CATASTROPHIC ROCKSLIDES AND THE GEOMORPHOLOGY OF THE HUNZA AND GILGIT RIVER VALLEYS, KARAKORAM HIMALAYA

With 5 figures, 2 tables and 8 photos

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Zusammenfassung: Katastrophale Bergstürze und die Geomorphologie der Hunza und Gilgit Flusstäler, Karakorum Himalaja

Der Beitrag beschreibt 79 Bergstürze, die in den Einzugsgebieten der Flüsse Hunza und Gilgit entdeckt wurden. Die Mehrzahl der Ablagerungen stammt von prähistorischen Massenbewegungen. Sie kommen in allen Höhenlagen, den dominanten geologischen Formationen und unter verschiedenen klima-morphologischen Bedingungen vor. Genauer beschrieben werden Beispiele aus den Tälern des Natlar und Batkor bei Nomal, Baltit-Sumayar und in der Nähe von Pasu im Hunza. Einleitend wird die Natur der Massenbewegungen kurz diskutiert. Deren Ablagerungen sind Gesteinstrümmer mit kantigem Schutt in allen Korngrößen. Proben des Grob- und Feinmaterials zeigen eine mit den umgebenden Talhängen übereinstimmende petrographische Zusammensetzung. Ablagerungsformen und Gesteinszusammensetzungen dokumentieren die Einheitlichkeit der Entstehung. Die Sturzbahnen werden deutlich von der zerklüfteten Taltopographie beeinflusst und lassen unverwechselbare Oberflächenformen entstehen. Die meisten Bergstürze wirken in den Flusstälern wie große Barrieren. Diese haben die fluviale Entwicklung, die Lage der Eisränder und die zugehörigen Oberflächenformen im Spätquartär bedingt. Große Mengen der talfüllenden Sedimente und die typischen fluvialen Formen zeichnen hauptsächlich Epizyklen von Aufschotterung und Zerschneidung nach, die mit den Ablagerungen der Bergstürze in Verbindung stehen. Dazu gehören die meisten der gut bekannten Seeablagerungen, Schwemmfächer, Flussterrassensysteme, gestuften Flusslängsprofile und gelegentlich auch das Auftreten von ins Festgestein eingeschnittenen Schluchten. Diese Formen sind die geomorphologischen Konsequenzen der postglazialen Instabilität der Felswände. Allerdings werden die Bergstürze bis heute fälschlicherweise als glaziale Ablagerungen interpretiert und erlangen als solche eine Bedeutung in der Glazial- und Landschaftsgeschichte. Die Identifikation dieser und anderer Talbarrieren als Ablagerungen postglazialer Massenbewegungen zeigt die Notwendigkeit auf, bisherige geomorphologische und quartärgeschichtliche Interpretationen zu revidieren.

Summary: The paper describes 79 rock slide-rock avalanches discovered in the Hunza and Gilgit river basins, mainly deposits of prehistoric mass movements. They occur at all elevations, and in each of the main geological terranes and climageomorphic environments. Examples from the Naltar and Batkor valleys, at Nomal, Baltit-Sumayar and near Pasu in Hunza, are described. The nature of such mass movements is briefly discussed. Their deposits are distinguished as coarse cataelastic 'fragmentites' with angular clasts in all grain sizes. Samples of rubble and matrix materials show homogeneous lithology derived from bedrock outcropping on nearby valley walls. Deposit morphologies and facies characteristics record large scale unity of emplacement. Run out of debris is often strongly modified by rugged valley topography, creating distinctive constructional landforms. Most examples formed large cross-valley barriers on the rivers. They have constrained fluvial development, ice margin deposition, and related landforms in the late Quaternary. Vast quantities of valley-fill sediments, and typical fluvial zone landforms, mainly record epicycles of aggradation and trenching related to the landslide barriers. This includes most of the well-known lacustrine beds, sediment fans, river terrace systems, stepped river profiles, and occasional rock bed gorges. The features reflect major geomorphic consequences of post-glacial rock wall instability. However, until now, the more accessible rock avalanches were mistaken for glacial deposits, and employed as such in glacial and landform histories. The identification of these and other cross-valley barriers as post-glacial landslides, indicates a need to revise Quaternary, as well as geomorphic, interpretations.

1 Introduction

Recent surveys have identified at least seventy-nine rock slide-rock avalanche events in the Hunza and Gilgit River basins of the Karakoram and Hindu Raj Ranges (Fig. 1). Some occurred in the last 150 years, and two episodes in the last 15 years, at high elevation in glacier basins. However, most examples were reconstructed from more or less ancient deposits. Nearly all descended onto the floors of ice-free stream valleys, making them late Quaternary, post-glacial events. They were identified through field investigations and sediment samples, assisted by inspection of satellite imagery.

Rock slide-rock avalanches ('Felssturz-Sturzstrom' events) derive from sudden rock wall failure or collapses, involving millions of cubic meters of bedrock. A steep descent of some hundreds of meters will usually cause thorough fracturing, crushing and powdering of the rock. This generates a rapid run out of dry rubble

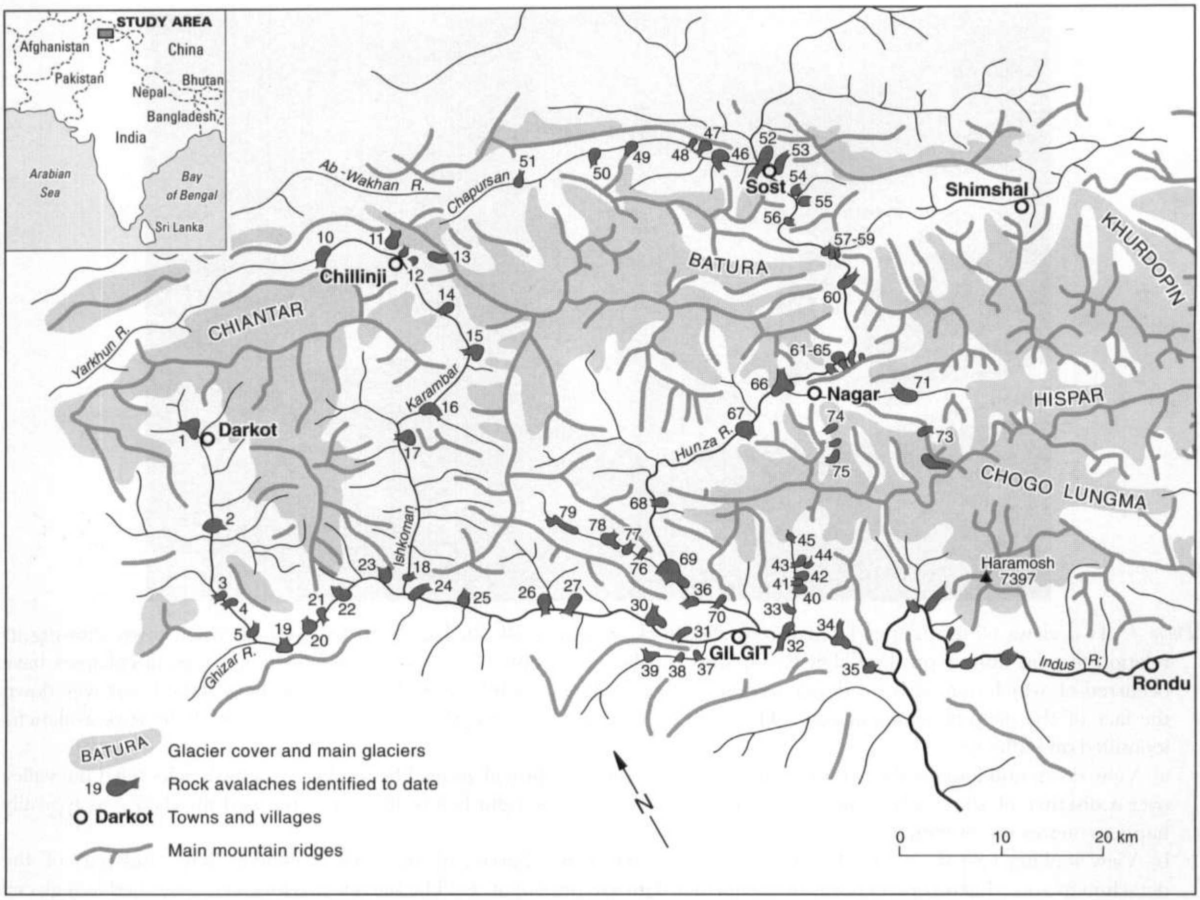


Fig. 1: Location map, distribution and inventory of rock avalanches found in the Gilgit and Hunza Basins, Central and Western Karakoram

Situationskarte. Bestand und Verteilung von Bergstürzen im Gilgit und Hunza Becken sowie im Zentral- und West-Karakorum

