Geogr. Fis. Dinam. Quat.
36 (2013), 81-94, 14 figg., 1 tab.

DOI 10.4461/GFDQ.2013.36.6

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«THE GREAT LATERAL MORAINE», KARAKORAM HIMALAYA, INNER ASIA

ABSTRACT: HEWITT K., *«The Great Lateral Moraine», Karakoram Himalaya, Inner Asia*. (IT ISSN 0391-9838, 2013).

Large moraines and related ice margin deposits, observed along the ablation zones of Karakoram glaciers, have been grouped together as the Great Lateral Moraine (GLM). It was formerly attributed to the Little Ice Age. Other studies propose a longer sequence beginning with late Pleistocene glaciations. All investigations have assumed the GLM records climate-driven glacier expansions. Evidence presented here challenges this, and the idea of a single origin in time or process. Bualtar Glacier in the Hunza Basin, with a much-discussed GLM, introduces the complexities involved. The glacier is surge-type, its fluctuations affected by large landslides onto the ice. Both have triggered depositional episodes out-of-phase with surrounding glaciers and climate variability. More decisive has been local base-level control by landslides downstream of Bualtar, especially the late Holocene, Baltit-Sumayar landslide. Similar conditions are shown to affect many, if not all, GLMs. No consistent relations were found with glacier size, morphology or known patterns of advance, but many surge-type glaciers and landslides in glacier basins are involved. A pervasive influence has been blocking of the upper Indus streams by large mass movements. To address these complex developments, valley glacier landsystems concepts are employed, especially as applied to debris-covered glaciers. Some distinctive Karakoram variants are identified. The regional environment seems not to produce a unique type, but a complete spectrum of valley glacier landsystems. Recent evidence of glaciers transitioning between landsystem types suggest how GLMs have developed and why interactions of glacial, fluvial, lacustrine and eolian systems, are important. GLMs are distinguished as «transglacial landsystems», developments in which glacial activity is disturbed and reconfigured by non-glacial processes. A paraglacial influence is also present, mainly through glacially induced rock slope instabilities. These lead to large postglacial landslides blocking rivers or descending onto smaller surviving glaciers. The interpretation offered is a challenge for existing views of late Quaternary developments.

KEY WORDS: Lateral moraines and troughs, Ice-marginal ramps, Moraine-dammed glaciers, Breach-lobes, Surge-type glaciers, Rockslide-rock avalanches, Fragmented drainage systems, Intermontane sedimentation, Transglacial processes, Valley glacier landsystems, Karakoram Himalaya.

INTRODUCTION

Along the ablation zones of many Karakoram glaciers bare cliffs in old lateral deposits rise from the ice edge and culminate above in prominent lateral moraines. The largest of these were formerly regarded as a single regional phenomenon and called the Great Lateral Moraine (GLM). Meiners (1998, p. 55) describes it as «*... a very well-marked and well-formed lateral, partly high moraine, which surrounds the glacier tongues*». A more explicit German term is *Ufermoranen-Dammen* [«embankment moraine dam (or barrier)»] (Wiche, 1961; Haserodt, 1989, p. 212). There are usually substantial troughs between the lateral moraines and valley sides - the «ablation valleys» of older literature (Visser & Visser-Hooft, 1935-1938; Hewitt, 1993). In them, heterogeneous and discontinuous deposits build up where avalanches, rock falls and debris flows come from the valley slopes, and where drainage is channeled or impounded (fig. 1).

In the 19th and early 20th centuries, glacier ice was commonly observed standing at or above the lateral moraines, adding to them and shedding water and debris into valley side troughs. It is something rarely observed since the 1920s except during glacier surges, making it seem logical to identify the GLM with the Little Ice Age (LIA). Some equated it specifically with the «1850 moraines» in the European Alps. According to von Wissmann (1959), «*... in High Asia [generally] the moraines...*

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The paper is dedicated to Prof. Monique Fort, to acknowledge her special and outstanding contributions to the geomorphology of the High Asian mountains. She has been an inspiration in tackling problems of scale and complexity that distinguish the region; that require attention to its peculiarities, and thinking «outside the box» of predominantly Eurocentric ideas (Fort, 1987, 1995; Fort & Peulvast, 1995; Fort, 2000). Investigations at Bualtar Glacier were funded by the International Development Research Centre, Ottawa, Canada; Pakistan's Water and Power Development Authority; and Wilfrid Laurier University's Office of Research. Local residents and mountain guides, especially Mr. Shaffi Ahmed of Nagar, gave invaluable information and field assistance. I am indebted to two reviewers for helpful comments, and Ms. P. Schaus for preparing the figures.

FIG. 1 - The GLM along the left flank, mid-ablation zone of Chogo Lungma Glacier. The marginal trough is to the left of the great lateral moraine. Active ice to the right is at a somewhat higher level, but below the GLM crest (photo: K.H., 2003).

originate in the high stand glaciation at the middle of the past [19th] century…». However, Kick (1989) challenged this view of the «large moraine» at Chogo Lungma and other Karakoram glaciers and supported Mason's (1930) view, that «*… the majority of glaciers in the region were in a condition of maximum advance between about 1905 and 1915*». Haserodt (1984, p. 83) argues, on the basis of tree ring data, for: «*… a minimum age of the GLM of Bagrot [Glacier, near Gilgit] of 280 years… closer to the beginning of the "Little Ice Age" period…*». However, since the mid-1980s, most studies invoke several glacial expansions to explain these features, including some much earlier than the LIA (Schneider, 1969; Haserodt, 1989; Kick, 1989). While not using the term, Kalvoda (1992) attributes lateral margin deposits called GLM by others to events beginning in the late Pleistocene.

All existing interpretations at least agree that the GLM records climate-driven glacier fluctuations. Evidence assembled here supports a diversity of origins, in time and process. Perhaps the term GLM should be abandoned. However, it identifies widespread, conspicuous ice-margin features in the region, is an important notion in the literature and, in itself, does not imply a particular explanation. Here, the plural is used to reflect the variety of GLMs. Quotes are applied when citing other usage. An example introduces the conditions of interest.

