

Landform evolution in the Nagar region, Hispar Mustagh Karakoram

JAN KALVODA, ANDREW S. GOUDIE

Abstract

Results of geomorphological analysis of climate-morphogenetic landform patterns in the Nagar region of the Hispar Mustagh Karakoram, related to morphotectonic features of relief-building processes in the Late Cainozoic, are presented. High-mountain landforms are the result of morphotectonic processes as well as of denudation and erosional efficiency under different paleoclimatic conditions during the Quaternary. Observations also suggest significant feedbacks between the rate of exhumation of deep crystalline rocks and the intensity of climate-morphogenetic processes. The high intensity of recent glacial and periglacial denudation and transport of weathered and eroded material correlates with an absence of older than Late Quaternary sediments.

The extreme exhumation of deep crystalline rocks in the Hispar Mustagh Karakoram is the result of morphotectonic processes as well as effective tuning of paleogeographical changes in the extent of the main climate-morphogenetic zones during the Late Cainozoic. Climate fluctuations in glacial and periglacial morphogenetic zones of the Nagar region determine the short-term and rapid geomorphic response of the landscape. The effectiveness of weathering and transport of its products increases with the frequency of alternations of glacial, periglacial and fluvial processes during the evolution of the high-mountain landscape in the Karakoram.

KEY WORDS: *glacial and periglacial processes; landscape evolution; Nagar region; Hispar Mustagh Karakoram.*

1. Introduction

1.1 Geographical position of the Hispar Mustagh Karakoram

The western Karakoram is a significant high-mountain range between the Tibetan Highland and the Himalaya on the one hand and between the Pamirs, the Thyan Shan and the Hindukush on the other. The Nagar region in the Hispar Mustagh Karakoram consists of mountain ranges characterized by alpine-type morphology, stretching between the Great Karakoram Range with the Trivor Massif in the N, and the Malubiting and the Diran Massifs in the S. The relative height of their relief is al-

