3-23-2011

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Mass movement in northeast Afghanistan

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Keywords:
Slope-failure, Landslide, Debris slide/flow, Rockfall/slide, Rock glacier, Slope-failure complex

Abstract
Mass movements of nearly all types occur in Afghanistan but in the high relief, rugged Pamir and Hindu Kush mountains of northeastern Afghanistan, mass-movement threats to lives and property necessitated study to elucidate problems to development. Twenty-two different mass movements in bedrock in the Badakhshan Province of northeastern Afghanistan were studied for this paper, including large rock falls and rock slides, along with massive slope-failure complexes with many types and rates of movement. Where higher altitudes prevail in the region, ice-cemented and ice-cored rock glaciers are also common and overlie some of the other mass movements. Inasmuch as seismic energy sources in the Eastern Hindu Kush are maximal in southern Badakhshan, and relief, slope angles and precipitation all increase from west to east as well, the causes of the pervasive mass movement are plentiful enough, although direct cause and slope-failure effect are not known. Some weak sedimentary lithologies downfaulted into, or draped across crystalline rocks, also failed. Some intermixed tills also occur but are not
easily differentiated, even with analysis on the ground.

Using high resolution satellite imagery and digital elevation models, we assessed geomorphologic parameters to characterize spatial-organization structures related to zones of erosion, deposition and further hazard potential. Analyses indicate that many of the massive slope failures can be characterized and differentiated into various process domains and chronologic-development zones with their different impacts upon the landscape. Mass movements in Afghanistan can exhibit unique topographic signatures that can be used to better assess hazards in other mountain areas, especially where landslide-dam break-out floods threaten. Development of roads, bridges, buildings, and irrigation networks should be done with care in these regions of Afghanistan.

1. **Introduction**

General mass movement and slope failures have been known to a limited extent in Afghanistan in the past but it was not until Shroder’s (1989;1998a,b) work that an initial investigation was made of the phenomena nation-wide. He noted that the country was a mosaic of sutured and uplifted crustal fragments whose widely varying rock types, great relief, and high seismicity caused many slope failures. Rock falls and rock slides were observed to be among the most common type of mass movement, but debris falls and slides were also noted. Slump and flow landslides were noted in some unstable sedimentary rocks. Finally, Shroder (1989) also noted that slope-failure hazards were an important constraint on Afghan development although little data have been collected to confirm this supposition to date.

Rock falls and rock slides from the profuse cliffs of Afghanistan into the many valleys have been noted by many researchers (Bruckl, 1935; Desio, 1975; Grötsbach and Rathjens, 1969; Mirzad, 1970; Shank et al., 1977; Shroder, 1989; Weippert, 1964). Some of these mass-movement events have dammed up rivers to produce lakes throughout the country. As occurs in many other parts of the world, there is some
danger of eventual catastrophic breakout flooding associated with this type of lake. This commonly happens when the water impoundments rise to the top of the mass-movement dam and the resulting overflow erodes the dam face to cause failure (Costa and Schuster, 1988). In Afghanistan, however, the generally small river discharges in the water-deficient country, coupled with apparently high hydraulic conductivity ($\sim 10^2 \text{ cm}^{-1}$) through the presumably relatively open matrices of the landslides, has allowed them to remain largely in place in many locations. Long-term weathering of minerals, or infiltration of fine clastics into such dams, however, could reduce water transmissibility over time and thereby increase dam instability.

Additional types of mass movement in Afghanistan are those wherein various mixtures of fine and coarse clastics (debris) move downslope as variable amounts of water enter pre-existing deposits on slopes and either add a surcharge load, or dissolve binding matrices, or produce hydrostatic head in the ground water, or add seepage pressures; any or all of these causes of failure together can result in different types of slope movements. Velocities of movement can be highly variable, depending upon slope angles, amounts of water, and proportions of fine clastics. Rapid debris avalanches and rapid wet debris flows can occur as a result of monsoonal rains. Slower debris-flows and earth-flows can result in areas where there is less water. Some of those discussed herein probably occurred as glacial ice retreated in the last deglaciation (probably the Little Ice Age (LIA) of a few centuries ago), and the permafrost came out of the ground as well.