Rock avalanche inventory

1 Dulung Bar
2 Thaus-Chajalti
3 Bujehjod
4 Nuh
5 Damalgam
6 Shamran
7 Rawat
8 Upper Kasundar
9 Kasundar II
10 Karambar Lake W.
11 Qalandar Uwin Pass
12 Chillinji Glacier
13 Chillinji Charagah
14 Pekhin
15 Bhurt
16 Imit-Bajgaz Gol
17 Asambar
18 Goldass
19 Gupis
20 Hakis
21 Roshai
22 Gonsin
23 Torechar
24 Gakutch
25 Gulmit-Bubur
26 Thing Das
27 Gich-Hamuchal
28 Sher Qila
29 Bargu-Shirot
30 Upper Henzul Complex
31 Lower Henzul
32 Dhak Chauki
33 Ishkandas
34 Batkor
35 Parri
36 Hirali
37 Shingah
38 Hydel Station
39 Jut
40 Kothi I (W)
41 Kothi 2
42 Bilchar
43 Sinakar-Hope Complex
44 Upper Bilchar
45 Chirah
46 Rishijerab
47 Ghamochar
48 Spandrinj
49 Kil
50 Kampire Dior
51 Ziarat
52 Bordon Tir
53 Shikarjerab
54 Gircha
55 Murkhun
56 Ghalapan
57 Bilgim Plat I
58 Bilgim Plat II
59 Bilgim Plat III
60 Yashbandan-Barut
61 Serat A
62 Serat B
63 Gamesa A
64 Gamesa B
65 Toljo Ghoro
66 Karimabad-Sumayar
67 Miachar-Hini
68 Juglot
69 Nomal Complex
70 Pilchal Ghali
71 Gharesa-Huru
72 Ganissh Chissh
73 Barpu-Choktans
74 Bualtar-Borossch
75 Bualtar (1986)
76 'Lower Naltar'
77 Naltar Village
78 Naltar Resort
79 Naltar Lakes

a)

Photo 1: Two views of the Upper Henzul rock slide-rock avalanche (# 30, Fig. 1) 20 km west of Gilgit town showing its relation to, and impact on the Gilgit River. This is called a 'complex' because a series of large rockwall collapses have occurred of which one, at least, developed into a rock avalanche, while several large blocks have stalled part way down the face of the steep detachment zone. The letters a–d represent a roughly mid-line cross-section of the rock avalanche identified on both views:

a) View down and looking due south from the head of the detachment zone. The fan-like rock avalanche filled the valley over a distance of some 5 km causing a large lake to form to the right before the river breached the dam – as typically happens, across the proximal part of the barrier

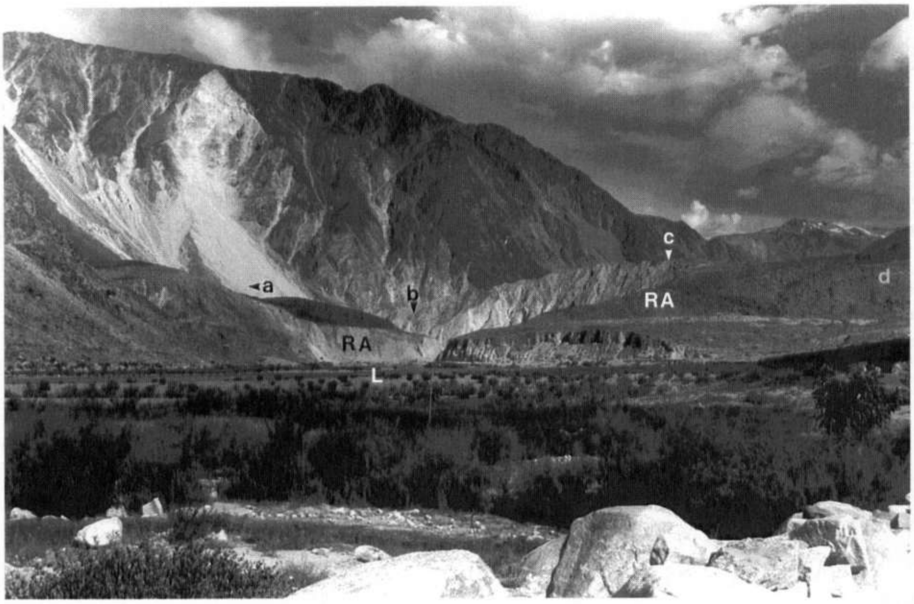
b) View looking east down the Gilgit showing the cross-valley barrier of the rock avalanche (RA), and part of the detachment zone. Lacustrine deposits of the former dam are present at 'L'. The barrier was formerly described as a glacial moraine (DESIO a. OROMBELLI 1983)

and dust – the rock avalanche or Sturzstrom. The former term is widely used in English (COATES 1977; SELBY 1993), although some argue for adopting HEIM's (1882) term sturzstrom (HSÜ 1978; HUTCHINSON 1988).

In the rock avalanche, debris travels many kilometers beyond the source slope (HUNGR 1989; COROMINAS 1996). It moves at velocities exceeding 100 km hr^{-1}, often over 250 km hr^{-1}, but stops suddenly through frictional 'freezing' when movement falls below such high speeds. The resulting deposits bury the terrain in sheets and mounds of bouldery debris. Depth varies from as little as a meter or two in the most mobile and unimpeded rock avalanche lobes, to tens or even hundreds of meters where topography blocks movement.

Large magnitude, sudden occurrence, and high velocities, place rock avalanches among the more catastrophic subaerial processes. Yet, if they rarely last more than two or three minutes, the morphology and composition of their deposits promote long-term resistance to erosion. They can continue to influence landscape development over millennia, or tens of millennia (WHITEHOUSE 1983; HEWITT 1998). It is argued here, that this involves singular consequences of catastrophic rock wall failures for the geomorphology of the Upper Indus valleys (Photo 1 a; b). Some of these geomorphological implications will be presented along with the results of the landslide survey.

The conditions required for their occurrence mean that rock avalanches are largely confined to the world's high mountain areas (VOIGHT a. PARISEAU 1978). Classic studies dealt with examples in the European Alps, the Western cordilleras of the United States, Canada and Alaska, the Peruvian Andes, and New Zealand (HEIM 1932; WHITEHOUSE 1963; MUDGE 1965; CRUDEN 1985; VOIGHT 1978). The regional environment of the Karakoram Himalaya seems likely to generate such events. However, before the past decade, only a handful of catastrophic landslides were known. No rock avalanche was definitively identified.



Zwei Ansichten des oberen Henzul-Bergsturzgebietes (# 30, Fig. 1), 20 km westlich des Ortes Gilgit, die den Zusammenhang mit dem Gilgit-Fluss und die Auswirkungen auf diesen zeigen. Das Szenario wird „complex" genannt, weil sich hier eine Serie von Felsstürzen ereignet hat, von denen sich mindestens einer zu einem Bergsturz entwickelte, während mehrere große Blöcke etwas unterhalb der steilen Scherzone stehen blieben. Die Buchstaben a–d kennzeichnen in beiden Ansichten die Profillinie durch die ungefähre Mitte des Bergsturzes:

a) Ansicht vom oberen Rand der Scherzone nach Süden auf den Bergsturz. Der fächerartige Bergsturzkörper verfüllte das Tal über eine Strecke von ungefähr 5 km und staute einen großen See auf der rechten Seite, bevor der Fluss den Damm im Bereich der Barriere durchbrach;

b) Ansicht flussabwärts nach Osten, die die Querverbauung des Tales durch den Bergsturz (RA) und Teile der Scherzone zeigt. Lakustrine Sedimente, die im ehemaligen See abgelagert wurden, lassen sich bei ‚L' erkennen. Diese Talverfüllung wurde zuvor als glaziale Moräne beschrieben (DESIO a. OROMBELLI 1983)

No examples from the region appeared in some major overviews of large landslides (COATES 1977; VOIGHT 1978; HUTCHINSON 1988). In part this is because many of the more accessible rock avalanche deposits were misidentified, usually as glacial deposits, sometimes debris flows. This requires a brief review of how the new discoveries relate to past literature on the region's geomorphology and Quaternary history (SHRODER 1998; HEWITT 1999).

2 *Geomorphic and Quaternary studies of the Karakoram*

Early Western visitors to the region did report large landslides, including several now identified as rockslide-rock avalanches (ADOLF SCHLAGINTWEIT, unpublished field notes of 1856–57, Staatsarchiv, München; DREW 1877; OESTREICH 1904; COCKERILL 1922). The geologist Blandford suggested, as will be done here, that landsliding is a major factor in the abundant valley fill along the Upper Indus streams (DREW 1873, 470). However, most other observers classed nearly all the cross-valley rock avalanche deposits they encountered as moraines. DAINELLI (1922) accepted these identifications and gave them a fundamental role in his, the most influential interpretation of the Karakoram landscape and Quaternary history. Quaternary reconstructions by NORIN (1925), SAVOLA-AOSTA a. DESIO (1936); BÜRGISSER et al. (1982); OWEN (1988), and CRONIN (1989) depend upon a number of rock avalanche deposits in Baltistan and Ladak, treated as morainic complexes (HEWITT 1999).

Relevant investigations in the Hunza and Gilgit valleys date from after the Second World War (PAFFEN et al. 1956; GOUDIE et al. 1984; HASERODT 1989; KALVODA 1992; SHRODER et al. 1993). Here too, however, interpretations are based upon DAINELLI's, or similar to it, if with great improvements in terms of process and deposit identifications (JIJUN et al. 1984). The extensive valley fill sedimentation and valley floor features are at-

Table 1: Dimensions of selected rock slide-rock avalanches in the Hunza and Gilgit Basins

Ausdehnung ausgewählter Bergsturzgebiete im Hunza und Gilgit Becken

	Survey # 79 Naltar Lakes	Survey # 66 Baltit – Sumayar	Survey # 60 Yashbandan – Barut	Survey # 34 Batkor	Survey # 69 Nomal
Area of deposit (km²)					
(i) Exposed now	10.5	4	5	12	18
(ii) Estimated original	14.0	9	33	23	40+
Volume of deposits					
(i) Estimated now	200×10^6	150×10^6	100×10^6	9×10^8	15×10^9
(ii) Estimated original	210×10^6	400×10^6	350×10^6	39×10^8	28×10^9
Rockwall source					
Exposure	–S	S	WSW	NNW	E
Rocktype(s)	metamorphic + intrusives	plutonic	carbonate	plutonic	plutonic
Maximum elevation (m.a.s.l.)[c]	4500	?	4420	3200	3160
Run out of debris					
Lowest elevation[c]	3350	2100	2400	1300	1600
Maximum drop, H (m)[c]	+150	–	2020	1900	1560
Maximum travel, L (m)	6500	6500+	11000	9000	10000+
'Coefficient of friction' (H / L)[e]	.19	–	.18	.2	.15
Highest run up, h_r (m)[a]	90	500	150	250	?