THE BUALTAR GLMS

Bualtar Glacier in the Hunza Basin, sometimes called «Hopar Glacier», has an area of 115 km^2 and a main ice stream 22 km long. It is largely avalanche-fed and drains northwards from a precipitous source zone below Diran Peak (7,266 m) in the Rakaposhi Range. With a terminus at 2,450 m, total basin relief is 4850 m. Surrounding the lower tongue and for some 10 km up-valley are huge lateral moraines (fig. 2). Substantial slope, kame terrace, and

FIG. 2 - Ablation zone of Bualtar Glacier looking downstream showing its GLMs (arrows), the associated valley side deposits, and steep cliffs to the present ice edge. Ultar Peak (7,388 m) is in the top right background (photo: K.H., 1986).

lacustrine deposits fill valley side troughs. Similar GLM features occur along the Barpu Glacier, which terminates beside Bualtar and was joined to it in the past (fig. 3).

Existing studies and interpretations

Bualtar and Barpu Glaciers appear in several influential investigations of the «GLM» and related matters. Haserodt (1984, p. 93) discussed the GLM at «Hoppar» and sketched its cross-profile, placing the highest ice in the «*17th, 18th or 19th c.*». A later paper describes the features as «High Stand moraines» of the LIA, defined by «*300, 75-100, and 10-25 year vegetation growth*» (Haserodt, 1989, pp. 214-217).

The same features are identified by Kalvoda (1992, Plate XXVI/2, p. 189) as: «*... Glacigenous sediments of the lower part of the Bualtar valley-glacier tongue... Huge, in some places up to 160 m high walls of lateral moraines dating from the distinct advance of this glacier...*». He adopts a much-expanded time frame, proposing that, «*The highest [moraines]... formed during the Hunza phase of glaciation in the upper Pleistocene*». In a more recent paper, Kalvoda & Goudie (2007, pp. 112-115) assign the «*huge walls of lateral moraines [close to Nagar village]...*» to «*... the last advance of the valley glacier in the upper Pleistocene [62,000-68,000 years ago]*» (p. 108 and 113). There are no actual age-determinations for GLM sediments or surfaces at Bualtar. Tree ages noted by Haserodt (1989), as earlier by Wiche (1958), were not supported by tree-ring or other dating methods (Kick, 1989). Chronologies are based on presumed morpho-stratigraphic relations and inferred elevation and vertical relations to glaciations of the Hunza valley (Shroder & *alii*, 1993, p. 154; Owen, 2006, p. 15).

The state of the Bualtar GLMs in recent decades is affected by erosion, or burial by wind-borne dust, and tram-

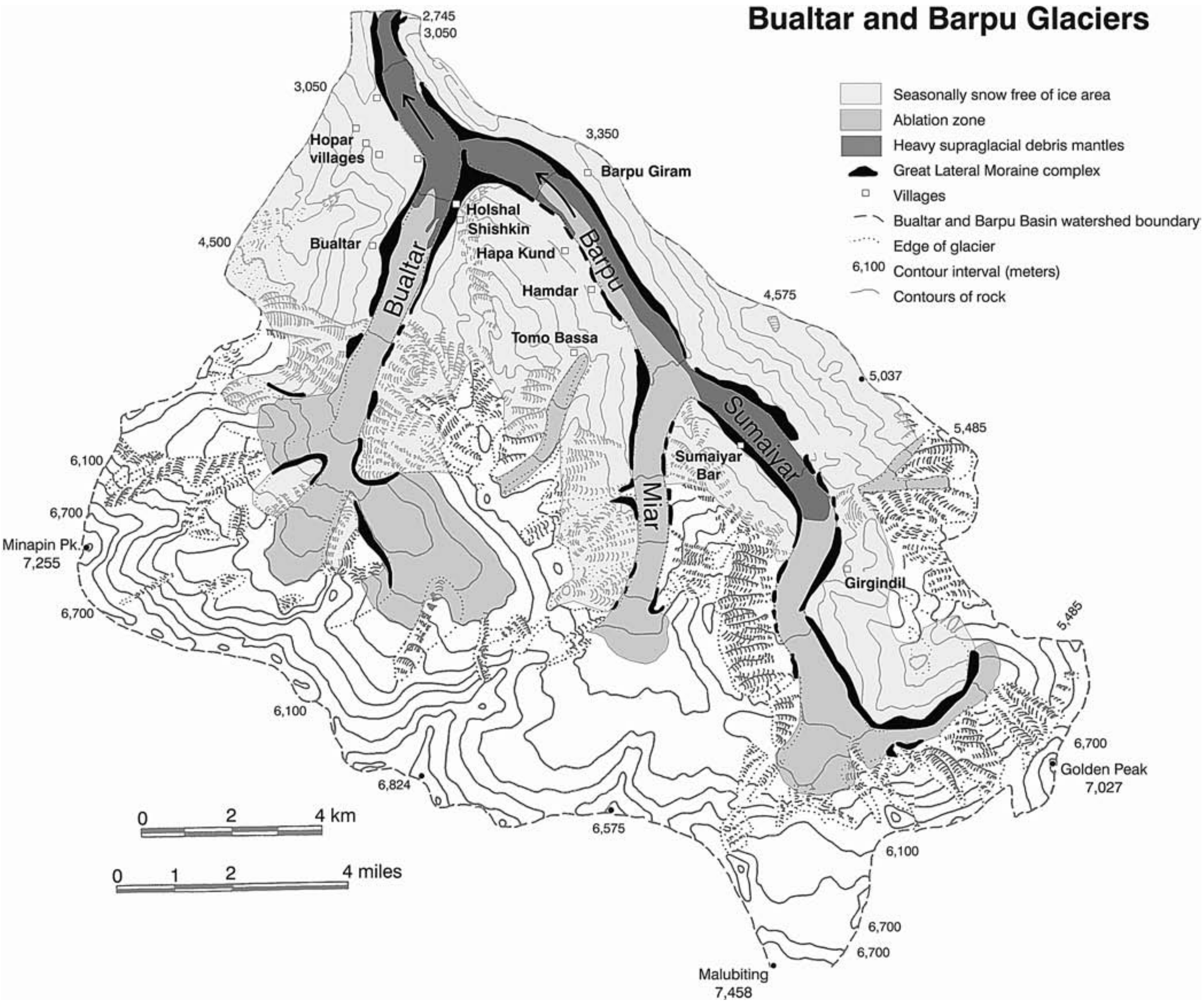


FIG. 3 - Topographical map of Bualtar and Barpu Glacier basins showing the extent of the GLM complex and debris-covered ice.

pling by animals and humans. More important, the great cliffs in former glacial deposits are «erosion» features. They do not record actual ice contact surfaces or trimlines of the highest, last, or any past glacier expansion, but an extended period of degrading of GLM deposits (fig. 4). In particular, large slump blocks continue to form and slide towards the glacier on the Hopar and Shishkin sides (MacDonald, 1989; Hewitt, 2009a). Erosion has removed over half the original sediment build-ups above existing ice levels. The original GLMs and Bualtar ice surfaces must have been tens of meters higher than today's remnants, and closer to the valley center (fig. 5). Conditions observed in recent glacier advances also need emphasis.