It is the purpose of this paper to describe and characterize multiple mass movements in northeastern Afghanistan in order to better understand distributions, modes of emplacement, and causes. As Afghanistan continues to be developed, to improve the life of its people and to help pacify the ongoing insurgency by increasing employment, protection of the transportation routes, bridges, fords, water supplies, and places of habitation must be developed against slope failures and associated breakout and other regional floods (Hagen et al., 2010), as much as possible.
Fig. 1. Index map of study area of northeast Afghanistan. Slope failure types of large slope-failure complexes, together with a few rock falls/rock slides and slow debris flows are the chief mass movements mapped in this study. The slope failures are plotted over an underlying geology map of Afghanistan by Wandrey and Law (1997). Numbered slope-failure names are listed by name and number in Table 1.
2. **Methodology**

Data sources included US Geological Survey (USGS) revisions and updates of historical Soviet geology maps at 1:250,000 scale, although care had to be taken to deal with variable lithologic designations, as for example where the metasedimentary rocks in many places were referred to by sedimentary rock names (e.g. silt-stone instead of argillite; shale instead of slate; sandstone instead of quartzite, etc.). High resolution satellite imagery and the included digital elevation model (DEM) from Google Earth™ were used to assess the character of all landslides; preliminary quantitative analysis was performed using a 15-m resolution DEM generated by us from ASTER imagery obtained through our designation as the GLIMS Regional Center for Southwest Asia (Bishop et al., 2004). Slope failures were classified according to generally accepted procedures in the literature (Shroder et al., 2005), and segmented into terrain units based upon geomorphometric parameters to characterize spatial organizational structure related to zones of both erosion and of deposition. Many slope failures were assessed and measured in Google Earth™ with synthetic topography created where high resolution satellite images were draped across an underlying digital elevation model (SIODEM). Care was taken to assess gravitationally lineated and streaked topography characteristic of mass movement that is known from hundreds of similar mass movements assessed by the senior author worldwide, to the exclusion of topography in which glaciation is the most recent and dominant process.

3. **Results: slope-failure complexes and rock falls/rock slides**

A number of large slope-failure complexes occur in Badakhshan Province (Fig. 1) that are unusual in their size and flow-like characteristics in areas of predominantly crystalline rocks. In part these properties have been produced by long-term extensive fault shattering, which in several cases also has apparently allowed friable sediments of Miocene and Pliocene age to be preserved, perhaps by downfaulting in a number of places in the mountains where such rocks could subsequently fail as they are re-exposed to mass-movement initiation. Causes of the extensive slope failures in this region would include various combinations of weak lithology, fault shattering, high relief, glacial valley-wall undercutting, debuttressing following deglaciation, unstable
tills, higher precipitation in the mountains, and high seismicity from the Hindu Kush seismic center (Billington et al., 1977; Crone, 2007; Searle et al., 2001; Vinnik et al., 1977) (Fig. 2). The highly seismic Hindu Kush and Pamirs are a region near the 3–4 cm yr\(^{-1}\) convergence of the Indian and Eurasian tectonic plates, where on average four magnitude P5 earthquakes yr\(^{-1}\) occur from the surface to depths of 330 km (Wheeler et al., 2005). In addition, the tectonic styles and directions of faulting (Fig. 3) in this collisional and transpressive region have changed through recent time, with the result that fault-shattered rocks and common seismicity (Ruleman et al., 2007) may have increased the occurrence of mass movement. Wheeler and Rukstales (2007) listed 21 M \(\geq 7\) earthquakes in the past 178 years in northeast Afghanistan, centered around the Kohi Bandakha massif where the Panshir Fault passes in a change of direction into the Central Badakhshan Fault (Fig. 4). The result is pervasive mass movement in the region around the Kohi Banda-kha, and the headwaters of the Kokcha, Sanglech, Wazling, and Warduj rivers that rise there as well.