[a] Combined dimensions of earlier (larger) and later rock avalanches, the latter having overrun and partly buried the former

[b] Deposits may represent two events

[c] Estimated from existing maps, probably not more accurate than ± 100 m

[e] See SCHEIDEGGER (1973), HSÜ (1975)

tributed largely to patterns of glacier expansion and recession, to glacier and morainic dams, or paraglacial redistribution of sediment (SCHNEIDER 1959; DESIO a. OROMBELLI 1971; DERBYSHIRE 1996). Again, however, these interpretations depend on more than twenty cross-valley rock avalanches assumed to be glacial deposits, or paraglacial debris flows (Tab. 1).

The problem has arisen in other, formerly glacierised, high mountains (HEIM 1932; PORTER a. OROMBELLI 1980; WHITEHOUSE 1983; HEUBERGER et al. 1984; EVANS et al. 1994). Nevertheless, it seems remarkable, given everything else that was known about the Gilgit and Hunza basins. Local relief, from valley floors to adjacent mountain ridges, is commonly greater than 2500 m and may exceed 5000 m. Thousands of square kilometers of steep rock wall comprise the main terrain element (HEWITT 1968; BURBANK et al. 1996). Geomorphic activity is described as extreme by global standards, especially the work of snow avalanches, valley glaciers, rock falls and rock slides, debris flows and flood-prone rivers (DE FILIPPI 1912, 93; GOUDIE et al. 1984; SHRODER et al. 1993). Some of the highest known rates of uplift have been found here – from 3–8 mm/yr in the central Karakoram (ZEITLER et al. 1989; SEARLE 1991). Comparably high rates of denudation are indicated (HEWITT 1968; SHRODER et al. 1993). Extreme weather, or hydrological and seismic events known to trigger catastrophic rock slides, have been widely recorded (HEWITT 1968, chapter 16 ; MILLER 1984). Since most or all of the Karakoram was glaciated several times in the Pleistocene (HOLMES 1993), the fact that so many rock slide-rock avalanches elsewhere descended from glacially over steepened rock walls, is pertinent (EISBACHER a. CLAGUE 1984).

The past decade has brought important changes in awareness of catastrophic landsliding in the region (SHRODER a. BISHOP 1998). In 1986, rock avalanches descending onto the Bualtar Glacier, Nagyr, provided unequivocal evidence of these events (GARDNER a. HEWITT 1991). Their deposits helped in developing criteria to identify older examples (HEWITT 1988). Well-known landslides along the Indus, just below its junction with the Gilgit, are now classed as rock avalanches (OWEN 1991; SHRODER 1993). Others have been recognised elsewhere in the Upper Indus Basin

Table 2: Rock slide-rock avalanche events in the Hunza and Gilgit Basins that have directly affected glacier termini, or valley fill sedimentation around and below them

Bergstürze im Hunza und Gilgit Becken, die sich direkt auf die Gletscherränder oder die Sedimentation in den Tälern ausgewirkt haben

River Basin	(#)[1] Rock Avalanches	Glaciers
Gilgit Basin		
Yasin	1 Dulung Bar	Rawat Gl.
Ishkoman-Karambar	10 Karambar Lake W.	Multiple (Karambar Pass area)
	11 Qalandar Uwin Pass	Chhateboi, + Q.U. and Khora Bhurt Pass glaciers
	13 Chillinji Charagah	Ashturgardan Gl.[2] Chillinji Gl.
	14 Pekhin	Ashturgardan Gl. Chillinji, Yasin Gl.[3]
	15 Bhurt	Karambar, Bhurt Gl.
Bagrot	43 Bilchar	Hinarche, Burche
	44 Sinakar-Hope Complex	Hinarche, Burche
	44 Upper Bilchar (E)	Hinarche, Burche
	45 Chirah (E)	Hinarche, Burche
Hunza Basin		
Chapursan	48 Spandrinj	Yashkuk Yaz, Kuk -i- Jerab
	49 Kil	Yashkuk Yaz, Kuk -i- Jerab
	50 Kampire dior	Yashkuk Yaz, Kuk -i- Jerab
	51 Ziarat	Koz Yaz
Hunza River	57 Bilgim Plat I	Batura
	58 Bilgim Plat II	Batura
	59 Bilgim Plat III	Batura
	60 Yashbandan-Barut	Pasu, Batura
	61 Serat A ('younger')	Ghulkin, Pasu
	62 Serat B ('ancient')	Ghulkin, Pasu
	66 Karimabad-Sumaiyar	Bualtar
	67 Miachar-Hindi	Minapin
Hispar	71 Gharesa-Huru	Hispar
Naltar	79 Naltar Lakes	Kutu

[1] See Figure 1; [2] immediately above and opposite Chillinji; [3] opposite and below Warghut

(SHRODER 1998; HEWITT 1998). Several of DAINELLI's 'glacial dams', in the eastern and central Karakoram, proved to be landslide barriers (FORT et al. 1989; HEWITT 1999).

3 *The reconstruction of past rock avalanches*

3.1 *Dimensions and morphology*

Sheer magnitude can make it difficult to recognise rock avalanches. Some examples described here traveled as much as 10–15 km horizontally and 1.5–2.5 km vertically. Their debris may cover from 10 to 50 km^2 (Tab. 2). Moreover, such events begin with rock wall failures in largely competent, unweathered bedrock. Huge volumes – between 10^6 and 10^9 m^3 – are converted to coarse rubble by fracture and crushing in the mass movement itself. From one-, to two-thirds, is ground and pulverised to silt-, sand-, and granule-sized material – all in just two to three minutes! Yet, the initial competence and great size of the bedrock mass, the momentum and crushing forces developed within it, are necessary conditions for generating the rock avalanche (HSÜ 1976; HUTCHINSON 1988).

Some of the more spectacular events descended from rock walls of extreme steepness and elevation. The Gannish Chhissh event (# 72) involved a 400 million m^3 slab of crystalline limestone that broke off the north wall near the summit. It descending some 2800 m, and traveled as much as 11 km down the Sumaiyar Bar tributary of Barpu Glacier (HEWITT 2001). Yet, some of the largest landslides involve the collapse of ridges of relatively moderate relief and elevation for this region. The Upper Henzul, Nomal and Batkor events had starting zones below 3500 m a.s.l., and descended not more than 1500 m.

Rugged terrain causes deflection, splitting, or blocking of the mobile rock avalanche debris. Complex emplacement morphologies and depositional styles result (COROMINAS 1996; EVANS et al. 1994; HEWITT 2001). In particular, deep gorges and steep, opposing

a)

Photo 2: Diagnostic features of rock avalanche deposits

a) Angular surface rubble of the Damagam rock avalanche (# 5), lower Yasin valley near junction with the Gilgit

b) Imbricated boulders on the surface of the 1986, Bualtar Glacier rock avalanche (# 75)

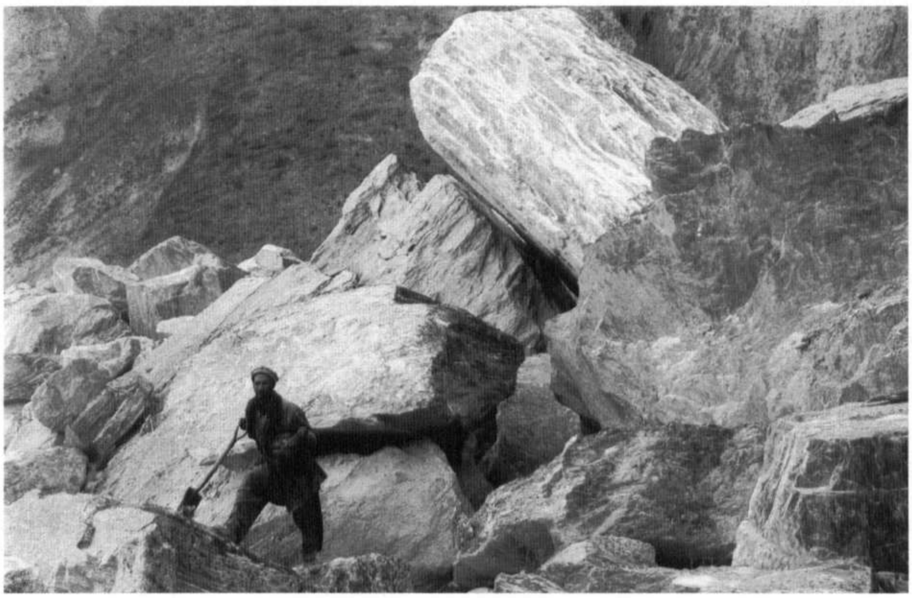
c) A quartz vein, attenuated and crushed to fine sand, at depth in the Batkor rock avalanche, nevertheless remains a discrete lithological until

Kennzeichnende Merkmale von Bergsturzablagerungen

a) Kantige Schuttmassen auf der Oberfläche des Damagam-Bergsturzes (# 5), unteres Yasin-Tal nahe der Einmündung in den Gilgit-Fluss;

b) Schuppenartige Blöcke auf der Oberfläche des sich 1986 ereignenden Bergsturzes am Bualtargletscher (# 75);

c) Ein Quarzgang, zerquetscht und zu Feinsand zermahlen, bildet an der Basis des Batkor-Bergsturzes noch immer eine abgrenzbare lithologische Einheit.



b)

c)

slopes affect the final configuration, creating asymmetrically thickened deposits and systems of pressure ridges – features often mistaken for lateral and terminal moraines. Irregular topography caused most Karakoram rock avalanches to split into two or more independent streams or lobes, moving around obstacles, up- and down-valley, and into other valleys at junctions (see below and Heim 1932, 60–112; Schuster a. Costa 1986; Hewitt 1999).