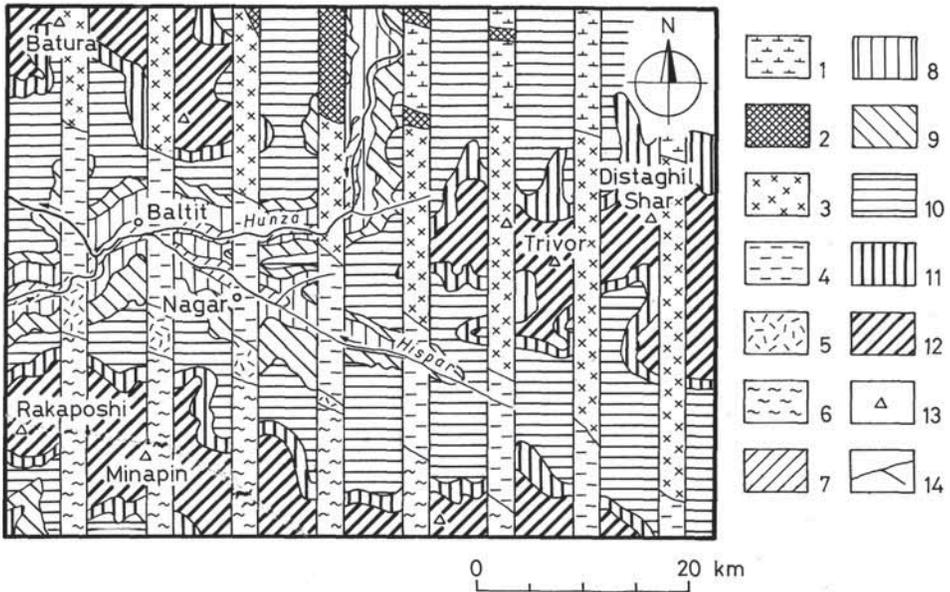


Fig. 1 Geological units and climate-morphogenetic zones of the Hunza and the Hispar Mustagh Karakoram in the Nagar region (modified after Kalvoda 1992). Key: 1-6 geological units: 1-2 northern Karakoram (Tethyan) Formation: 1 - Gircha group, 2 - Pasu group; 3 - Great Karakoram crystalline zone, 4 - Dumordo Formation (Darkot group), 5 - Chalt Formation, 6 - Yasin group; 7-12 climate-morphogenetic zones: 7 - moderately warm (1,600-2,400 m, with maximal temperatures of over 25 °C), 8 - moderate (2,400-2,900 m, 20-25 °C), 9 - moderately cold (2,900-3,500 m, 15-20 °C), 10 - cold (3,500-5,400 m, 5-15 °C), 11 - very cold (5,400-6,000 m, 0-5 °C), 12 - extremely cold (above 6,000 m, below 0 °C); note: the average of annual precipitation increase from the moderately warm to the extremely cold zones from about 150 mm to 2,400 mm; 13 - main summits, 14 - rivers.

most 5,300 m. The axis of these mountain ranges is formed by the Hispar valley from the Hispar glacier to its junction with the Hunza valley W of the village of Nagar. This region occupies a central position in the western Karakoram, geographically forming a part of Baltistan.

The Nagar region is situated between the Hunza river and the Hispar glacier in the morpho-tectonically conspicuous Karakoram suture zone (Fig. 1). The Hispar Mustagh mountain group, where the Nagar region extends, is separated from the Rakaposhi group by the wide Hispar glacier, from the Batura Mustagh by the deeply incised Hunza valley (Photo 1), from the Ghurlerab group by the Shimshal valley, and from the Panmah Mustagh group by the high Khurdopin La, the Khurdopin glacier and the Biafo glacier. The average altitude of the Hispar Mustagh mountain group crests exceeds 6,000 m. A number of summits reach more than 7,000 m. Relief dissection of the Hispar Mustagh as a projection of the altitude areas in 1,000 m intervals is shown in Fig. 2. Among the Hispar Mustagh peaks from W to E, the following ones dominate: Lupar Shar (7,200 m), Momhil Shar (7,342 m),

Trivor (7,720 m), Distaghil Shar (7,886 m), Khunyang Kish (7,852 m), Pumarikish (7,491 m) and Kanjut Shar (7,760 m). West of the Hispar Mustagh behind the deeply incised Hunza valley, the Batura Massif (7,985 m) spreads (Photo 1) as well as further peaks: Kampire Dior (7,143 m) and Bojohaghar Duonasi (7,328 m); in the S, in addition to the Rakaposhi Massif (7,788 m), the Minapin (7,271 m) and the Malubiting (7,458 m) are the nearest (Photo 2). The extreme amplitudes, varying between 7,720 and 2,000 m at mutual distances of about 40 km (comp. Fig. 2) and the dissection of the relief, render the geological and morphostructural patterns of the western Karakoram more pronounced.

The permanent snow line on the northern slopes of the Hispar Mustagh Karakoram oscillates between 5,400–5,600 m, and on the southern slopes between 4,700 and 4,900 m. The timber line oscillates between 3,600–3,700 m (Visser, Visser-Hooft 1935–1938, Paffen *et al.* 1956, Wiche 1959, 1962). The following vegetation zones may be distinguished on slopes of the Nagar region (Paffen *et al.* 1956, Kalvoda 1984, Esper 2000): 1) alpine steppe zone from 3,800 to 4,600 m (4,200–4,600 m low growing mats of *Cobreria* and *Polygonu* spp., 3,800–4,200 m willow scrub and recumbent juniper), 2) subalpine zone from 3,200 to 3,800 m (3,400–3,800 m birch, willow and mountain ash-tree, 3,200–3,400 m temperature coniferous forest