A significant proportion of the larger of these slope-failure complexes occur along the Panjshir and Central Badakhshan Fault system and collateral branches, from the Anjuman Pass to the Zebak area and along the Warduj Valley (Table 1). A number of others occur close to the high relief associated with the incision of the Abi Panj River border with Tajikistan. All are characterized by exceptionally hummocky topography, closed depressions, lakes, and extensive flow features in which the topography is variously curvilinear and streaked. Some tills will be intermixed but the dominant process is slope failure of the bedrock into various well known forms (Shroder et al., 2005) of mass movement. Many have high rocky main scarps and exposed slip surfaces at their head but a few have evacuated almost all of the unstable rocks to lower elevations, leaving little behind at the head.
Fig. 2. Map by Ruleman et al. (2007) showing general tectonic context of Afghanistan, rates of overall plate motion, and general shallow (<35 km deep) historical seismicity of the region, which can be a leading factor driving mass movements. Approximate plate boundaries are in yellow. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Although the large mass movements in Badakhshan seem to be associated with the zones of highest seismicity, no direct observation of coupled seismicity and slope failure confirms this supposition. The zones of major mass movement also coincide with zones of highest precipitation (Fig. 5) in the Pamir and Hindu Kush, so an association with increased moisture could also be in part causative.

A number of large rock-slide and rock-fall complexes also occur in this region, where the characteristics of flow are not as obvious and instead large masses of rock fragments have accumulated through obvious catastrophic failures of cliffs and high
mountain slopes. As with the large slope-failure complexes above, many of these rock-slide and rock-fall complexes have had multiple episodes of failure at the same sites, and some are also overlain by rock-fragment accumulations wherein underlying ice cores from glaciers or subsequent ice cements into talus have been mobilized by internal ice deformation and flow and have slowly overridden the previously emplaced landslides. The results are mass-movement complexes with multiple generations of types and times of movement.

Fig. 3. Probable and possible faults of Quaternary age in Afghanistan divided into three categories of slip rate (red = >10 mm/yr; green = 1–10 mm/yr; blue = indeterminate). The tectonic domain of most of the large slope failures in Afghanistan is in the (3) Hindu Kush – Pamir intermontane region, (after Ruleman et al., 2007). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Fig. 4. Excerpt from the map of Wheeler and Rukstales (2007) showing the 21 magnitude P7 historical earthquake epicenters in the past century and three quarters in southern Badakhshan that exemplify the exceptionally high seismicity of the region. Such high seismicity has provided rapid ground accelerations that have led to profuse and widespread mass movement close to the epicenters.

The morphologies of the various mass movements are in general discussed herein from south to north. Only the largest or more obvious such deposits were selected for more detailed inspection in order to establish proofs of concept for later quantitative geo- morphometric and object-oriented analyses.
3.1.  **Parso rockslide (#1)**

This small rockslide dammed the right tributary of the Darya Parso, which itself is a tributary to the Kokcha River to the north (Fig. 6A and B). The landslide dam has attenuated overland runoff from the melting of both the debris-covered Sare Rastdare Glacier, as well as the also debris-covered Sare Kohi Mazard Glacier at the heads of two upper tributary valleys. This has resulted in the formation of the Hawdze Parso, a small lake backed up behind the landslide mass.

Table 1

List of mass movement types studied in Afghanistan, location mapped in figure 1, and discussed by number throughout the text. Attributes of the mass movements are included as averages or generalized data on size, volume, and aspect.