Sometimes, a direct connection can be made between boulder-covered deposits on the valley floor and a detachment zone high on adjacent valley walls. Such cases offered valuable pointers for ambiguous or fragmentary remains. Most Karakoram examples have been considerably modified by erosion and burial. The pressure ridges or raised rims are more likely to survive but, superficially, resemble ice-margin forms, requiring attention to other diagnostic features.

3.2 Rock avalanche deposits

Their distinguishing features include morphology, sedimentology, facies and, especially, composition. Typically, the undisturbed surface has an openwork cover of boulders, most exceeding 1 m in diameter, often 10 m. They are angular or very angular, except for post-depositional weathering (Photo 2 a). Locally they display imbrication and 'jostling' (Photo 2 b). Traction in the fast moving debris sheet orients the largest boulders parallel or transverse to movement. Sudden halting leaves crushed corners or edges.

The surface rubble overlies and continues down into a densely compacted main body. It may also consist largely of boulders but in a matrix of crushed and pulverised rock (Photo 3). Matrix proportions are quite variable locally, and between different examples, but sand-sized material generally exceeds silt, while clay-sized is negligible (Hewitt 1999, Fig. 3; Blair 1999). Individual clasts in all grain sizes are, again, angular or very angular. They are products of cataclastic fracture and crushing or coarse 'fragmentites' (Laznicka 1988). Most important, from fine matrix to largest boulders, they have the same lithology. Where two or more lithologies are present they do not mix, despite being crushed, sheared and attenuated (Photo 2 c). Bands of uniform lithology, arranged sequentially outwards from the source, represent 'remnant stratigraphy' (Heim 1932; Hewitt 1988).

In such dry flows, there is no transport medium that might preferentially move, or sort, different size and shape fractions. The whole mass deforms and spreads to a thin sheet, but individual grains cannot move independently through it. In this way, lithology is preserved and helps distinguish the deposits from those of glacier origin which, in the valleys of interest, are almost always of mixed lithology and include materials from tens or hundreds of kilometers away.

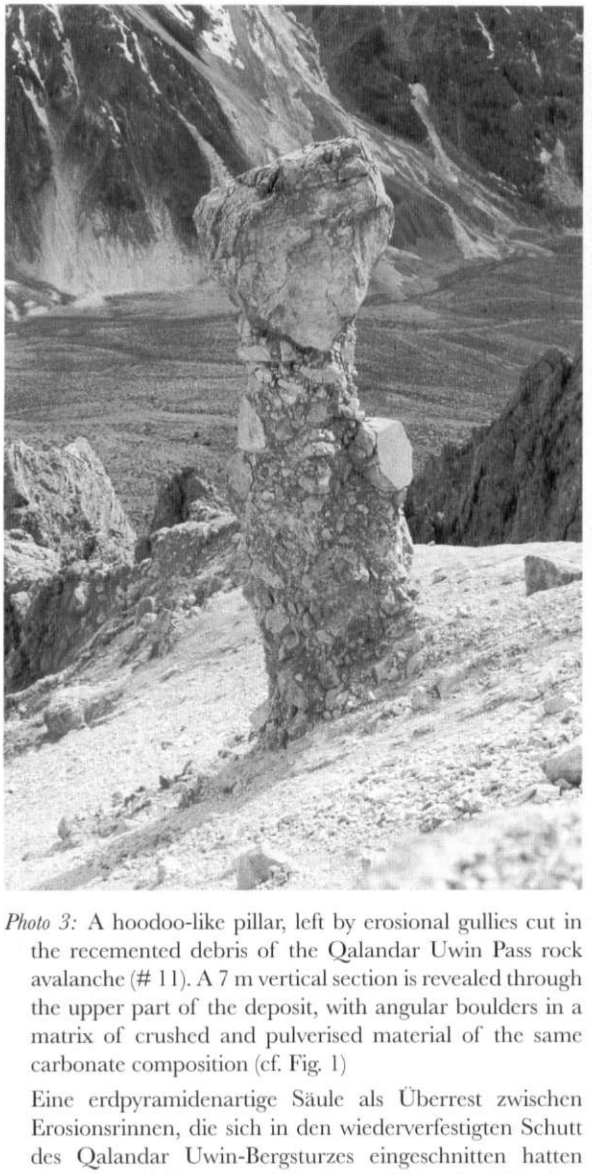


Photo 3: A hoodoo-like pillar, left by erosional gullies cut in the recemented debris of the Qalandar Uwin Pass rock avalanche (# 11). A 7 m vertical section is revealed through the upper part of the deposit, with angular boulders in a matrix of crushed and pulverised material of the same carbonate composition (cf. Fig. 1)

Eine erdpyramidenartige Säule als Überrest zwischen Erosionsrinnen, die sich in den wiederverfestigten Schutt des Qalandar Uwin-Bergsturzes eingeschnitten hatten (# 11). Ein 7 m hoher Aufschluss mit kantigen Blöcken in einer Matrix von zermahlenem und pulverisiertem Material derselben karbonatischen Zusammensetzung ist aus der oberen Ablagerung freigelegt (vgl. Fig. 1)

Topographic blocking constrains cataclastic processes in rock avalanches, and creates distinctive facies at depth. Where deposits are more than 15–20 m thick, incipient and distinctive brecciation are preserved. There are crackle, jigsaw or mosaic breccias; respectively, where former bedrock units are severely fractured but not separated, or slightly separated but in the same geometric positions, or with very slightly changed positions (LAZNICKA 1988, 136–138). Masses of rock, intact or partly sheared and crushed, are stalled against topographic obstacles or in the bottom of narrow gorges. Relatively great confining and crushing pressures produce zones where the rock is completely reduced to fragments of sand grade and smaller. Distinctive rock units or veins may be sheared, contorted and attenuated, but there is no mixing of lithologies (HEWITT 1999). Such features, widely displayed in the Naltar, Nomal and Batkor events described below, can also be seen in the well-known Flims event in Switzerland, where the Upper Rhine cuts through (HEIM 1932; ABELE 1974).

Further complications arise with deformable and erodible substrates. Rock avalanche debris may plough into soft regions, and be thrown into longitudinal and transverse pressure ridges in more resistant areas. Careful inspection will show the ridges have a geometry and composition reflecting the large-scale unity of rock avalanche emplacement (KRIEGER 1977; JOHNSON 1978, 492–496; YARNOLD a. LOMBARD 1989; HEWITT 1999). Examples from the Hunza and Gilgit Basins reinforce and extend these observations.

4 *Individual Gilgit-Hunza rock slide-rock avalanches*

4.1 *The Naltar Lakes event (# 79)*

An important tourist destination, the Naltar Lakes turn out to lie in basins impounded by a rock avalanche, and depressions on its surface (Fig. 2). The detachment scar, just inside Kutu valley, on its left/north wall, lies above a transport slope some 900 m high, now buried in post-landslide talus (Photo 4). Bedrock is heavily folded and faulted metamorphics of the Chalt Volcanic Group (SEARLE 1991).

The right hand lobe spread across the mouth of the Kutu, and climbed the opposing slope to form a local, main accumulation ('Hauptanlage') and pressure ridge, the 'brandung' or 'surge deposit' of HEIM (1932; cf. HEWITT 2001). It impounds a 3 km^2 lake, originally larger and 50 m deeper. A left hand lobe crossed the mouth of upper Naltar valley, also creating a dam that is now infilled with some 10 km^2 of braided valley train. Meanwhile, the largest, central lobe, traveled down Naltar valley for 6 km. Undisturbed deposits consist mainly of mounds, or transverse and longitudinal ridges with a relief of 15 to 30 m, their angular boulders covering some 5 km^2 of valley floor. Bands of different colour represent 'remnant stratification' from distinctive lithologies in the bedrock source. Deformable and wet valley fill sediments are incorporated into ridges around the main Naltar Lake and down the valley, especially in the lowest 2 km of the lobe.

