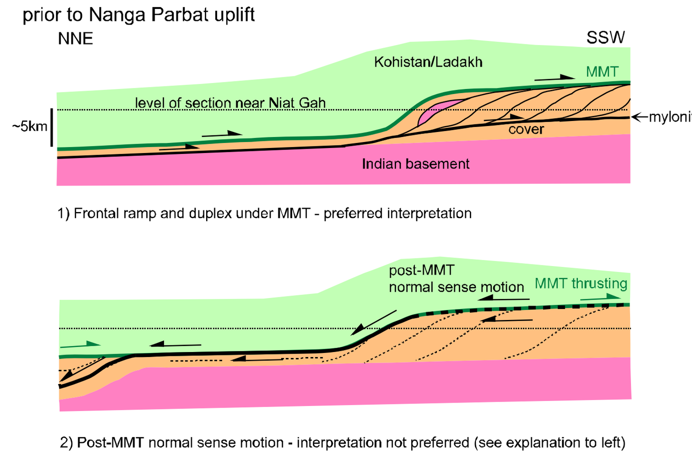


Fig 5 Structural cartoons for possible large-scale Kohistan/Ladakh MMT - Indian cover - basement relations prior to Nanga Parbat uplift



Jalhari Granite synkinematic in Diamir Shear Zone

Structurally lower in the MMT footwall, and to the east (fig. 3), the cover sequence passes into a dominantly plutonic, ~5 km thick crystalline sequence that forms a continuous, ~30 km long, ~N-S belt with vertical to steeply E-dipping fabrics. The Diami r and Airl Gah (both ~W-E) valleys offer almost continuous outcrop sections through the belt. From these valleys, it is clear that a coarse-, to medium-grained biotite granite (the Jalhari granite) grades into granitic and porphyroclastic gneiss due to syn- to post-plutonism deformation. Jalhari leucogranite lenses (10s - 100s m thick) showing little to no sub-solidus deformation are separated by 10s - 100s m thick layers of gneiss where deformation of the granite has been localised. These higher strai n layers anastamose around the granite lenses, and mark reverse faults that climb to the west. The granitic gneiss shows significant sub-solidus strain, including S-C porphyroclastic fabric whose sense of shear consistently indicates east side (NPHM) up and over west. Well-developed ductile/brittle shear bands and local fault gouge horizons, both of the same range of orientations as the ductile fabric, are also common. Late strain is often indicated by narrow (metres) zones where hydrothermal flux has d eveloped thick biotite accumulations. Prominent asymmetric folding (cm-wavelength) of the biotite layers indicates east side up and over west. Th-Pb microprobe [UCLA's Cameca IMS1270] analyses of monazites separated from deformed and undeformed portions of the granite give ages ranging from 2-8 and 12 Ma [5].