<table>
<thead>
<tr>
<th>Mass movement type</th>
<th>Average length</th>
<th>Average width</th>
<th>Estimate thickness (m)</th>
<th>Approximate volume (km$^3$)</th>
<th>Slope aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Parso rockslide</td>
<td>260m</td>
<td>900m</td>
<td>200</td>
<td>0.05</td>
<td>NW</td>
</tr>
<tr>
<td>2. Upper Anguman SFC</td>
<td>1.5km (2.3 laterally)</td>
<td>3.5km</td>
<td>100</td>
<td>0.6</td>
<td>SE</td>
</tr>
<tr>
<td>3. Lower Anjuman SFC</td>
<td>2.6km</td>
<td>3.6km</td>
<td>100</td>
<td>0.9</td>
<td>SE</td>
</tr>
<tr>
<td>4. Upper Munjan SFC</td>
<td>9.4km</td>
<td>9.4km</td>
<td>100</td>
<td>4.3</td>
<td>SE</td>
</tr>
<tr>
<td>5. Lower Munhan SFC</td>
<td>4.6km</td>
<td>5.9km</td>
<td>500</td>
<td>12</td>
<td>SE</td>
</tr>
<tr>
<td>6. Dashmiak SFC</td>
<td>3.75km</td>
<td>4.0km</td>
<td>100</td>
<td>1.5</td>
<td>SE</td>
</tr>
<tr>
<td>7. Audan SFC</td>
<td>1.3km</td>
<td>2.5km</td>
<td>200</td>
<td>0.7</td>
<td>SE</td>
</tr>
<tr>
<td>8. Dzhurmdara SFC</td>
<td>1.7km</td>
<td>1.9km</td>
<td>100</td>
<td>0.3</td>
<td>SE</td>
</tr>
<tr>
<td>9. Armazdon SFC</td>
<td>4.5km</td>
<td>9km</td>
<td>60</td>
<td>2.3</td>
<td>SE</td>
</tr>
<tr>
<td>10. Farakhsheng rockslide</td>
<td>1.7km</td>
<td>1km</td>
<td>50</td>
<td>0.75</td>
<td>SE</td>
</tr>
<tr>
<td>11. (Middle) Sanglech SFC</td>
<td>3.0km</td>
<td>3.9km</td>
<td>100</td>
<td>1.2</td>
<td>SE</td>
</tr>
<tr>
<td>12. Vashm SFC</td>
<td>4.3km</td>
<td>2.5km</td>
<td>100</td>
<td>1.0</td>
<td>SE</td>
</tr>
<tr>
<td>13. Amari-Pira SFC</td>
<td>3.5km</td>
<td>1.8km</td>
<td>10</td>
<td>0.06</td>
<td>E/NE</td>
</tr>
<tr>
<td>14. Gul Khana DF</td>
<td>3.25km</td>
<td>0.3km</td>
<td>5</td>
<td>0.005</td>
<td>S</td>
</tr>
<tr>
<td>15. Zar Zhan DF</td>
<td>4.0km</td>
<td>0.4km</td>
<td>5</td>
<td>0.008</td>
<td>E</td>
</tr>
<tr>
<td>16. Parkan East SFC</td>
<td>5.6km</td>
<td>2.9km</td>
<td>100</td>
<td>0.7</td>
<td>SW</td>
</tr>
<tr>
<td>17. Parkan West SFC</td>
<td>8.4km</td>
<td>2.0km</td>
<td>30</td>
<td>0.5</td>
<td>NW</td>
</tr>
<tr>
<td>18. Bshun rockslide</td>
<td>3.34km</td>
<td>1.04km</td>
<td>100</td>
<td>0.3</td>
<td>NW</td>
</tr>
<tr>
<td>19. Yardar rockslide</td>
<td>2.7km</td>
<td>1.40km</td>
<td>80</td>
<td>0.03</td>
<td>S/SW</td>
</tr>
<tr>
<td>20. Lake Shewa SFC</td>
<td>5.5km</td>
<td>3.5km</td>
<td>120</td>
<td>2.3</td>
<td>SW</td>
</tr>
<tr>
<td>21. Gardzhavin SFC</td>
<td>2.0km</td>
<td>1.6km</td>
<td>100</td>
<td>0.4</td>
<td>E</td>
</tr>
<tr>
<td>22. Pajwar SFC</td>
<td>3.1km</td>
<td>7.25km</td>
<td>500</td>
<td>10</td>
<td>E</td>
</tr>
</tbody>
</table>

The rocks of the slope failure are dark argillite metasediments that were mapped as siltstone and sandstone of Triassic age by Lindsay et al. (2005). The landslide came from an extensively foliated and frost-shattered 5400-m-high cliff directly to the south; the contrast with the light Oligocene granitoids upon which the fragments of the
landslide rest is quite obvious. The boulders of the failure reach up to 20 m in longest dimension and are piled up in the valley bottom from an altitude of ~3825 m to as high as 4050 m, with a thickness of >200 m (Table 1). Causes of this failure are likely to be some combination of deglacial debuttressing, coupled with frost shattering and probable seismic acceleration.