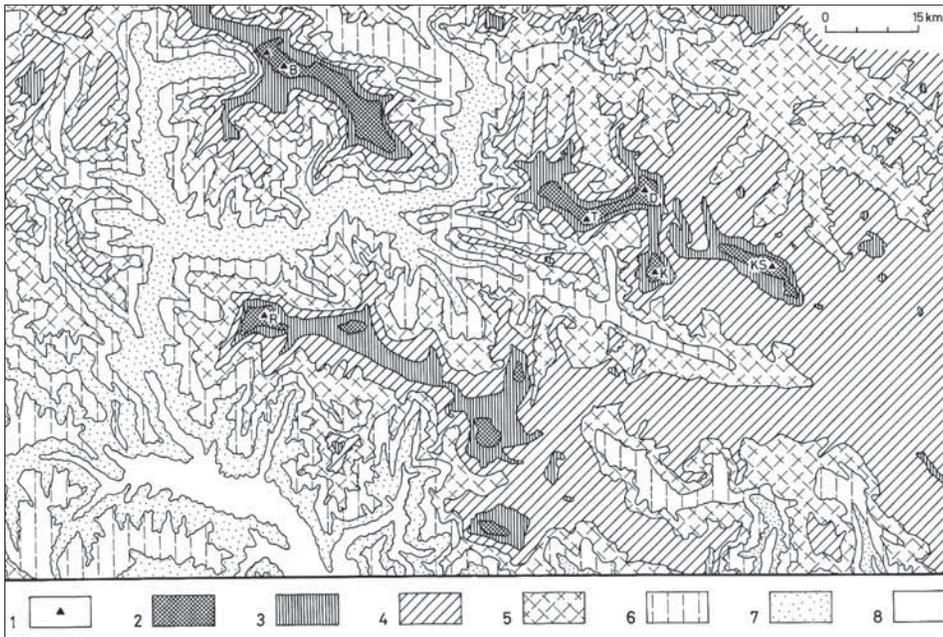


Fig. 2 Sketch of slope altitudes in the area of the Hunza and the Hispar Mustagh Karakoram. Key: 1 – summits above 7,500 m, 2–8 categories of slope altitudes: 2 – above 7,000 m, 3 – 6,000–7,000 m, 4 – 5,000–6,000 m, 5 – 4,000–5,000 m, 6 – 3,000–4,000 m, 7 – 2,000–3,000 m, 8 – 1,500–2,000 m; D – Distaghil Shar (7,885 m), K – Khunyang Chhish (7,852 m), R – Rakaposhi (7,788 m), B – Batura (7,785 m), KS – Kanjut Shar (7,760 m), Trivor (7,728 m).

with spruce, mesic pine and juniper), 3) mountain semi-arid to steppe zone below 3,200 m (2,700–3,200 m *Artemisia* steppe, below 2,700 m desert steppe with grasses (e.g. *Ephedra*, *Salvela*), coniferous trees, *Artemisia* and *Capparis spinosa*).

Distinctive vertical climatic zoning influences the variable features of the morphostructural and lithological control of characteristic weathering phenomena (Cílek, Kalvoda 1983, Goudie 1984, Whalley 1984, Waragai 1999). Observations of landform patterns of peculiar relief types between the Distaghil Shar (7,886 m) and Hunza valley (2,000 m) suggest extremely high rates of denudation, sediment transfer and deposition (Ferguson 1984, Whalley *et al.* 1984, Kalvoda 1990, Collins 1999). Striking is a vertical hierarchy of variable high-mountain reliefs (Schneider 1957, Hewitt 1989, Owen, Derbyshire 1989, Derbyshire 1996) from the extremely cold arête ridges of the Great Karakoram Range through the heavily glaciated and periglacial areas to the seasonally cold/warm semiarid Bualtar, Nagar and Hunza valleys.

1.2 Definition of the topic

Landforms in the Himalaya and the Karakoram provide evidence for the nature of very dynamic landscape evolution. The Himalaya and the Karakoram are in the colli-



Photo 1 Conspicuous vertical climate-driven morphogenetic zoning of the high-mountain relief in the Hispar Mustagh and Hunza Karakoram originated on different lithological and morphostructural units. Rocky slopes above the lower part of the Ghareisa glacier (3,800–4,000 m a.s.l.) display a system of slope and periglacial sediments. In the background, the canyon-like Hunza valley (2,000–2,200 m) appears under eastern face of the Batura Massif (7,980 m). (Photo Jan Kalvoda)