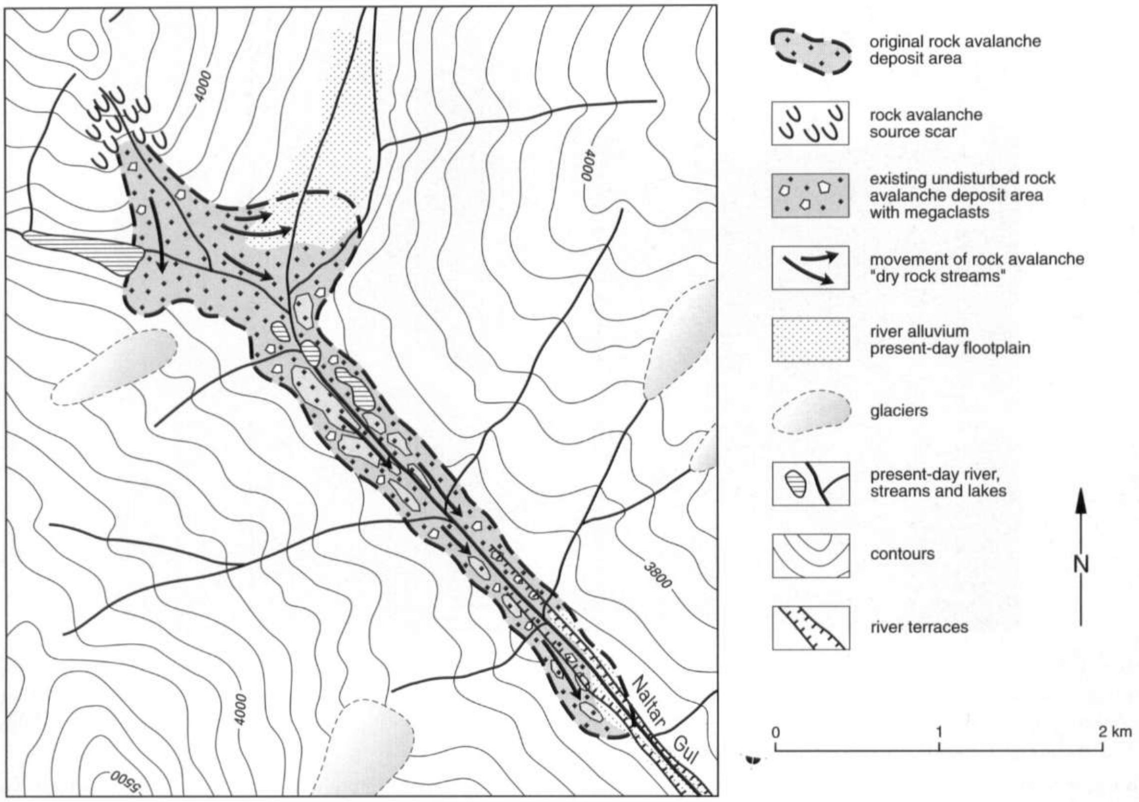


Fig. 2: Sketch map of the Naltar Lakes rock avalanche (# 79)
Skizze des Naltar Lakes Bergsturzes

The rock avalanche impounded, and rerouted the Naltar and other streams. Eight small lakes lie in depressions on its surface, while others have been infilled by fluvial and lacustrine debris. Avalanche and debris-flow fans from valley walls and hanging tributaries have covered parts of it. Stream incision has begun to cut through and create low river terraces.

In fact, this and four other catastrophic landslides have drastically modified valley floor development of the Naltar. The Naltar Lakes event overlaps and buries valley-fill behind a rock avalanche located further down valley near Dumial (# 78). It descended from the left/north east wall, and surged as much as 400 m up the opposite flank leaving an enormous brandung ridge some 2.5 km long. Between this ridge and the valley wall is a well-defined trough – the 'Brandungstälchen' of Heim (1932; Hewitt 20001) – where houses and the lower fields of Dumial are located. The middle and lower parts of the rock avalanche are cut through by the river, but its upper section impounds and underlies extensive valley fill deposits.

About 4 km further down, a third rock avalanche, from the left/north east flank, fills the valley for some 3 km (# 77). The river flats and terraces occupied by Naltar village formed behind it. Below them, the road follows a deep gorge cut through rock avalanche debris.

Half way between Naltar village and the Hunza, a fourth, smaller event descended from the right/south-west wall. Formerly, it dammed the upstream section, but now the river follows a rock gorge superimposed from the cross-valley deposit.

A fifth landslide, the Nomal Complex, discussed below, dammed the whole Naltar valley, and explains its final sharp bend and outfall to the Hunza facing upstream. The ancient, lower course of the Naltar and its junction with the Hunza, lie buried under the Nomal landslide.

4.2 The Nomal complex (# 69)

This is the largest landslide system yet identified in the western Karakoram. It derived from collapse of the right/west wall of the Hunza valley (Photos 5 a. 6). About 15 km^2 of the landslide were found in field surveys and on satellite imagery; probably less than half its original extent. It is composed of bedrock from plutons of the Kohistan batholith (Petterson et al. 1990; Treloar et al. 1996). The head wall and some

Photo 4: View over surface rubble of the Naltar Lakes rock avalanche, where it blocks the upper Naltar (to the right of the photo) and Kutu valley (snow covered, background). The detachment zone lies above the scree-covered slope, right background. The cataract in the foreground, is the Naltar's spillway over the lowest part of the rock avalanche dam. Alluvial flats in the right, middle ground, represent sedimentation behind it

Blick über die Schuttmassen des Naltarsee-Bergsturzes, der den oberen Naltar (im rechten Bereich des Fotos) und das Kutu-Tal (schneebedeckt, im Hintergrund) blockiert. Die Scherzone befindet sich oberhalb des schuttbedeckten Hanges im rechten Bildhintergrund. Der Katarakt im Vordergrund bildet den Überlauf des Naltar über den niedrigsten Bereich des aufstauenden Bergsturzes. Die alluvialen Flächen im rechten Mittelgrund zeigen die Sedimentation hinter dem Damm

upper, rotational blocks, appear to come from the 'late undeformed' Shirot pluton of PETTERSON (1985, Figs. 1–10). The main mass derives from his Nomal-Matum Das 'early deformed plutons'. It is a 'complex' in exhibiting varied styles of movement, facies, and morphology (HUTCHINSON 1988).

Today, the landslide mass is truncated by a great cliff, 900–1200 m high, cut by the river and stretching for some 5 km behind the Nomal settlements (Fig. 3). This exposes a transverse cross-section in severely brecciated, crushed and powdered rock. It is a source of repeated, sometimes destructive, debris flows and rock falls for the Nomal settlements. The extreme cataclasis of locally derived bedrock seems due to the landslide. However, PETTERSON (personal communication) attributes the bands of intense and widely varying colours in it, to chemical alterations in the original Matum Das Pluton.

Above the cliff is an extensive plateau whose flatness mainly reflects infilling of depressions by stream, debris flow, aeolian and lacustrine deposition. Multi-year lake deposits, up to 20 m thick in places, record the initial, large scale damming of the Naltar and Hunza basins. A zone of backward-rotated blocks in partly intact bedrock, occurs in the south west sector below the headwall. The latter is 300–500 m high, and represents steep fracture planes. At its head, and running parallel to it, are long narrow depressions and reverse scarps, or 'sackung' features (HUTCHINSON 1988; BOVIS 1990).

Glacial over steepening, where ice was forced against the valley wall, followed by debuttressing at the end of the last glaciation, seem important locational factors. Well-preserved glacial deposits cover the interfluve above Nomal, where high level Hunza-Naltar ice overflowed, to join ice overflowing from the Gilgit. These diffluent ice streams drained down the short, intervening Hirali valley, whose arid floor now supports a 'misfit' stream, once fed by meltwater of late Hunza and Gilgit Glaciers. The Upper Henzul Complex (see Fig. 1 and Photo 1), on the Gilgit side, compliments the Nomal, and is located where maximum undercutting and overflow of the former Gilgit Glacier occurred. It also displays identical sackung features. In both cases, these cut the ice-moulded, bedrock knolls, and disturb

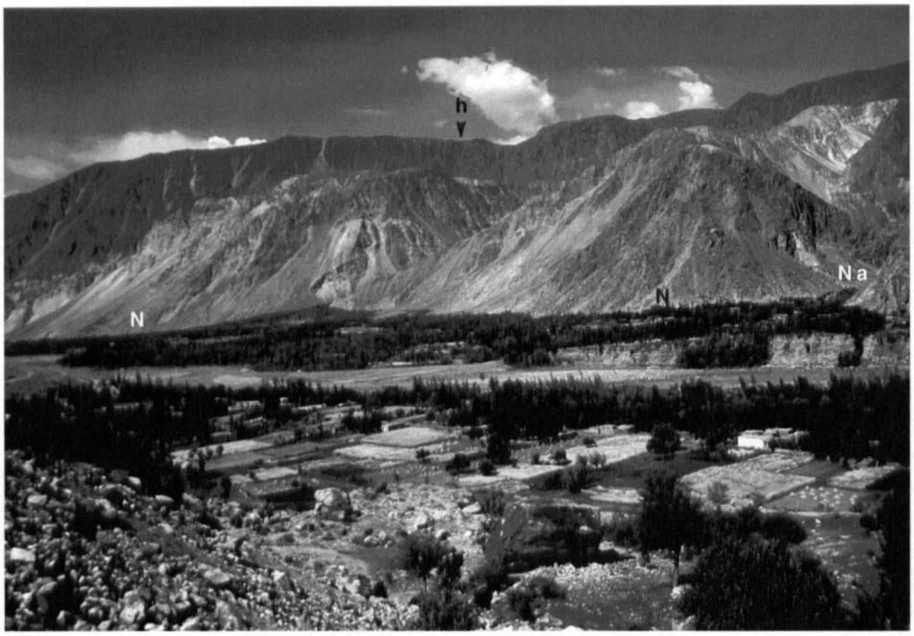


Photo 5: View from the distal rim of the Nomal Complex across the Hunza valley towards the main, surviving mass on the west side of the river. The arrow indicates the head of the detachment zone in the mid-region and is the viewpoint of Photo 6. The cross section in Fig. 3 passes from there through the middle h = ground of this photograph. N = the Nomal villages. Na = entrance to the Naltar valley

Ansicht vom distalen Rand des Nomal-Komplexes durch das Hunza-Tal auf die übrig gebliebene Hauptmasse am westlichen Flussufer. Der Pfeil markiert den oberen Rand der Scherzone im mittleren Bereich und ist gleichzeitig Aufnahmestandort für das Foto 6. Das Profil in Fig. 3 verläuft von dort durch die Mitte des Fotos (h). N = Siedlung Nomal, Na = Eingang zum Naltar-Tal