Bualtar fluctuations

Reports describe intermittent sudden advances of Bualtar, alternating with large retreats, sometimes stagnation (Conway, 1894; Workman, 1908). Rapid advances were re-

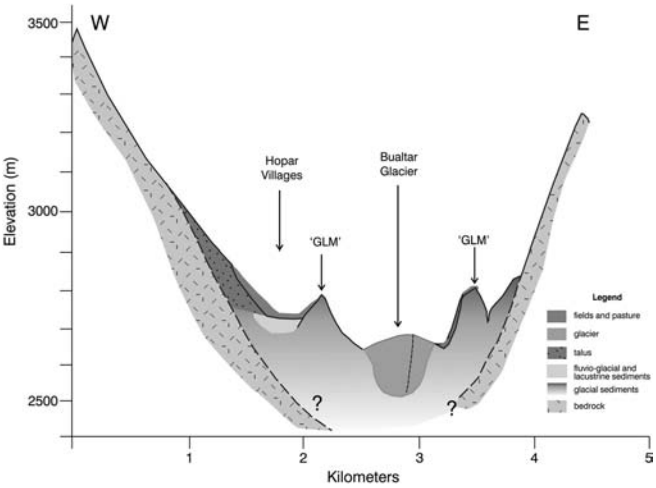


FIG. 5 - Present-day transverse cross section of Bualtar Glacier, 5 km above the terminus to illustrate relations of present ice to GLM remnants. Depth of ice here (maximum 230 m) is based on monopulse radar depth soundings. (Vertical exaggeration, x 3).

FIG. 4 - View from the GLM crest down the left cliff face to the lower Bualtar. Large rotational landslips carry former GLM deposits to the glacier margin. Clearly, the blocks in the foreground were much higher than the existing, eroded crest. Note the abandoned old road, paths and irrigation channels on top of the nearest landslips (photo: K.H., 2006).

ported in 1922 and 1923, and in 1929-1930 (Visser, 1928; Mason, 1930). Two separate, rapid accelerations occurred in 1987 and 1990 (Gardner & Hewitt, 1989; Hewitt, 2009a). They lasted a few months, causing massive disturbance of the glacier and confirmed that Bualtar is a surge-type glacier (Hewitt, 1969). In both recent events, fast flow stalled before reaching the terminus, but the glacier advanced gradually thereafter, and further than at any time since the 1920s (Mason, 1930, 229-301). The surges triggered or accelerated large-scale mass movements in GLM materials (fig. 6).

In surge-type glaciers, thickening and advances arise from surges in a cycle unique to each glacier (Sharp, 1988; Jiskoot, 2011). They complicate mass balance and relations to climate. In the late LIA, when most nearby glaciers were advancing, Bualtar retreated. Recently, when most others were retreating, it advanced.

It is unlikely Bualtar only became surge-type in recent centuries when rhythms show roughly two episodes and four surges per century. If at all representative, these indicate 200 and 400 Holocene events, respectively. Surge activity could help explain the massive moraine building and other GLM features discussed below.

Conditions are further compounded by landslides. In 1986, massive rock slope failures deposited about 20 Mm^3 of debris onto Bualtar (Hewitt, 1988). By 2012, the debris sheet, some 4.5 km^2 area, had been transported 10 km down-glacier, while suppressing ablation and standing 10-20 m above the surrounding ice. Rock avalanche material is shed from the raised glacier surface. It forms ridges of lateral moraine that rise, fall or pinch out irregularly along the ice-edge (fig. 7). The deposits are «moraines» in geometry and depositional style, but their composition and timing depend upon rock avalanche materials. The landslides, lasting a few minutes, created a disturbance continuing for decades and producing distinctive deposits (Hewitt,

FIG. 6 - Bualtar Glacier during the 1987 surge. The flood of ice and severe crevassing can be compared with 1986 in fig. 2. There was increased landslide activity along the margins and numerous outburst floods from ice margin lakes (arrow), all helping erode GLM materials (photo: K.H., 1987).

FIG. 7 - Bualtar ice margin during passage of thickened ice showing (high stand-type?) moraine-building fed by rock avalanche debris (photo: K.H., 2010).

2009a). The relevance to GLMs, of course, depends on landslide frequency.

Local accounts describe a similar landslide onto Bualtar Glacier in the late 19th century and are supported by field inspection of the source area. In the 1980s, sand avalanches from the GLM cliff at Hopar had sedimentary characteristics of rock avalanche matrix materials, apparently from a prehistoric event (fig. 8). In Barpu basin remnants of three prehistoric rock avalanches have been found that descended onto the glacier (*ibid.*). The largest, from near the summit of Spantik Peak (7,027 m), travelled 11 km down-glacier. Debris from it caps GLM ridges for another 5 km at least, apparently emplaced in a surge event (Hewitt, 2002, p. 368). Thus, landslide forcing seems a recurring source of moraine-building episodes (Hewitt & *alii*, 2011a). Even so, neither the landslides, surges, or the neoglaciation formerly invoked, offer sufficient explanation of the GLMs.

GEOMORPHIC SETTING OF THE BUALTAR GLMS

Bualtar and the Hispar valley

As Kalvoda & Goudie (2007) observe, the huge terraces of sediment on the Hispar River left bank, below the Bualtar junction, seem related to its moraines. So are landforms around the junction of Bualtar and the Hispar, where multiple shifts in the glacier and stream channels are recorded. Several superimposed or «epigenetic» rock