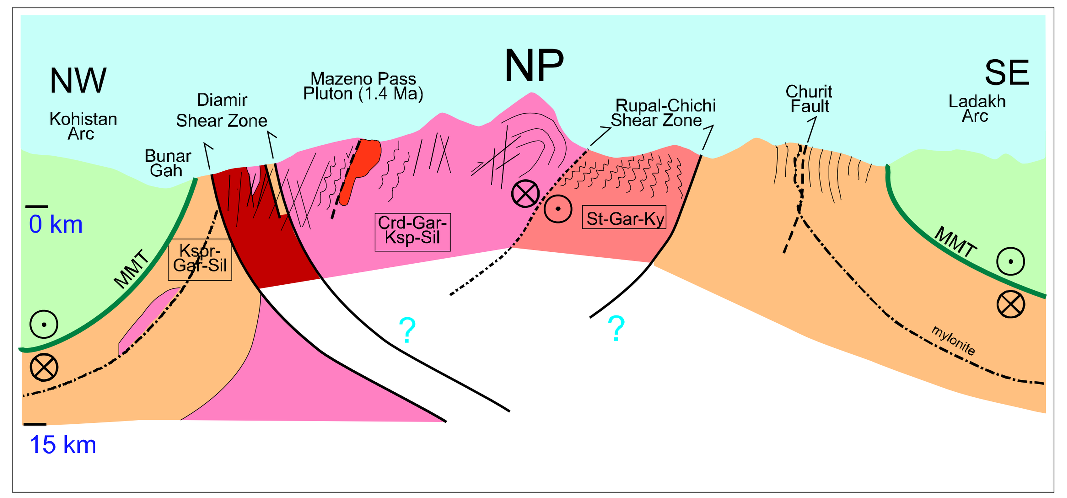
Overall, the granite gneiss belt defines a N-S trending, W-vergent, reverse sense shear zone ~5 km in width (Fig. 6). We term this the Diamir Shear Zone [25]. The E over W displacement sense of the Diamir Shear Zone is consistent with the development of the Gashit f old, and with the upper limb that includes the overturned cover/MMT layers. This shear zone forms the mechanical continuation of the main Raikhot Fault (a NW-vergent reverse fault with NPHM in the hanging wall [6,20]). The Raikhot Fault is much narrower and represents more focused strain.

We interpret the emplacement of the Jalhari granite to be at least partly syn-kinematic with exhumation of NPHM, intruded in discrete episodes between 2 and 12 Ma.

Eastern margin of Diamir Shear Zone and Mazeno Pass section

The geology between the Diamir Shear Zone and the central portions of massif is well exposed in the Diamir and Airl Gah valleys. The zone boundary is marked by brittle deformation within layers/lenses of retrograde (highly chloritised) metapelite. These then pass to more typical basement gneisses (e.g. showing metre-scale layering due to differing Fe-weathering & biotite content). From here to Rupal Valley, structures are more complex. Across Mazeno Pass, the 1.4 Ma[4] pluton (Figs.2; 6) shows evidence of some normal motion associated with its emplacement. (top to NW on steep, NW-dipping fabric). Principal gneissic fabric here is N-NE trending. In places this is cut by qtz-feldspar-biotite pegmatites, and by leucogranite dykes that stem from the Mazeno Pass pluton. Some of the leucogranite dykes cross-cut the pegmatites, and in both cases, wall rock margins show normal sense of opening, but this may not be significant if (e.g.) the granite remained super-solidus during much of the strain.

Fig. 6 Cross Section across Nanga Parbat (NP) including Diamir Gah, Mazeno Pass, and Rupal Valley