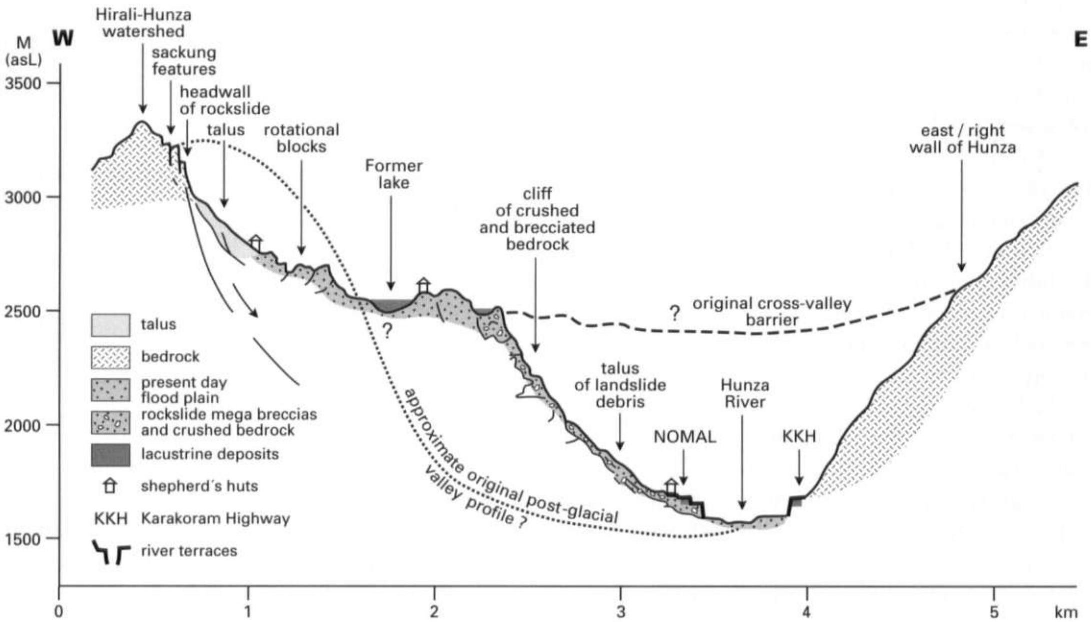


Fig. 3: Schematic cross-section of the Nomal Complex

Schematisches Querprofil durch den Nomal Complex glacial deposits, indicating postglacial rock wall collapse.

4.3 The Baltit-Sumayar event (# 66)

Where the Hunza valley is joined by the Hispar, a rock avalanche descended from the cliffs above Ultar Glacier and the narrow gorge behind Baltit Fort (Fig. 4). The central lobe climbed the opposing valley wall to create an imposing brandung 350 m above Dalto-Sumayar. A second lobe, deflected down-valley, is recorded in a barren, boulder-covered ridge parallel to the river where the Boys High School and a grave yard lie. The four streams that were dammed by the landslide – Ultar, Hunza, Hispar and Silkiang – subsequently cut it into seven segments. Good vertical exposures occur behind Baltit Fort, whose foundations and stone work are rock avalanche materials. The distinctive, densely compacted, crushed, angular debris, with smeared out quartz veins, contrasts with glacial and debris flow deposits in the same area. The bedrock of the Hunza valley here, consists of metamorphics of the Dumordo Marble and Ganchen Pelite Units (SEARLE 1991, 110–115). But the boulders and matrix of the rock avalanche are composed of granodiorite from the Hunza Plutonic Unit. Coarse stream gravels and other valley fill beneath the rock avalanche, seem undisturbed in some places. In others they are strongly folded and faulted; for instance, gravel beds on the point between the Hunza and Hispar streams.

Along the Hunza, thick, multi-year lacustrine beds, like those used by the China-Pakistan brick works upstream of Ganesh, record a major landslide lake. The 'Sacred Rock', famous for its ancient petroglyphs, is one of several mid-valley bedrock salients or 'isolated rocks', created as the rock avalanche dam was breached. The river, superimposed upon bedrock of the right-west bank, forms a typical 'epigenetic gorge' along the proximal zone (cf. HEIM 1932). The old channel lies on the other flank of the Sacred Rock, buried under lacustrine and other valley fill.

The rock avalanche deposits have been classed as 'deformed tills of trunk valley glaciation' (DERBYSHIRE et al. 1984, 488), the lacustrines attributed to an ice dam (GOUDIE et al. 1984, 383). However, glacial materials are absent from the coarse, cross-valley deposits. The river gravels underlying them record an ice-free valley floor. A Hunza or Hispar Glacier would hardly have carried purely granodiorite materials. Thus ancient lateral moraines, high above the rock avalanche on the spur between the Hispar and Hunza rivers, are composed of other, and mixed lithologies from the respective basins.

4.4 The Yashbandan-Barut complex (# 60)

Between Pasu and Sesoni, on both sides of the Hunza River, are remains of a catastrophic rock slide, whose original volume probably exceeded $500 \times 106\ m^3$. It descended from cliffs overlooking the left-east bank, to cover more than 20 km^2 (Photo 7). The deposits, densely compacted and recemented, have been severely eroded but leave little doubt about their origin. The main body comprises cobble to boulder-sized angular clasts, embedded in matrix of identical composition. They consist entirely of bluish-white marble of the Shaksgam Formation, even where resting on bedrock of Pasu Slates or the Hunza Plutonic Unit.

Extensive remains lie on the spur between the Pasu and Ghulmit Glaciers. The rock avalanche climbed 250 m up the slope west of Barut Lake (= 'Bhorit Jheel'), some 9 km from its source, to leave thickened, distal rim deposits. It climbed the spur opposite Sesoni to leave deposits 450 m above the present Hunza River. Embedded in well-preserved surfaces of these rim deposits, are rounded granodiorite blocks and angular clasts of black, Pasu slates. Absent at depth, they were picked up and carried on top of the rock avalanche.

Formerly, these deposits were classified as tills of widely different ages (GOUDIE et al. 1984, 377; DERBYSHIRE et al. 1984, 473–476; JIJUN et al. 1984, 500). Thickened sections, emplaced as the rock avalanche climbed to different heights, or in response to topographic blocking, were misinterpreted as lateral or terminal moraines of different ice advances. Spillways, diverted by the rock avalanche, were also attributed to ice, notably that across the spur between the Pasu and Ghulkin Glaciers, whose deeply scoured lower basin encloses Barut Lake.

Where the detachment zone occurs, Pleistocene Hunza ice would have been forced against the valley wall by the inflow of Batura, Pasu and Ghulkin ice. Shimshal ice crossed the ridge at maximum glaciation, but otherwise added to ice undercutting the embayment. This, and debuttressing with glacier recession, seem major factors locating catastrophic failure here. However, SEARLE (1991) also shows a fault across the lower detachment zone.

4.5 The Batkor event (# 34)

This huge, conspicuous rock avalanche deposit was derived from rock wall collapse 6 km into Batkor valley, where two branches join and the former Batkor Glacier excavated a deep basin (Fig. 5). Its amphitheatre-shaped detachment zone faces north, and a huge area of rock slide debris with angular megaclasts lies below it (Photo 8 a). Previously it was mapped as 'till' (SEARLE

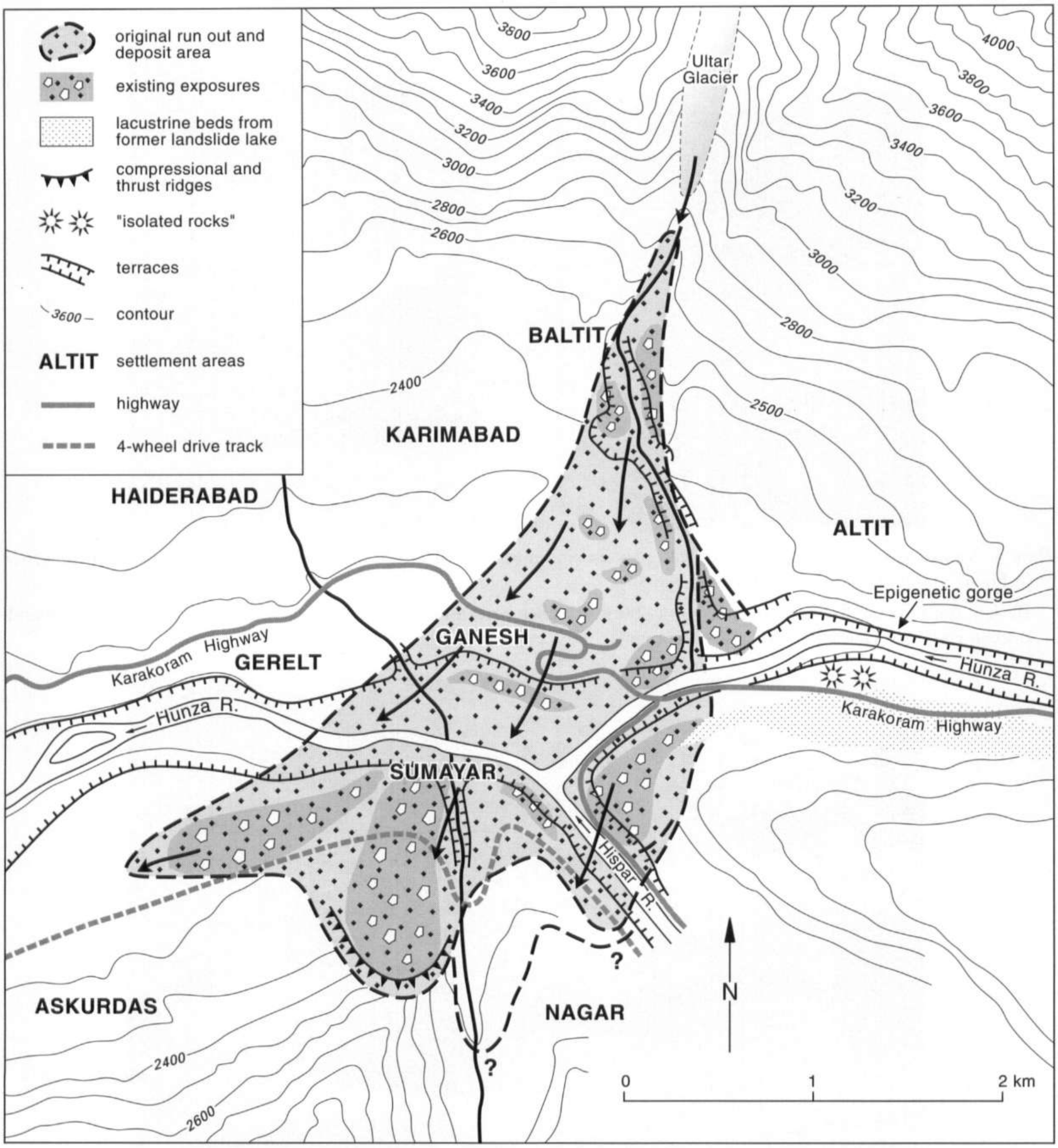


Fig. 4: Sketch map of the Baltit-Sumayar rock avalanche (# 66), and related valley floor features where it dammed and controlled sedimentation along the Hunza and Hispar