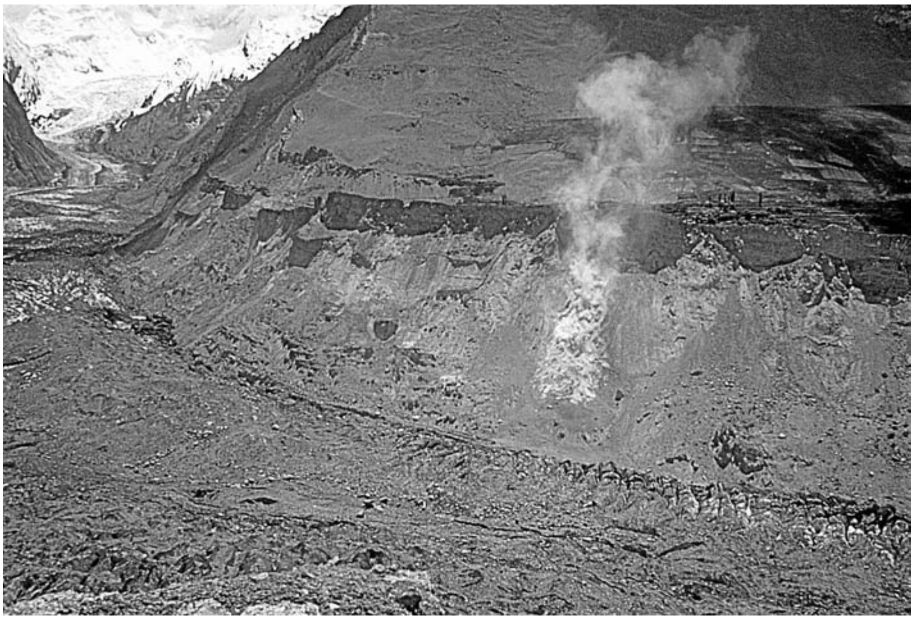


FIG. 8 - Sand avalanches from the flank of the Bualtar GLM below Hopar villages. Dozens were observed in 1985 and 1986. The composition, combining a single lithology and angular or very angular clasts, suggests prehistoric rock avalanche material deposited in that horizon of the GLM (photo: K.H., 1986).

gorges occur, where streams were let down onto former valley flanks or bedrock spurs from valley fill, landslide debris, or moraines (Hewitt, 1998; Ouimet & *alii*, 2008).

Presently, Hispar River enters the Bualtar Glacier fore field and together with its outlet stream, rejoins a former Hispar epigenetic rock gorge, choked above by talus. Bualtar ice has dammed the Hispar, and outburst floods are reported from the glacial lakes (Workman, 1908). Landslides have dammed the river up-valley of the Bualtar entrance.

A more surprising feature is how closely the GLM location and morphology conforms to today's ice tongue (fig. 9). Ice surface levels up to 250 m higher are not matched by evidence of comparable advances or lateral expansion of the ice (fig. 10). In recent years, a mere 10-15 m thickening of the lower Bualtar involved an advance of 3.5 km. Lateral moraines spread outwards tens of meters as well as building 5-15 m vertically within the old GLMs (Hewitt, 2009a). Another discovery seems key to the scale of locally confined GLM sedimentation.

The Baltit-Sumayar landslide

A large, late-Holocene landslide blocked the Hispar River at its junction with the Hunza. A massive rock slope failure descended from above Baltit into and across the Hunza River, also damming the Hispar and Silkiang rivers (Hewitt, 2001). Deposits record lakes impounded for decades if not centuries. The terrace sediments on which the Nagar villages lie were likely deposited behind or protected by the landslide in the older glacial valley of the combined Barpu-Bualtar, Gharesa and Hispar glaciers.

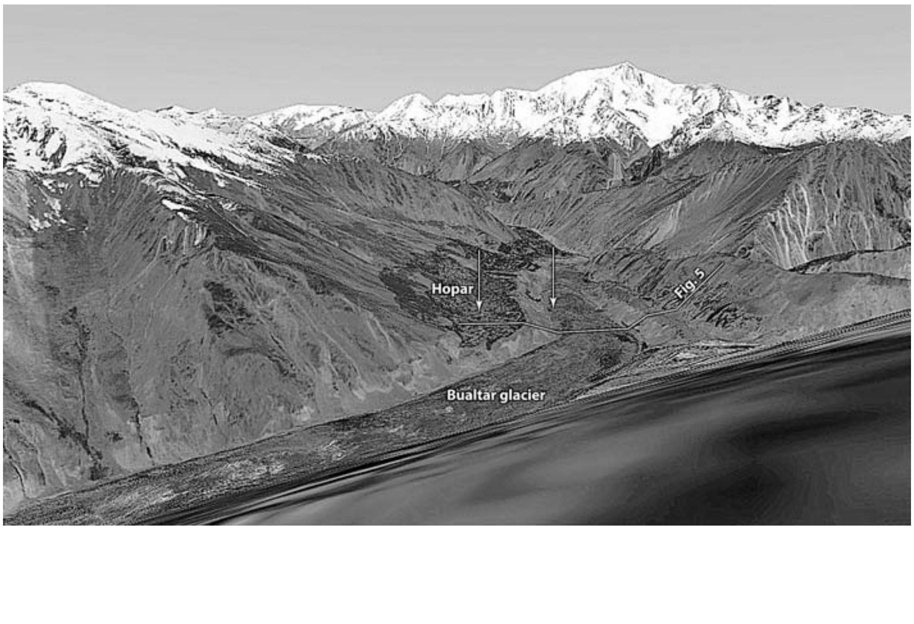
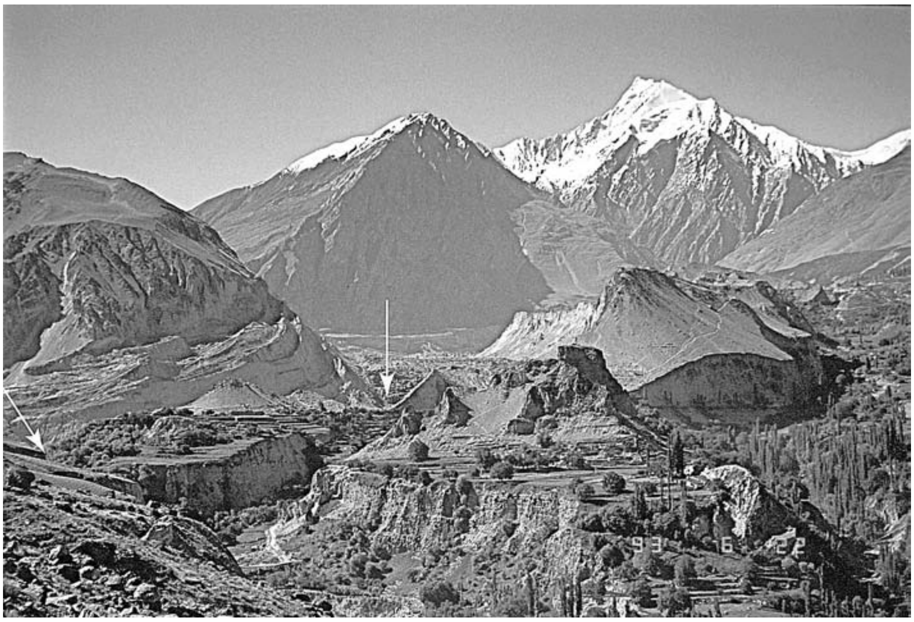


FIG. 9 - Satellite image of Bualtar glacier tongue showing close relations of GLMs to existing Hispar and Barpu ice streams (source: landsat ETM+ image, acquired 2006-07-26, covering a SRTM DEM, resolution 90 m). Location of the cross-section in fig. 5 is shown. Remains of the 1986 rock avalanche debris are at and below right hand arrows. Vegetated areas are irrigated land of Hopar villages (left hand arrow).