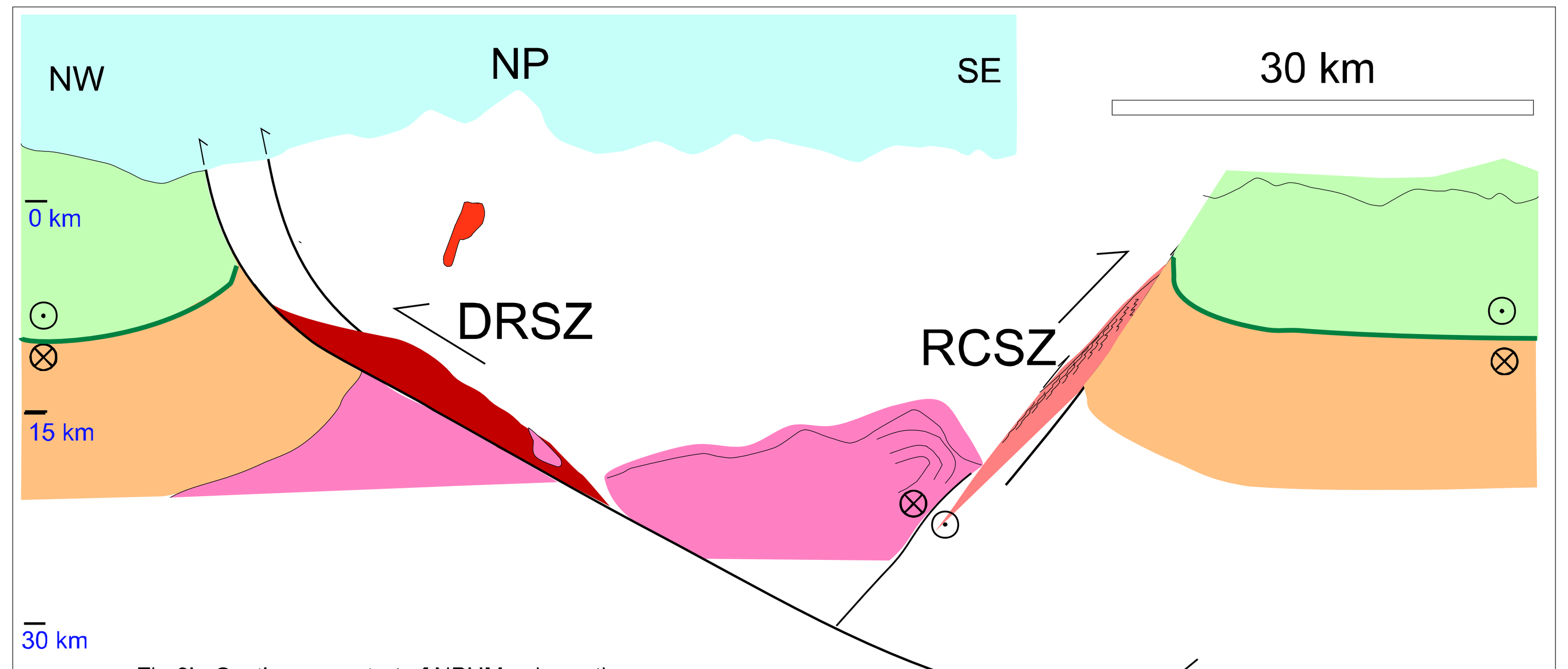
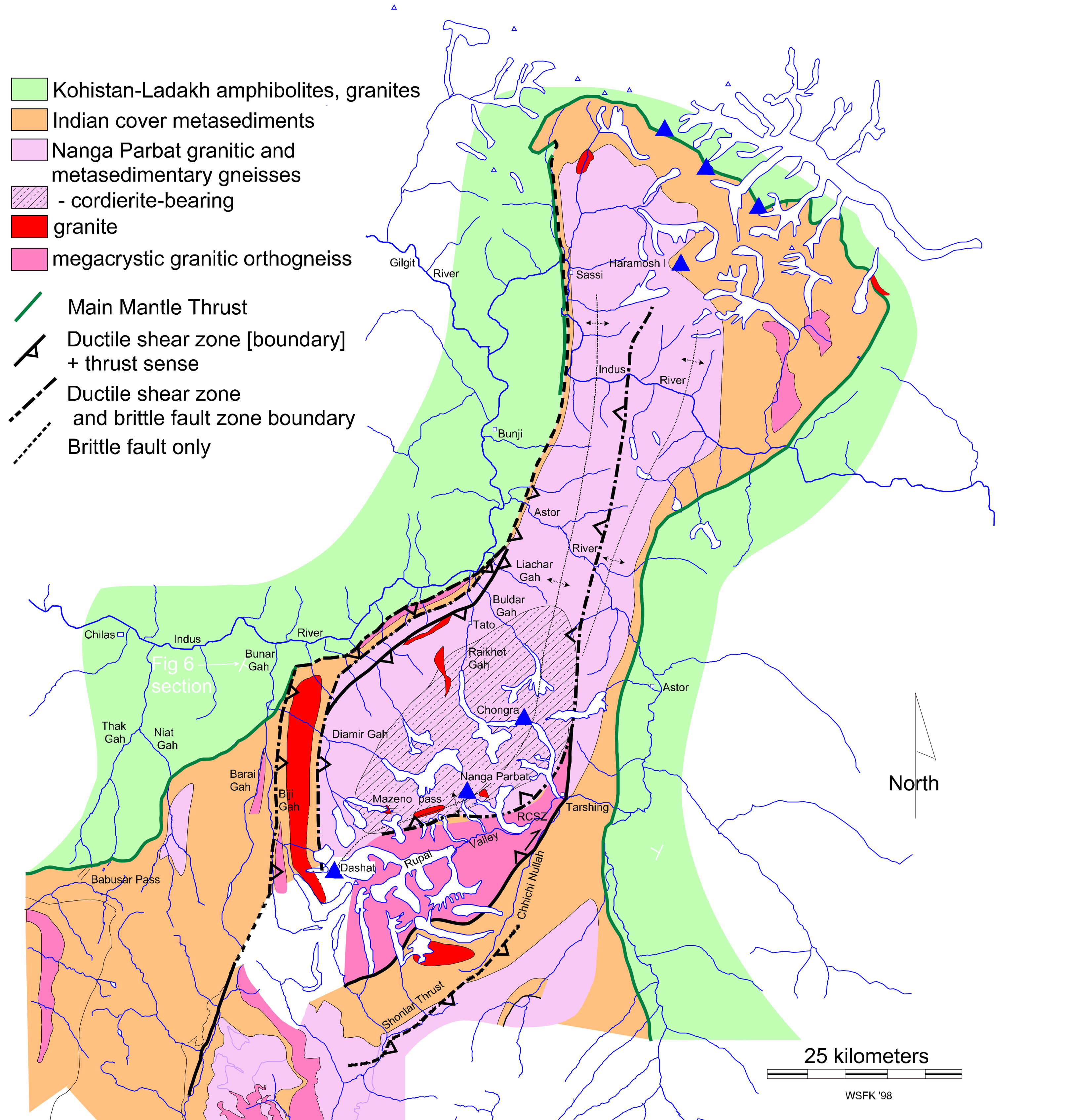