3.2. **Anjuman and Munjan slope-failure complexes**

The Anjuman and Munjan slope-failure complexes are characterized by combinations of differentially unstable lithologies, close proximity to major faults and high seismicity, high altitudes, and greater moisture and freeze thaw. Their close proximity to each other provides some similarities but their differences in lithologic source areas are reflected primarily in size variations and slope angles.

Fig. 5. Precipitation map of Afghanistan (after the National Atlas of the Democratic Republic of Afghanistan, Geokart, Poland, 1984).
Both the Upper and Lower Anjuman slope-failure complexes (Fig. 7) have extensive areas where the bedrock and the mantle on the southeast-facing, north slopes above the Anjuman Valley have failed in multiple slides and flows. Precise division and mapping of the boundaries of such features is somewhat arbitrary, with the result that areas several km upstream and downstream of the two main masses that reached or crossed the Anjuman stream are now included as various subparts of the two failures. The valley upstream above both of the slope-failure complexes has the Tagabe Rast stream in it; below the failures and a confluence with the Darya Paghar from the south, the stream is considered to be the Anjuman. The two slope failures have had so many different episodes of movement that it is not possible to put them into any sort of relative timing sequence, only that they are clearly post-glacial and intermixed tills are highly probable.

The basic bedrock geology of the north slope of the Anjuman area was mapped (Lindsay et al. (2005)) as sandstone and siltstone of Ordovician age, which inasmuch as it is also intruded by various plutons, is probably now actually low-grade metasediments that were originally listed by the Soviet geologists as the sedimentary rock types noted above. In any case, the fine clastic nature of such rocks, whether sedimentary or low grade metamorphic, appears to have been a cause of a number of slope failures there. In addition also is the likelihood that the high altitude, plentiful precipitation in the Hindu Kush, and extensive fault and frost shattering may have contributed, as well as failure of unstable tills, and earthquakes in this highly seismic region.

### 3.2.1. Upper Anjuman slope-failure complex (#2)

The Upper Anjuman slope failure has diverted or blocked the Rast stream in the upper Anjuman Valley enough to produce a lake some 0.75 x 0.45 km in size (Fig. 7A). The overall failure itself is variable in length along the hillside downstream to where the river is almost blocked. Here the toe can be measured in the river canyon to be ~100 m thick (Table 1).
Fig. 6. The Parso rockslide, with (A) topography from US DOD 1:100,000 scale series sheet U611 x 3188 for We-lo, Afghanistan, contour interval 50 m, grid squares = 1 km; and (B) Parso rockslide from the south developed in a high resolution synthetic view of Google Earth™ satellite imagery draped over an underlying digital elevation model (SIODEM). The Parso lake (Hawdze Parso) is frozen over in this view.
3.2.2. **Lower Anjuman slope-failure complex (#3)**

The lower slope failure probably has a thickness similar to the upper (Table 1). Unlike the upper landslide mass, this lower one crossed the river valley, presumably blocked it entirely for a time, and is now trenched by the river (Fig. 7B). Upstream of this slope failure no lake exists and the valley floor (~0.5 x 0.2 km) is entirely filled with sediment, perhaps from erosion by the stream through the sediments of the upper landslide. The lower landslide itself has several small lakes upon its surface, however. The subsidiary streams of Sare Hawdz and Kkawya flank this slope failure on the north slope.

3.2.3. **Upper Munjan slope-failure complex (#4)**

This unusual slope-failure complex is difficult to study and describe because it has an atypical configuration, unknown amounts of internal or lateral movement, with uncertain inclusion of tills, and uncertain boundaries (Figs. 7C and 8). Nevertheless, the fact that unusual slope movements have occurred in this area are shown by: (1) comparison laterally of adjacent stable bedrock and landforms to the north where large-scale movement of the bedrock has not occurred; (2) the obvious and unusually smooth, main-scarp slip surface down from the Kohi Nawa, Kohi Peregoshti and Kohi Khoghesi ridge top (~5000–5400 m) along light colored foliation planes that dip southeast; (3) Kohi Peregoshti is an upstanding peak of dark gray rock that is an entirely different lithology overlying the light colored foliation planes of the main-scarp slip surfaces; (4) numerous subsidiary slip-surface escarpments and lobate flow forms within the mass movement that help define it; (5) hummocky topography and landslide blocks on part of the movement mass; (6) mass-movement deflection to the east by the Darya Sakhi (river) at the base; and (7) plentiful slump blocks and ice-cemented rock glacier fronts at the angle of repose in several places. The general region of the Upper Munjan slope failure is also characterized by a number of other unusual factors that add to the complexity. For example, the linear, apparently fault-trained Sakhi River valley at the base of the slope failure rises 22 km due north in an apparent fault-breached glacial cirque. The valley has the 2.9 km-long, 0.5 km-wide Sakhi lake in its
middle that was dammed by mass movement. In addition, the river travels an additional 18 km south and southwest around the toe of the main Upper Munjan slope failure to join the upper Kokcha River, which then turns abruptly back to the north in what appears to be a profound elbow of capture apparently caused by interacting glacial- and fault-diversion processes.