FIG. 10 - View looking north east from above Hispar River, showing the vertical extent of the Bualtar GLM deposits and how they wrap around the existing, lower Bualtar tongue (arrows). The treed valley side trough at the right of the photograph was occupied by the breach lobe in fig. 13 (photo: K.H., 2001).



The Baltit-Sumayar deposit is 8-10 km downstream of the Bualtar junction, but the dam crest is at a similar height to the highest GLMs (fig. 11). These morphological relations suggest an alternative explanation of sediment build-up around Bualtar terminus. In its present position the Bualtar tongue seems likely to have floated in the landslide lake until sediment build-up filled the lake and elevated the ice. The Baltit-Sumayar event affected developments along the lower Hispar for several millennia. High stand conditions lasting some centuries would give ample time for glacier surges and landslides to influence moraine building. Subsequently the landslide dam was breached, but gradually, and is not fully cut through. It remains local base level for the Hunza and Hispar valleys.

Relations to Baltit-Sumayar are complicated by other landslides that have blocked Hunza valley. There are at least fifteen large, post-glacial rock slope failures between its junction with the Gilgit and Sost (Hewitt, 2001). Ghulkin and Gulmit glacier tongues lie at the head of a river reach that has been repeatedly blocked and aggraded, as in the 2010 Atabad landslide. Two prehistoric events in the adjacent Sarez section involved long-lived lakes. The uppermost lake beds over the Nomal megaslide close to Gilgit are at elevations of 2,500-2,600 m, meaning its lake could have reached the Bualtar terminus and Batura's. There is no age-determination, but the landslide post-dates the last major glaciation (Hewitt, 2001, 2009b).

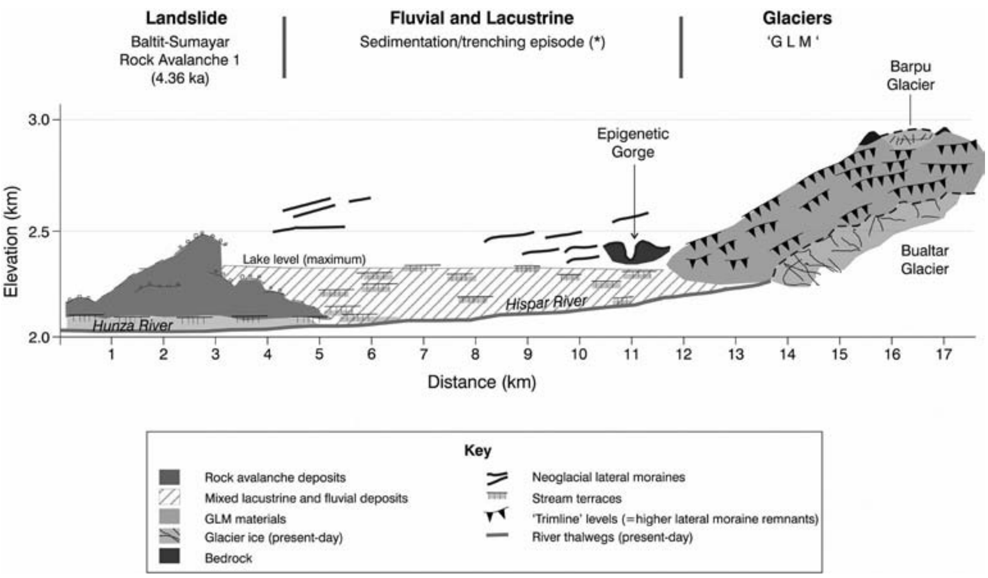


FIG. 11 - Schematic longitudinal cross-section of the lower Hispar valley from Baltit-Sumayar landslide dam to the Bualtar and Barpu GLMs.

INTERPRETATIONS

The origins of the GLMs involve two interrelated sets of causal factors: ice-margin and valley side depositional processes, and controls capable of altering ice levels, dynamics and, perhaps, debris supply. The first set of causal relationships can be addressed in terms of the «landsystems» of Benn & *alii* (2003). The second, involving external controls, require some modified and extended «conceptual relationships», to use their terms.

Debris-covered valley glaciers and landsystems

Landsystems, as they apply to valley glaciers, have been developed by Boulton & Eyles (1979), Eyles (1983), and Benn & Evans (1998, Part 2). Appropriately, for GLM concerns, the focus has been on glacial sediments and deposit assemblages. Those at glacier margins depend, firstly, on the ratios of sediment and ice reaching them, and the efficiency or otherwise of transport through and beyond pro-glacial areas. In these terms, Benn & *alii* (2003) propose a spectrum of landsystems, from clean or «uncovered glaciers», through increasingly heavy mantles in «covered» glaciers, to rock glaciers at the other extreme (*ibid*., p. 375, their figs. 15.23).

Uncovered glaciers promote «*... coupled ice margins...*» with efficient transfer of sediment between the glacier and pro-glacial fluvial systems. Lateral and terminal moraines tend to be minimal. By contrast, debris-covered glaciers are portrayed as «decoupled», with high sediment supply, inefficient or absent removal at the margins, particularly relevant for the «giant build-ups» associated with GLMs. Heavily debris-covered, «moraine-dammed» glaciers, are singled out as typically Himalayan. In general, «covered» glaciers are identified with high mountains and/or drier climates. Changes in landsystems are said to be responses to climate, especially increasing aridity or humidity.

This is a comprehensive approach, but requires qualification in the Karakoram context. Debris-covered ice and huge lateral margin complexes are widely present, but moraine-dammed termini like the example they give of Ghulkin Glacier, much less so. Many heavily «covered» Karakoram glaciers in fact belong to Benn & *alii*'s (2003) «coupled», «outwash-head» types, including Bualtar now and including most of the largest ice masses like Siachen and Baltoro. Their snouts overlook powerful outwash streams and there are few or no frontal moraines. Up-valley some, like Bualtar, Panmah and Chogo Lungma, have well-developed GLMs. In others, like Baltoro and Sarpo Lago, they are poorly developed or absent.