Photo 2 High-mountain relief with conspicuous morphostructural features in the contiguous zone of the Great Karakoram Range with Malubiting Massif (7,458 m) of the northwestern Himalaya. In the background (left), the Yengutz Har Peak (7,027 m) is built of Paleogene sandstones, limestones and quartzites. Alpine-type crests above the Hispar valley are formed on the Upper Paleozoic gneisses, micaschists and marbles. (Photo Jan Kalvoda)

sion zone of the Indian and Asian plates (Searle 1991, Zanchi, Gritti 1996, Searle *et al.* 1999 and others) where orogenic movements are still very active. The challenge of searching for landform development as the geomorphological record of active orogeny (Kalvoda 1988, 1992, Owen 1989a, b, Fielding 1996) is in the western Karakoram traditionally integrated with the investigation of recent climate-morphogenetic changes of relief and landscape patterns (Paffen *et al.* 1956, Schneider 1959, Wiche 1959, Goudie *et al.* 1984a, b, Li-Jijun *et al.* 1984, Finsterwalder 1996). The nature of the Hispar Mustagh Karakoram has been studied to more than a century (e.g. Rabor 1904, 1905, Oestrich 1906, comp. Miller 1984, Finsterwalder 1989). The first observations of glaciers (Workman, Workman 1910, Dainelli 1922, 1934a, b, Norin 1925, Visser 1928, Mason 1929, 1930, 1935) indicated the extraordinary features of natural hazards in the Karakoram (Desio 1954, Hewitt 1961, 1964, 1968, 1969, 1984, 1988, Belousov *et al.* 1980, Brunnsden, Jones 1984, Kurshid *et al.* 1984, Gardner, Hewitt 1990, Shen-Yongping 1991, Kuhle *et al.* 1998, Derbyshire *et al.* 2001). The other topics of research in the western Karakoram have been the dynamics of glaciers (e.g. Pillewitzer 1957, Zhang Xiansong 1980, Zhang Xiansong, Shi Yafeng 1980, Derbyshire 1984, Dong Bin *et al.* 1984, Goudie *et al.* 1984b, Oswald 1984,

Kalvoda 1987, Drozdowski 1989a, b, Ding-Yougjian 1992), and, especially, glacial history in the Quaternary (Derbyshire *et al.* 1984, Kuhle 1988a, b, 2001, Xu 1991, Meiners 1997, 2001, Owen *et al.* 2002). These studies are also connected with the Late Glacial and Post Glacial sedimentary record of geomorphological processes (Owen, Derbyshire 1988, Derbyshire, Owen 1990, Iturrizaga 1999, 2001) and very high erosion rates (Jones *et al.* 1983, Carpena, Rutkiewitz 1989, Foster *et al.* 1994, Bhutiyani 2000, Shroder, Bishop 2000) in the Karakoram and western Himalaya.

The Karakoram is a region of frequent natural disasters with high risks involved in all types of human activities. It was Kenneth Mason (Professor of Geography at Oxford University and Fellow of Hertford College) who described in the Hispar Mustagh Karakoram region more than 75 years ago the extremely dangerous process of glacier surging and rapid advance of the tongues of the side-glaciers. Also a large area of Nagar oasis originated on fossil landslide and glacier accumulations with present-day large slope movements.

The studied relief section of the Nagar region encompasses a conspicuous set of vertical climate-morphogenetic zones corresponding to recent relief-forming processes. Therefore, sculptures of the morphostructural landforms are controlled by vertical zoning of the climate-morphogenetic processes (Goudie, Kalvoda 2004a, b). Recent climate-driven morphogenetic processes are described in the framework of glacial and periglacial zones, and the seasonally cold/warm semiarid zone. Research on the present-day landforms and the main features of climate-morphogenetic processes and phenomena in the Hunza Karakoram gives evidence for 1) recent evolution of extremely dissected high-mountain relief, and 2) present-day natural hazards and risks. These aspects of geomorphology of the Nagar region can also contribute to the knowledge of a long-term integration of climate-driven morphogenetic and active tectonic processes in dynamically evolving mountainous regions of collision orogeny.