Fig 6b. Section near start of NPHM exhumation

Fig. 2 Geology of Nanga Parbat-Haramosh Massif



Shonthar Thrust

In southernmost Chhichi Nullah, within the locally SE-dipping marbles & amphibolites, several reverse faults define a >200m wide, NW-vergent thrust zone. This is most spectacularly expressed by a clear box fold (box = 10's m area of section) within the zone. The thrust is observed to continue SW over the southern wall of Chhichi Nullah. Its surface trace can be drawn from here and confidently joined with the Shonthar (Gali) thrust that has been mapped (Fig. 2) in Azad Kashmir near the Pak-Indo Line of Control[8,9]. Also noteworthy is that in southern Chhichi, the sheared orthogneiss of the RCSZ dies out. This is replaced (further south) by a largely undeformed, fine-grained leucogranite [19], the newly discovered early Miocene Southern Chichi leucogranite pluton.

NPHM-uplift-related shear zones in the SE

The Rupal-Chichi shear zone [26] (RCSZ) is a km-scale, dextral, W-side up, high strain zone defined by a continuous belt of non-coaxially sheared granitic orthogneiss with impressive C/S fabrics along its entire length. This hitherto unrecognised feature is a fundamentally important discovery for constraining the tectonics of NPHM; it is now clear that the RCSZ has acted as the conjugate, "retro-" shear zone to the southern Raikhot & Diamir shear zone system to define a crustal scale pop-up structure [26]. Displacement along the RCSZ may have migrated "inwards" to the centre of the massif based upon the ages of (1) cross-cutting leucocratic granitic dykes, and (2) total fusion Ar/Ar biotite-cooling ages of the orthogneiss, both of which show an overall youngi ng towards the centre of the massif [19]. This shear zone is traced northwards across the Astor Valley in the tight east-vergent synform which separates the two antiforms of the central and northern NPHM.