Conversely, steep tributary glaciers with clean ice, or only irregular patches of debris, can be «moraine-dammed» (fig. 12). Whether, and to what extent, debris builds up on the glacier surface depends as much on steepness, icefalls and crevassing, as the ratio of ice and debris supply.

If largely neglected, there are thousands of rock glaciers in the Karakoram, many of them glacier-derived (Owen & England, 1998; Shroder & *alii*, 2000). They differ from the moraine-dammed glacier type in having tip-heap margins, usually continuous with surface ridge-and-trough features, not a sharp transition between active ice and moraines (Whalley & Martin, 1992; Humlum & *alii*, 2007). There is exceptional variety of sizes and genesis (Giardino & *alii*, 2011). Much larger examples occur than are reported from intensively studied mountains elsewhere (Haeberli, 1985; Barsch, 1988, 1992).

All the terminus types proposed by Benn & *alii* (2003) are found in the Karakoram. A unique landsystem is not associated with its climatic regime or high mountain setting. Other conditions intervene to create a diversity of types, including the glacier surges and landslides mentioned above. Furthermore, it is evident that changes in landsystem type need not depend upon climate change or glaciations.

FIG. 12 - A tributary glacier in Nangmah valley, Hushe Karakoram; an «uncovered glacier» that is «uncoupled» and has a «moraine-dammed» terminal complex (photo: K.H., 2012).

Transitional types

Bualtar's lower tongue has been debris-covered since the earliest modern observations, but is outwash-head or «coupled» type. By contrast, the GLMs record former «giant bounding moraines» and «moraine-dammed» margins. Typical build-ups include the «repeated superposition of moraines around the margins» as described by Benn & *alii* (2003, p. 384). The GLM deposits record typical combinations of the «dump moraines and ice-margin aprons», the «ramps and fans» described by Benn and Evans (1998, pp. 475-480). Kuhle (1990) identified other relevant processes, as did Shroder & *alii* (2000) on Nanga Parbat glaciers. In each case, debris-mantled ice is considered important. It suggests that, when the high stand GLMs were being built, the moraine-dammed type and related features were more common.

The «Ghulkin-type» of Owen (1994), heavily mantled and moraine-dammed, is proposed by Benn & *alii* (2003) as typical of debris-covered glaciers. Karakoram examples include the Gulmit and Barpu, and the Lupghar and Kunti Glaciers whose GLMs are described by Meiners (1998). This type seems important for GLM interpretation. However, on the one hand, as noted above, such conditions are actually quite rare today. On the other hand, recent behaviour of Chillinji Glacier on the upper Karambar, or Yazghil in Shimshal, suggest this landsystem type is, at least partly, a response to other and special conditions, not only the debris cover. They may be fairly unstable. These two were Ghulkin-types in the recent past, Chillinji until 2002. Both have shifted to coupled, outwash-head types, mainly through «breach lobes» that overwhelmed moraine dams (see below). The transitions observed seem relevant for interpreting Bualtar GLMs. Relatively small increases in ice thickness and velocity, in Chillinji's case following a large landslide onto the glacier (Hewitt, 2001), carried lobes of terminal ice through the bounding moraines and down their steep forefronts. Most of the neighbouring glaciers in Hunza have giant GLMs but are also outwash head types. They involve another distinctive characteristic of the Ghulkin-type; ice levels elevated by sub-glacial deposition, not necessarily dependent on ice thickness or confinement behind moraine-dammed margins.

Gulmit and Ghulkin also sit up on ramps of sediment behind moraine dams, at the head of an aggraded river reach. Bualtar, however, has eroded its bed to a level where the outlet stream crosses bedrock to join a degrading main valley that is deeply entrenched in valley fill. The right flank below the active terminus is complicated by the large mass of stagnant ice related to the recent surges.

Kuhle's (1990) discussion of «ice-marginal ramps» deals with moraine-dammed, «decoupled» tongues where debris accumulates underneath as well as on and around ice margins, similar to Ghulkin Glacier. «Breach lobes» can be a singular indication of such conditions, where ice bursts through lower or weaker bounding moraines to emplace secondary lobes (Benn & *alii*, 2003, p. 384-385; Deline, 2009). Other examples are recorded in moraine formations near the Ghulkin and Ghulmit termini, and hundreds can be found in satellite coverage of Karakoram glaciers. Moreover, there is evidence of some five breach lobes along the left flank of the Bualtar GLM - intriguingly, opposite where Barpu could have joined it. The highest of these also marks the largest distributary path of Bualtar, possibly involving both Barpu and Bualtar tongues (fig 13). It is 150 m above today's ice, at the same level as today's lower Barpu. It confirms that the original GLMs were much higher than today's remnants, and the ice stream(s) elevated on an aggraded bed (fig. 14).

FIG. 13 - Moraines and channel of a breach lobe on Bualtar GLM left flank, 3 km from the present-day terminus. This and other examples suggest the ice lay in «ice-marginal ramps» (Kuhle, 1990), was «moraine-dammed» (Benn & *alii*, 2005), and at a higher level than existing GLM remnants. Note the large landslips in GLM materials, collapsing towards the present ice surface (photo: K.H, 1987).

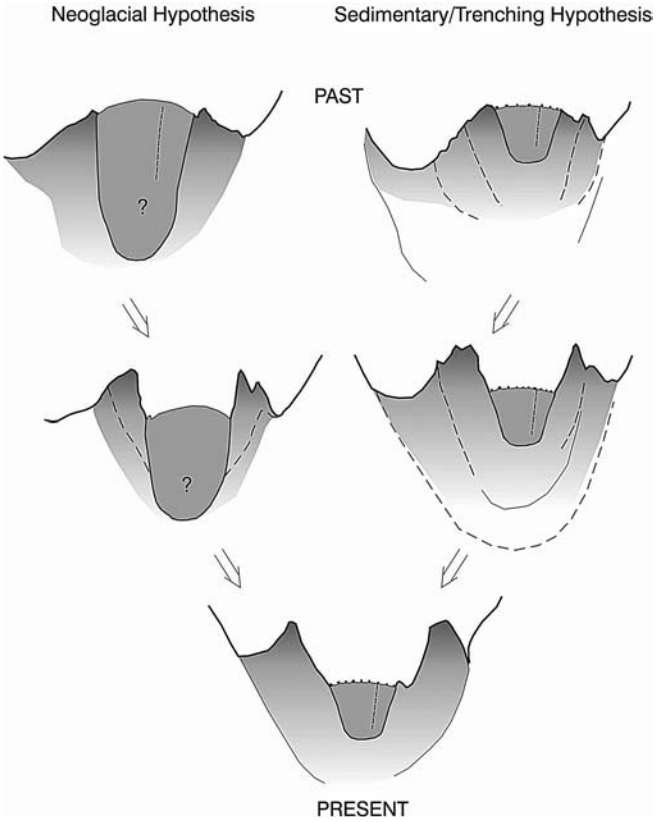


FIG. 14 - Schematic representation of sequences involving neoglaciations versus a «transglacial» sedimentation/trenching hypothesis. The former requires massive and unlikely thickening of the ice without much lateral expansion or ice advance. The latter involves changing sub-glacial as well as lateral sedimentation, and requires no great changes in ice thickness. The reality may well involve some combination of both types of control, but with ice thickening and advance during surges.