Skizze des Baltit-Sumayar Bergsturzes und der zugehörigen Talbodenformen, die durch die Sedimentation beiderseits des Hunza und Hispar entstanden sind

1991, Fig. 11.6). Here, the debris traveled northwards, surging up the slope opposite, to leave a conspicuous brandung ridge. However, most of the mass was deflected to the left, through 180 degrees, and descended southwards into the Gilgit valley (Photo 8b). Down valley, on the right flank, the brandung is replaced by a 'trim-line' ridge of rock avalanche debris exhibiting the well-known 'caroming' rise and fall of lateral margins (FAHNESTOCK 1978; PORTER a. OROMBELLI 1980; BLAIR 1999). Matching pressure ridges occur, further down, on the left flank. They were stranded 30–60 m above the main deposit, as mass was evacuated into

Photo 6: View across the Nomal landslide complex looking north east from the head of the detachment wall at the arrow in Photo 5, and in the opposite direction

Blick in nordöstliche Richtung über den Rutschungskomplex bei Nomal von der oberen Abrisskante zum Aufnahmestandort von Foto 5 (in Gegenrichtung aufgenommen)

Photo 7: View looking east from the Karakoram Highway just above Sesoni, towards the source area (D) of the Yashbandan-Barut rock avalanche. RA = remnants of the recemented crushed and pulverised carbonate rock. SB = slump block of bedrock on the right/south flank of the rock avalanche detachment zone

Blick nach Osten vom Karakorum Highway oberhalb Sesoni auf das Ursprungsgebiet des Yashbandan-Barut-Bergsturzes. RA = Überreste des wiederverfestigten, zermahlenen und pulverisierten Karbonatgesteins. SB = Gleitmasse anstehenden Gesteins auf der rechten südlichen Flanke der Scherzone des Bergsturzes

Gilgit valley, where boulder covered, lateral ridges also extend sharply outwards, for 200–300 m. The main deposit, an immense, kidney-shaped lobe, some 150 m thick in the central parts, plugged the Gilgit valley, ascending over 200 m up the south wall. The existing, steep front at Chhamogar is an erosional feature, where

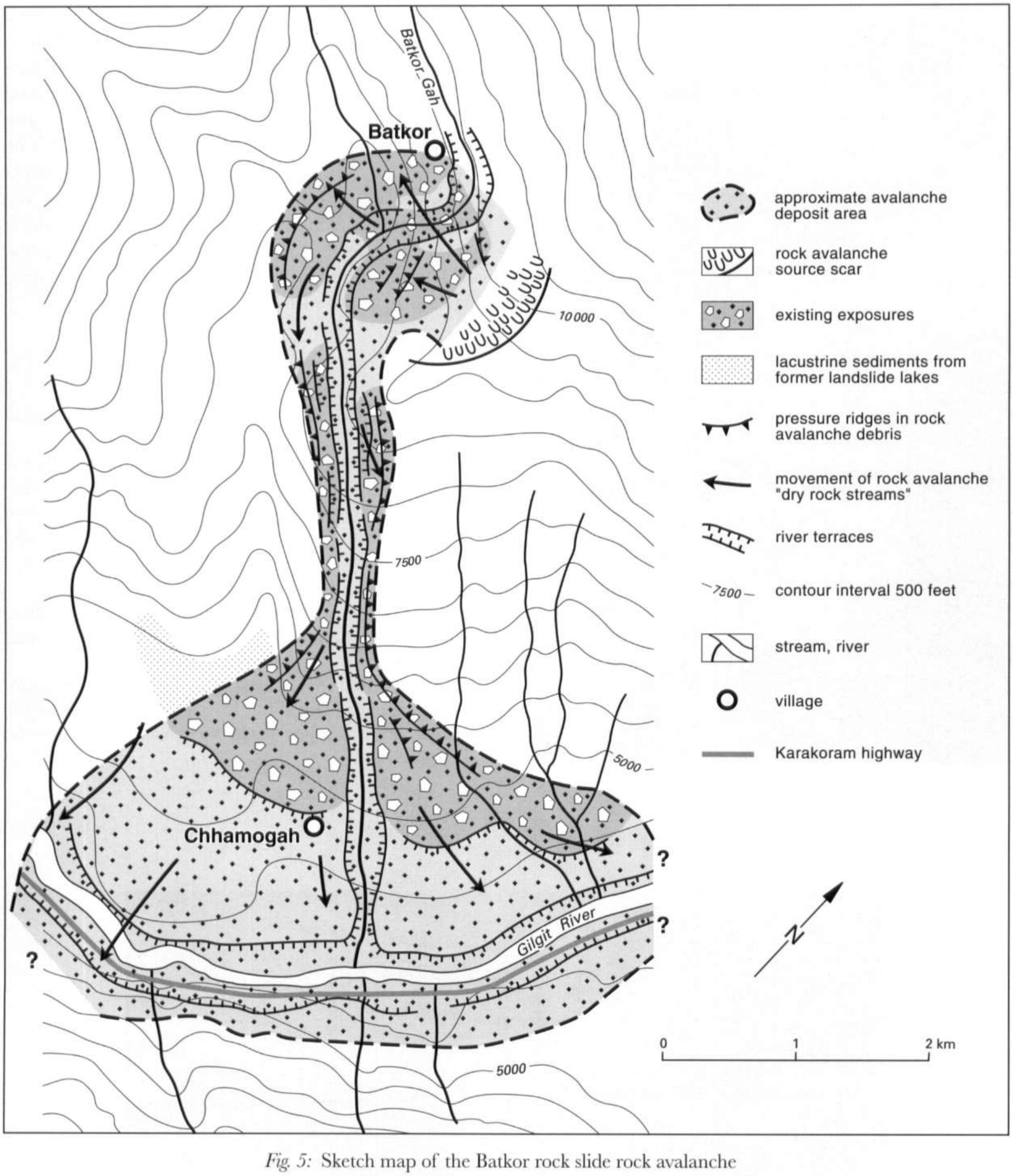
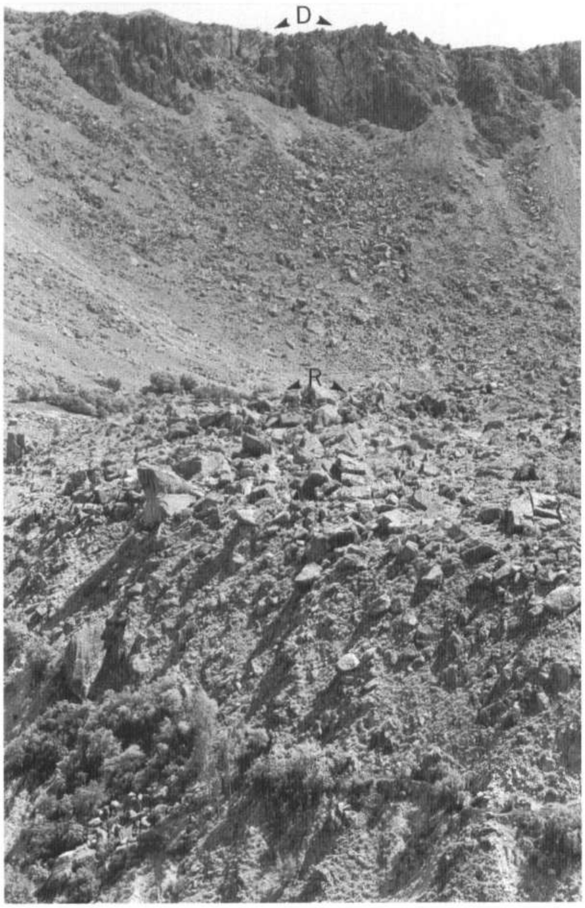


Fig. 5: Sketch map of the Batkor rock slide rock avalanche
Skizze der Batkor Bergsturzbahn

the river cut through, removing much of the original lobe.

At depths greater than about 10 m, the bouldery diamicton displays typical bands of remnant stratification, and flame-like, crushed and attenuated quartz veins. However, the material is entirely broken and pulverised bedrock, of a composition identical to that in the detachment zone. It is not paraglacial debris flow materials, as was suggested (DERBYSHIRE a. OWEN 1990, 37 and Fig. 2.11). Debris flows of reworked rock avalanche material, are present as relatively superficial materials over parts of the lobe above Chhamogar.



a)

Lacustrine deposits around Batkor village record damming of this stream. The entire Gilgit-Hunza drainage was also impounded. The height of the barrier make it a possible candidate to explain well-defined lacustrines stretching well beyond Gilgit town, previously attributed to a 'Glacial Lake Gilgit'. (N.B. The 'Dhak Chauki moraine' of DESIO and OROMBELLI (1971), is also, unmistakably, a rock avalanche (# 32), that descended from the Gilgit's south/right wall. It was formerly seen as evidence for the lake being due to a late glacial Hunza Glacier damming an ice-free Gilgit valley (DERBYSHIRE a. OWEN 1990, 40).)