2. Morphostructural patterns

2.1 Brief paleogeographical history of collision orogeny in the western Karakoram

The Hispar Mustagh Karakoram is situated in the western part of the collision zone of orogeny where the Indian lithospheric plate deeply wedges into the southern margin of the Asian continent (Desio 1974, Searle *et al.* 1999). The controlling element of this collision consists in the movement of the Indian plate going roughly from S to N and in its moderate counter-clockwise rotation. The relics of the Tethyan fossiliferous sediments, deposited along the Main Karakoram Thrust, indicate that the closure of the sea took place in the course of the Cretaceous. The origin of the Kohistan island are occurred in the Mesozoic in which, in the Late Jurassic, the intraoceanic subduction advanced corresponding to the collision of the continents (Kravchenko 1979, Tahirkheli *et al.* 1979). It went on along the Main Karakoram Thrust from the Late Cretaceous to the Paleocene. The Indus suture, continuing its course, bifurcates into

two sutures in Ladakh (Searle 1991). The northern one is represented by the Main Karakoram Thrust, and the southern one corresponds to the Main Mantle Thrust where the Indian plate was subducted below the Kohistan arc. The sea closure along the Main Mantle Thrust went on from the end of the Paleocene to the outset of the Eocene. The island arc collision with the continent occurred in the Middle Eocene. The Indus river probably was initiated by early Tibetan uplift and has remained in the collision suture zone since Eocene time. The river has migrated only ca 100 km east since the Eocene (Clift 2002) and has been located to its present position within the foreland basin since the Middle Miocene.

Uplifts, the amplitudes of which exceed several thousand metres on areas of the order of 10^5 km², represent a dominant feature of the morphogenesis of the western Himalaya and the Karakoram, which occurred mostly in the Late Cainozoic (Gansser 1964, 1983) after the time span of orogenic movements of the nappe character and after intervals of regional high-pressure and/or high-temperature rocks metamorphism. Zones of deep-seated igneous rocks in the eastern Karakoram, the age of which oscillates around 40 million years and which represent the continuation of granite bodies of the Transhimalayan region, was influenced by rapid uplifts of these mountain ranges. In their vicinity in the molasses sediments of Ladakh (Shigatse Formation, Desio 1964, 1979), there have been found conglomerates containing large granite boulders with Eocene clasts as the youngest components. Deeper-seated beds, exposed to intense tectonic deformations, still contain coarse conglomerates (comp. Farah Abul, De Jong 1979, Tahirkheli *et al.* 1979) with pelagic shales carrying Upper Cretaceous ammonites. Thus, the Tertiary morphotectonic uplift of the Karakoram and the Tibetan Himalayas is indicated both by the origin of the Shigatse Formation molasses and by their subsequent folding.

In the Hispar Mustagh Karakoram, a mountain crests zone on mostly Paleozoic, Tethyan folded sediments may be distinguished in a wider view directed N-S, situated northwards of the Great Karakoram crystalline rocks (Fig. 1). The crystalline complexes occur in the zone between the Batura, Trivor and Pumarikish Massifs and consist mostly of Miocene granodiorites (Desio, Zanettin 1970, Desio, Martina 1972, Desio 1964, 1974, 1979). They appear near the surface of the Chitral area and constitute the crest part of the mountain range up to the Shyok valley in the E. They intrude into the Precambrian and Paleozoic rocks of the Darkot group which is built of an up to 6,000 m thick formation of phyllites, biotitic slates, amphibolites, paragneisses and medium-metamorphosed limestones up to marbles. The Darkot group is limited by the Main Karakoram Thrust in the S (Farah Abul, De Jong 1979, Kravchenko 1979), cut by the Hunza river valley W of the Rakaposhi Massif. Furthermore, the greenstone complex of the Chalt Formation, representing an ophiolitic mélangé, occurs on the mountain slopes.

The Mesozoic formation of igneous rocks and sediments, metamorphosed to various degrees, comprise shales, phyllites, limestones, sandstones and conglomerates with intrusions of basalts, andesites, rhyodacites and tuffs (Yasin group, Desio 1979). The Yasin group is a flyschoid formation about 1,000 m thick representing a relic of the shrinking Tethys in front of the collision contact of the continental plates.

At the present time this flyschoid formation is placed between the Main Karakoram Thrust and the Chalt Formation ophiolites (Gattinger 1961, Matsushita, Huzita 1965, Desio 1979). In the area of confluence of the Gilgit and Hunza rivers, the mountain massifs are built again of granodiorite intrusions of the Ladakh type of Upper Cretaceous and Eocene age.