It is suggested that the Bualtar GLMs record episodic or transitional behaviour between aggraded, «Ghulkin-type» and degraded outwash-head type landsystems. This does return us to the broader question of how such changes could come about. Equally intriguing is how both types occur in «covered» glaciers, in close proximity and, today, at the same time. As indicated, hitherto GLMs have been attributed to glaciations, and reasons for challenging this must first be addressed.

The glaciation hypothesis

The main, «high stand» Bualtar GLMs have been placed in the «Ghulkin I stade», described as an «expanded foot», or «minor valley glaciation» with an age of a 25.7-21.8 ka (Kalvoda, 1992; Shroder & *alii*, 1993, p. 154; Owen, 2006, p. 15). It coincides with the last major glaciations of the Northern Hemisphere variously named «Wisconsinian/Würm/Weichsel» and when the Laurentide Ice Sheet reached almost to New York, and most of Scandinavia and Britain lay under ice. If it is true that ice limits in the Hunza Basin were only minimally beyond today's, Karakoram glaciation appears radically different from most of High Asia as well (Porter, 1970; Fort, 1995). The evidence has been challenged (Kuhle, 2004, 2006).

The Baltit-Sumayar deposit enters this picture as «moraine». Schneider (1959, p. 207) calls it a «hardened rubble» formation (= «*verfestiger Blockschutt*»). It is a «deformed till» in Derbyshire & *alii* (1984, p. 488), and «morainic conglomerates» in Kalvoda & Goudie (2007, p. 109). Deposits upstream are attributed to glacial lakes of the «last main [Pleistocene] advance» (Goudie 1984, p. 383). The events are placed in the «Bhorit Jheel expansion» between 50-65 ka (Li & *alii* (1984), or 54.7-43.2 ka (Derbyshire & Owen, 1990; Owen & *alii*, 2002). It interprets the deposits as quite separate from, and much older than, the Bualtar GLMs.

These dates imply an extraordinary slowing or cessation of erosion. The Baltit-Sumayar deposits were emplaced over fluvial gravels and much deeper, buried valley fill, still intact. It implies that, in 40+ ka, «no net» erosion has occurred; not in pre-existing valley fill let alone in bedrock. The Hispar between Bualtar and the Hunza flows over valley fill pre-dating the «Ghulkin I stade» which precludes net erosion there for 20+ ka (Kalvoda & Goudie 2007, p. 112). It means all the sedimentation and trenching that shapes the GLMs and valleys below them, has occurred above valley floor levels from the late Pleistocene, and well above the last phase of valley incision.

It should be recalled that the region has globally exceptional relief and some of the highest known rates of uplift and denudation (Searle, 1991; Park & *alii*, 2001; Zeitler & *alii*, 2001). The Hunza valley here has been called «the steepest place on Earth» (Miller, 1984). Other evidence suggests exceptional rates of denudation and present-day geomorphic activity (Shroder & *alii*, 1993; Burbank & *alii*, 1996). However, the glaciations view means that for 50,000 years or more, and while hundreds of meters of late Quaternary uplift occurred, there was no equivalent incision.

The same view also invokes «much more» ice to explain the huge GLM deposition. At Bualtar and elsewhere, trenching and removal of that debris are identified with major glacier thinning and present-day conditions. It seems to run counter to what is usually thought to strengthen or weaken glacial processes.

The re-interpretation of the Baltit-Sumayar deposit as a landslide, not «moraine», is based on diagnostics from lithology and morphology (Hewitt, 1999). Granitics and granodiorites from the Ultar Massif above Baltit, comprise 100% of the main deposit, and are emplaced over Hunza schists and carbonates of the Karakoram Metamorphic Complex. The latter outcrop along both flanks of the Hunza and Hispar valleys (Searle, 1991, p. 111). A trunk glacier descending either valley would carry and deposit some, if not mainly, metamorphic debris. Other rock avalanche criteria include distinctive broken and crushed clasts in all size fractions, long run-out and run-up morphologies, while characteristics definitive of moraine are absent (Hewitt, 2001).

Recently, the landslide event has been bracketed by a well-constrained ^{10}Be terrestrial cosmogenic nuclide age. Quartz-rich rock, retrieved from boulders on the landslide surface has an exposure age of 4.36±0.14 ka (Hewitt & *alii*, 2011b). It implies zero net erosion for barely one-tenth of the glacial time frame, and massive aggradation and trenching associated with the landslide, more in accord with regional geomorphic activity. However, the significance of these findings also depends on how far landsystem features at Bualtar apply elsewhere in the region.

OTHER KARAKORAM GLACIERS

GLM constraints and correlates

Barpu and its GLMs have been affected by the same constraints, if partially buffered by Bualtar. Tributaries of Barpu's Sumaiyar Bar branch are surge-type, possibly the whole glacier. The large mass of dead ice and thermo-karst forming its moraine-dammed terminal lobe may derive from a late 19th century surge (Conway, 1894). Several large landslides onto Barpu were identified earlier. However, this is a very local comparison.

Bualtar shares a number of relevant landsystem conditions with, for example, the Siachen, Kondus, Baltoro, Chogo Lungma, Hispar, and Bagrot glaciers. In addition to well-developed GLMs, their termini are: (i) Debris-covered: heavy supraglacial debris occurs over the lower 15 km or more of each glacier tongue, but none is «de-coupled»; (ii) Outwash head type: all examples have this style of terminus with powerful pro-glacial streams and no or limited terminal moraines; (iii) GLMs were emplaced over valley fill: each terminus has advanced and retreated over valley fill tens to hundreds of meters thick. Ice levels, terminus behaviour and pro-glacial sediment removal have been constrained by downstream aggradation or trenching, as reflected in; (iv) Relations of stream terrace and GLM geometries: downstream of the termini stream terraces have upper levels generally lower than the high stand GLMs, but continuous with associated glacier margin troughs; (v) Landslide interrupted drainage: in every case, one or more cross-valley landslide barriers exist a few kilometers downstream of the termini (Hewitt, 1998, 2006).