Photo 8: The Batkor rock slide rock avalanche, 20 km east of Gilgit

a) View of the detachment zone (D) from near Batkor village. R = rubble in the proximal region of the rockslide

b) View down the lower Batkor valley towards its junction with the Gilgit showing the remnants of 'trim-line' and caroming flow of the rock avalanche

Batkor-Bergsturzbahn, 20 km östlich von Gilgit

a) Blick auf die Scherzone (D) aus der Nähe der Siedlung Batkor. R = Schuttmasse in der unmittelbaren Umgebung des Bergsturzes;

b) Blick in das untere Batkor-Tal in Richtung der Einmündung in das Gilgit-Tal. Es zeigt die letzten Reste der Sturzmasse ("trim-line") und den chaotischen Fluss des Bergsturzes

b)

5 Rock wall instability and failures

The examples indicate something of the diversity and complexities of rock slide events in the region, but it will be useful now to return to broader issues. Catastrophic rock wall failure is commonly triggered by extreme climatic events, as at Bualtar in 1986 (HEWITT 1988), or by earthquakes, as in the 1841 Nanga Parbat event (SHRODER 1993, 22–23). We lack observations to deduce what triggered the cases described above. Nevertheless, they show how failure itself is prefigured by structural, lithological and tectonic developments, and more or less long-term processes that expose and weaken rock walls (SCHEIDEGGER 1999).

Detachment scars of rock slides along these valleys are usually identified with specific geological structures, bedding or foliation planes, faults or major joint systems. Rivers tend to be aligned parallel, or nearly so, to geological lineaments or the margins of stratigraphic and plutonic units (SEEBER a. GORNITZ 1983; CRONIN 1989). Valley incision and alignment prefigures the local geometry of rock walls.

Most of the layered rocks have been subject to complex over folding and thrust faults. Failure geometries, as in the Naltar Lakes and Bualtar Glacier events, tend to involve several planes of weakness. They can also be defined by sets of intrusive sills and dikes. Planes of failure in plutonic rocks may involve discontinuities in the original intrusions, or foliation associated with synorogenic emplacement, or later tectonic disturbance. Hunza and Gilgit rock slides include many of a size and character to comprise 'unroofing events', that have exposed or degraded outcrops of the many small and large plutons of the region (SEARLE 1991, 65–73, 99, 119–130). However, while individual examples relate to specifics of local geology, the whole set includes nearly every rock formation, rock type, structural style, and clima-geomorphic context in the region.

Erosionally-induced stresses are also important, whether directly, or from exploiting preexisting lines of weakness. Glaciation and deglaciation are uniquely identified with most detachment scars. They tend to occur near the upper limit of the last major valley glaciation (HEWITT 1999; SELBY 1993, 323). Detachment zones often lie at valley junctions, for example the Qalandar Uwin, Nomal and Naltar lakes events; or directly opposite the entrance of large tributaries, for instance the Bhurt, Batkor and 'Dhak Chauki' events. Some very large events originated where ice was strongly forced against an over steepened valley wall, as with Nomal, Upper Henzul, Yashbandan-Barut, and Naltar-Dumial.

Gravitational sagging or spread of mountain ridges (= 'sackung'), is associated with mass rock creep, brittle fracture and differential movement. In glacially over steepened rock walls, it is known to precede some catastrophic landslides (RADBRUCH-HALL 1978; BOVIS a. EVANS 1996). Moreover, glacial over steepening and debuttressing were identified with failures in plutonic, metasedimentary and metamorphic rocks.

In general, this reinforces an emerging picture of catastrophic rock wall failures as likely in most tectonically active, high relief areas, especially following glaciation (GARDNER 1970; VOIGHT 1978; WHITEHOUSE 1983; SHRODER 1989; SELBY 1993, chapter 15; SCHEIDEGGER 1998; BLAIR 1999; EVANS 2001). Yet, the density and scale of such events in the Karakoram does seem exceptional. Meanwhile, their influence on river valley development seems unprecedented.

6 Impacts of rock avalanche deposits on valley development

Seventy-three of these events left cross-valley deposits that interrupted the rivers. There is, on average, one rock avalanche for every 12 km of river length surveyed. More than one fifth of main channel length passes through and over rock avalanche debris, or places where it has been reworked and removed. Stream thalwegs and valley fill sediments reflect disturbance by rock avalanches, and superimposition of bedrock channels from them.

Two main, form-generating episodes are recorded in these landslide-fragmented river reaches. With emplacement of the rock avalanche, local base level is raised and an aggradational sequence or epicycle occurs upstream. Most of the well-known lacustrines, braided river gravels, and sediment fans developed upstream of landslide impoundments, and to a level determined by them. At least 44 rock avalanches dammed landslide lakes, including most of those reported by SEARLE (1991, 283). Karambar Lake at the head of Ishkoman valley, and 'Kutu Lake' in Upper Naltar, are the only two contemporary, main valley lakes yet identified. At Jut (# 40) in Kargah and Naltar Lakes (# 79), are fully intact barriers, but their reservoirs are totally infilled. The lower parts of at least thirty-four others, breached to some extent, continue to act as natural weirs.

Once a dam is completely infilled or breaching begins, valley-fill sediments start to be reworked and removed. Sediments of the aggradational sequence are cut through. This explains most of the segmented or 'lion's paw' sediment fans. The spectacular suites of river terraces along these rivers mainly record the pace and extent of barrier breaching. Whereas channels above and, often, below a barrier, become braided or anastomose, a single, steeper channel cuts through it. Boulders, in place or eroded from the rock avalanche, armour the bed.

As the constructional landforms are degraded, streams are superimposed onto underlying bedrock, or pre-landslide valley fill. Another typical feature results, the superimposed or 'epigenetic' gorge (VON ENGELN, 1942, 224–225; COTTON 1958, 230–233). Most rock gorges examined are of this type (HEWITT 1998). Examples occur at Dulung Bar-Darkot (# 1), Gakutch-Gilgit (# 24), and Rishijerab (# 46) in Chapursan. A few others are rock bed spillways where tributary glaciers diverted main streams along valley walls; for example where Yashkuk Yaz blocked Chapursan valley, or Bualtar blocked the Hispar.

However, in these, and at least twenty-two other cases, downstream rock avalanche barriers control local base levels, and influence sedimentation around the glacier termini (Table 3; HEWITT 1998). Sedimentation and landforms at Hispar Glacier and below it, record effects of the Gharesa-Huru event (# 71). It formerly blocked the valley to at least 450 m above present river level, causing the build up of vast quantities of valley-fill sediment that reach back to Hispar village. Moreover, ice margin sediments around the lower Hispar record these developments, not just glacier fluctuations. An extensive area of young moraines occurs around Falolingkish shepherds' huts, opposite Hispar village and 20–60 m above the present ice, recording a formerly much wider terminal zone. But it was a response to aggradation behind the rock avalanche. As the pro-glacial valley floor before the Hispar snout was again lowered by some 150 m+ of reexcavation, the ice abandoned that area. Trenching of valley fill also created the suites of high river terraces, including those on which Hispar village lies.

7 *Concluding Remarks: geomorphology of landslide-interrupted rivers*

The surveys have shown that landslide-interrupted river reaches are responsible for most of the 'diluvial' deposits of SCHNEIDER (1959), the 'valley fill sedimentation' and sediment fans of DERBYSHIRE a. OWEN (1990), and the 'late glacial lake sediments' of BÜRGISSER et al. (1982), OWEN (1989) and SEARLE (1991). Terraces in, and trenching of, valley fill, mainly reflect degrading of landslide barriers. The cutting of bedrock straths and most bedrock gorge sections represent superimposition of streams from sediments accumulated with these barriers.

It should be reemphasised that these are features long recognised as characteristic of the Upper Indus fluvial landscape (DAINELLI 1922). However, they had been attributed to late Quaternary climatic and tectonic trends. It now appears they relate, most directly, to postglacial rock wall instability and catastrophic failures. The features involve but do not specifically recording late-, post- and paraglacial sedimentation (OWEN a. DERBYSHIRE 1993), nor are they direct consequences of on-going tectonic uplift (HOWARD 1996).

The many landslide interruptions have occurred more or less independent of each other in space and time, but their fluvial zone consequences have interacted for millennia or tens of millennia. The responses of stream, mass movement and other processes, along valleys fragmented by landslide events, appear as overlapping but out-of-phase episodes. The sediment bodies and erosional features they create are not merely, and only indirectly, expressions of larger climatic or geological controls. Even specific regional features of lithology, structure and rates of uplift, or of deglaciation and dessication, are masked.

The resulting, diachronous sets of aggradation-degradation episodes tend to preclude or mask systematic adjustments through the stream system. They temporarily disengage main and tributary valleys, whose landform development may be forced in opposing directions. Rapid down cutting in a main stream can occur while landslide-impounded aggradation occurs in a tributary or, if the latter is a hanging valley, vice versa. Such divergence has applied, for extended periods during the Holocene, in the relations of the Chapursan, Hispar and Naltar valleys to the main Hunza, or of the Bagrot, Kargah or Yasin valleys to the Gilgit.

In general, landslides buffer the effects of endogenetic and exogenetic controls, and can temporarily reverse or reallocate their influence on stream development. Aggradation occurs in impounded valley reaches regardless of the direction in which climate or uplift are tending to drive stream power or sediment yields. The breaching of cross-valley barriers initiates and regulates terrace cutting, entrenchment of sediment fans, regardless of whether sediment delivery from tributary valleys or the whole basin is increasing or decreasing.

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