Astor valley and SE NPHM

Two antiforms (with broadly differing overall lithology) are observed in the main Astor Gorge; the Burdish Ridge and Dichil antiforms, in the west and east, respectively. The Burdish Ridge antiform is asymmetric with a thinned E-limb, while the Dichil a ntiform is asymmetric with a thinned W-limb. This is recognised by a very tight, pinched fold morphology of the accompanying (Dashkin) synform. The Iskere gneiss [6,20,21] is present near the core of, and w est of, Burdish Ridge antiform as a series of 100's m to < 2 km sections interlayered with the porphyroclastic and coarsely to finely laminated, occasionally calc-silicate gneisses. We suggest that the discontinuous nature of the Iskere gneiss in Astor G orge compared to the Indus Gorge (ibid.) is largely due to "fingering" (thinning / pinching out of multiple tabular or elongated peripheral portions) of the edge of the main body that is seen along the Indus Gorge . The Indian "cover" sequence of the eastern limb of t he Dichil antiform includes various conspicuous gneisses and schists that can be followed through the (~W-E trending) valleys of SE NPHM, including (e.g.) the "lath unit" [22,23,19,18,24]. These form the footwall of the original MMT and within them there is a significant mylonitic high strain zone related to original Himalayan thrust-sense displa cement. There is no significant displacement fabric related to the uplift of NPHM, only overturning of the previous "high Himalayan" fabric that is part of the "bulging out" of southern NPHM outside the RCSZ.

Deformation in Rupal

Normal structures (top-to-NNW) are seen throughout Rupal valley. All, however, are brittle, probably very late, and of minor displacement. Most are developed on older thrust planes that are ~W-E trending; the western portion of the Rupal Chhichi Shear Zone (RCSZ 7). There are vast thickness of orthogneiss in Rupal showing top to SSE thrusting (Fig. 6). The NW-dipping fabric is continuous throughout the Rupal Face; biotite gneiss dips ~43NW at the summit of Nanga Parbat. Locally, a ~2 km thick leucogranite with irregular margins intrudes western Rupal Face, above Shaigiri village (between ~5000 & ~6800 m). This may be emplaced in the axial zone of a tight antiform with NW-dipping axial surface, and whose axial trace passes to the south side of the summit ridge. This antiform is seen on Chongra ridge (again NW-dipping) and can be traced to the "western antiform" described [7] from the Astor Gorge (Fig. 2). In both of the valley walls of central Rupal, amphibolite, coloured marbles and metapelites are found as fairly homogeneously deformed metre-scale layers/lenses within the extensive orthogneisses. At lowest elevations in the valley walls, numerous thick fault gouge zones are seen, possibly indicating that at least part of Rupal valley has provided a (topographic) local crustal weakness to focus late brittle deformation. In the southern portions of western Rupal (in Shagin Glacier valley, and all along the south side of Rupal & Toshain Glaciers) gnessic fabric dips SW to S and shows excellent SW stretching lineation, typically with a clear top-to-SSW sense of shear. Intrusive, now-L-tectonised granite pods[7] pre-date this fabric. The orientation, petrographic texture, and sense of shear of the fabric resembles the mylonitic and high strain zones of the MMT footwall that we see elsewhere. We note that the top-to-SSW sense of shear is best explained by rotation (from ~N-dipping) of the original MMT thrust-displacement fabric; such a rotation is to be anticipated here on the SW flank of the uplifting massif.

The brittle normal fauting seen in a number of places in the massif indicates that the central part of southern NPHM is in a state of extension near the surface. It seems that there is a small value for normal stress on existing fractures of many orienta tions, and that only a small rotation of the stress field is required to switch from reverse to normal motion on pre-existing fault surfaces. Some focal mechanisms for resolvable seismic events within southern NPHM are consistent, showing extensional firs t motions occurring to ~6 km depth[12]. Note, however, there is no evidence for large-scale tectonic exhumation at NPHM.

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