Other well-known examples such as Biafo, Batura, Yashkuk Yaz and Pechus may seem different. Their GLMs include extensive terminal moraines marking former and present ice positions. However, each has a low angle ice tongue entering a main river valley. Terminal moraines sit on top of river terraces that continue down-, and up-valley of the glacier tongue. In these cases too, glacial deposition matches aggradation levels in pro-glacial streams, as in item (iv) above. The other four conditions also apply to these glaciers.

An inventory of forty glaciers across the Karakoram and with well-developed GLMs extends the perspective (tab. 1). A third involve surge activity, and massive rock slope failures are known in a quarter. In all cases, the valleys downstream have been blocked by one or more cross-valley landslide barriers (Hewitt, 1998, 2006).

TABLE 1 - Forty Karakoram glaciers with GLMs identifying those with developments similar to Bualtar Glacier. This is a very small, preliminary sample but sufficient to point to a diverse group across the Karakoram

GLACIER	BASIN	Surges[1]	RAs on ice	RA dam	Glacier block	GLOFs
N. Terong	Nubra	?	X	X	X	X
Kondus	Saltoro		X	X		
Charakusa	Hushe	X (T)		X	X	X
Aling	Hushe	X (T)	X	X	X	X
Baltoro	Braldu	X (T)	X	X		
Panmah	Braldu	X (T)		X	X	
Biafo	Braldu	X (T)		X		X
Kutiah	Stak	X		X	X	X
Mani	Phu'gam	?	X	X	X	
Hinarche	Bagrot	?		X		X
Virjerab	Shimshal	?			X	X
Khurdopin	Shimshal	X		X	X	X
Yazghil	Shimshal	?	?	X	X	X
Malangutti	Shimshal		X	X	X	X
Koz Yaz	Chapursan	?		X	X	
Yashkuk Y.	Chapursan	?		X	X	X
Kuk-i-J.	Chapursan	?		X	X	X
Murkhun	Hunza	?	X	X		X
Batura	Hunza	? (T)		X	X	X
Pasu	Hunza		X	X	X	
Ghulkin	Hunza		X	X	X	X
Hispar	Hunza	X (T)		X	X	X
Garumbar	Hunza	X		X	X	X
Barpu	Hunza	X	X	X	X	X
Bualtar	Hunza	X	X	X	X	X
Silkiang	Hunza	?		X		
Karambar	Hunza	X		X	X	X
Minapin	Hunza			X		
Kukuar	Hunza	X		X	X	
Jaglot	Hunza	X		X	X	
Shani	Naltar			X		
Kutu N.	Naltar			X		
Bhurt	Karambar			X		
Karambar	Karambar	X		X		X
Pehkin	Karambar			X	X	
Chillinji	Karambar	X	X	X	X	X
Chatteboi	Karambar	?	X	X		X
Karambar P.	Karambar		X	X	X	X
Chiantar	Yarkhun			X		
Pechus	Yarkhun	?		X	X	X

[1] «X» identifies an evident influence on GLMs; «T» refers surge of tributary of glacier named; «?» suggests possibility based on indirect evidence; and blank no evidence for an influence.

«Transglacial» Landsystems?

GLM features of the Bualtar occur widely in larger Karakoram valley glaciers; most importantly a particular form of «coupling» of sedimentation between glacial and fluvial systems (Hewitt & *alii*, 2011a). The GLMs are composed largely and uniquely of glacigenic sediments. High stand moraines and other final touches may record climate-driven expansions, or surges, or pulses of debris following landslides onto the ice. However, in all examples investigated the timing, heights and volumes of GLM features are not simply outer or high stand markers of glacier advances. They cap massive sediment build-ups extending and controlled beyond the ice fronts. This distinguishes them from conventional latero-terminal deposits. It extends the range of valley glacier landsystems to include responses to non-glacial conditions.

When other earth surface processes significantly influence glacial processes they generate what may be termed «transglacial» landforms or sediment assemblages. «Transglacial» has been applied especially mass movements along glacier flanks (Iturrizaga, 2006, 2011). It compliments but is clearly distinct from «paraglacial», the direction of influence being reversed (Slaymaker, 2011). GLMs involve styles and combinations of ice-margin deposits and large-scale assemblages. Not only are deposits of other processes intercalated with glacial ones, but glacial action is directly influenced by non-glacial processes. As such the GLMs comprise a set of «transglacial landsystems». What distinguished them has been the influence of post-glacial developments along the upper Indus streams, notably the widespread occurrence of massive rock slope failures. The main consequence has been chronic disturbance and fragmenting of the rivers leading, not only to intermontane fluvial and lacustrine sedimentation, but episodes of aggradation around glacier termini that reach the stream valleys (Hewitt, 2006).

The GLMs are linked to episodes of intermontane sedimentation in landslide-disturbed river reaches; not only, and not necessarily at all, to glacier fluctuations. There seems to be, in part at least, a paraglacial influence of glacially over-deepened and steepened valley walls (Hewitt, 2009b). This supports an interpretation in which widespread and recurrent interruption of pro-glacial rivers by post-glacial landslides, and related geomorphic responses, has been critical for the timing, intensity and scale of GLM-building. Since landslides onto the ice and processes affecting valley side troughs are important for the GLM assemblages, these tend to be transglacial landsystems in a broader sense (Iturrizaga, 2011).

CONCLUSIONS

Past work has interpreted GLM and related deposits as driven by climate change and recording neoglaciation. There is no question that latero-terminal moraines and sediments assemblages found in the Karakoram do record purely glacial fluctuations due to climate, mass balance change or surge activity. Countless examples have been observed during LIA fluctuations and subsequent advances, and in surge events. However, neither the direct nor indirect roles of glacier fluctuations explain the scale, timing, complexities and ice levels peculiar to the major GLMs. What is distinctive about these developments involves post-glacial adjustments in Karakoram and surrounding mountain ranges. They are mainly driven by slope instability, massive collapses, and interactions of large landslides with axial drainage systems. It seems likely that this, and GLMs, are typical of interglacial conditions, but they should not be confused with more strictly glacial landsystems.

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(Ms. received 30 June 2012; accepted 1 March 2013)