The geological contact of the three main tectonic entities – the Karakoram area, the Kohistan island arc and the Himalayan Nanga Parbat Massif – took place from the Cretaceous to the Miocene. The further succession of orogenic events under the compression regime of lithospheric plates collision (Menke, Jacob 1976, Farah Abul, De Jong 1979), controlled in this region especially by continuing movement of the Indian plate northward (Desio 1974, Shu Pei Yi, Liu Ban Zuo 1984, Searle 1991, Searle *et al.* 1999), influenced the tectonically joined paleoreliefs of these morphostructural entities as early as in the Neogene. Certain features of the former southern sedimentary foredeep have probably been preserved in this relief until the present time. They correspond to those of relatively lower parts of mountain reliefs in the northern Karakoram suture zone. In the southern sectors of the latter zone it is worth noting the extremely high position of the dissected reliefs, displaying alpine-type morphology, on the ophiolite rocks of the Chalt Formation. In the Neogene, Chalt Formation rock complexes were not only intensely folded and metamorphosed, but in the Late Cainozoic they were successively uplifted to altitudes of 7,000 to 8,000 m in the region between the Rakaposhi and Malubiting Massifs.

2.2 Lithostructural features of high-mountain relief in the Hispar Mustagh Karakoram

Destructional landforms of the Nagar region in the Hispar Mustagh Karakoram are represented by partly glaciated alpine-type reliefs and extensive areas of steep structural-denudational slopes of several geological units. Whereas in the upper part of the Hispar valley there is a relatively narrow zone consisting of dark grey to black phyllite paragneisses and light-coloured gneisses (Desio 1974, 1979), in the middle and lower parts of the valley there are Paleozoic rock complexes of grey-white layered marbles, grey-black garnetiferous calcschists, gneisses and micaschists. Mountain crests situated northward of the Hispar valley are built of migmatite gneisses and granodiorites of the Great Karakoram Range. The crests in the S are composed of green sandstones, quartzites, crystalline limestones and conglomerates of Cretaceous up to Eocene age.

The Hispar valley course is morphostructurally bound to the selectively eroded area of Paleozoic formations lying at the immediate contact to the Main Karakoram Thrust. A roughly 10 km broad zone stretches between the rock complexes of the flyschoid Yasin Group and the Chalt Formation in the Rakaposhi, Minapin and Yengutz Har Massifs (Photo 2), and the huge crystalline rock complexes of the Lupal Shar and Trivor Massifs of the Great Karakoram Range (Fig. 1). Structurally conditioned slopes in the Main Karakoram Thrust zone permit a thorough morphological investigation in the Hunza valley between the village of Hindi and the Silkiang



Photo 3 Extremely dissected rock relief of the Chogo Lungma ridge (7,000 m) in the Hispar Mustagh Karakoram was developed by the integration of orogenic uplifts with rapid climate-morphogenetic processes in the Late Cenozoic. Glaciated ridges consist mainly of crystalline limestones and dolomites, gneisses and amphibolites of Mesozoic age, large lower slopes are formed on limestones, marbles and gneisses. (Photo Jan Kalvoda)

glacier tongue and southwards of the village of Nagar. Morphostructural conditions between the Malubiting and the Chogo Lungma Massif (Photo 3) are very complicated toward the E. Their summit part and practically the whole Haramosh Massif lying farther to the S are already constituted of migmatite, granite and gneiss bodies so that Chalt Formation rocks are preserved only in a narrow (ca 10 km wide) zone between the Minapin Peak and the Chogo Lungma glaciers' collecting area.

The direct distance between the main Malubiting summit (7,458 m, Photo 2) and the Haramosh Peak (7,397 m) is 16 km, that from the latter peak southward to the Indus canyon bottom (1,500 m) only 15 km. North of the crests connecting the Rakaposhi and Malubiting Massifs, there runs a zone of flat parts of glacier collecting basins at altitudes of 6,000–6,200 m. It is bounded in its lower part by very steep rock steps and structural-denudational slopes. Only above this even level, there are raised gigantic rocky slopes of peaks, displaying varied dissections of the alpine-type relief, mostly on amphibole-biotite gneisses, migmatites and granite gneisses. Further northward, there is the crest zone between the Mirshikar and Yendutz Har Peaks, and at altitudes of 5,200–5,400 m the zone of flat ridges extends on the greenstone complex of ophiolitic *mélange* rocks. This zone is crossed by the Silki-