The bedrock geology of the region is Archean gneisses through which pass various splays of the Panjsher and Central Badakhshan Fault. To the west below the Peregoshti and Khogheshi ridge top near the bottom of the cliff in the Kokcha River valley occur the carbonate beds of the famous Sare Sang lapis lazuli beds; to the east of the ridge top are the southeast ~25° dipping foliation planes of light-colored gneisses that constitute the exposed shear planes of the main scarp. This dip of the foliation planes is shown quite clearly in the smooth sides of the Kohe Moranstan a few km east of the Sakhi River valley as well. Faulting on the geology map by Bohannon and Stoeser (2005) is shown improbably at the top of this ridge, rather than at its base, perhaps because of uncertainty of which rock is in place, or which was moved that was produced by the mass movement under discussion here.

For convenience, and in part because of the complexity and uncertainty, as well as because of its large size (~10 km south to north), the Upper Munjan slope-failure complex is divided into both a south and a north part, which are separated by valley-side gulleys formed largely by runoff, and perhaps also by modification in some places by multiple cryospheric processes. Thus the northern half of the complex is shaped in plan view as a triangular, lobe form some 4.8 km north to south in its midsection, and ~5 km long in the direction of movement downslope. A 100 m thickness is a reasonable estimate, so the total volume might be 2.3 km³ (Table 1). Similarly the triangular-shaped, south half measures ~4.6 km across its midsection, 4.4 km in a downslope direction, and is perhaps 100 m thick to measure a total volume of ~2 km³. The top of the northern triangle shape is characterized by a small glacial cirque with small rock glaciers in it, whereas the apex of the southern part is characterized by a small upstanding (400–500 m) pinnacle mass (Kohe Peregoshti) of the isolated dark bedrock in place with strong talus to its north and south. On the slope below occur multiple flow lobes, slump blocks, small
rock-glacier remnants, and the mottled appearance of multiple slope movements of the dark bedrock that has moved downslope to a greater or lesser extent.

Fig. 7. (A) Upper Anjuman slope-failure complex SIODEM (arrow indicates lake dammed by landslide); (B) Lower Anjuman slope failure SIODEM (arrows indicate lakes produced by landslide, with sediment filling in lake on left); (C) Upper Munjan slope-failure complex SIODEM; (D) Lower Munjan slope-failure complex SIODEM.

On the lower slopes of both the north and the south portions of the slope failure a number of other unusual features exist as well. For example, on the northern toe, two subsidiary curvilinear scarps show where part of the toe failed and flowed down into the lower valley. From there and on down the valley to the southern half of the slope failure, several lineations indicate probable lateral glacial moraines. Most striking of all, however, at the base of the south-central part of the mass movement, a 0.8 km-wide
alluvial–colluvial fan is traversed by numerous debris-flow channels and levees that are cut through by one strong ground fracture and three less prominent shear planes across the slope of the fan that appear to have resulted from strong local seismicity rather than mass movement. These ground ruptures appear to pass as faint lineations into the surrounding mass of the landslide and across its toe to both the northeast and the southwest (Fig. 8). In addition whereas the fan grades smoothly toward the lower Sakhi stream in the valley bottom, the river valley is entrenched up to ~20 m below the fan surface, which is clear evidence of local recent uplift (Seong et al., 2009). In addition where the Sakhi stream valley enters into the main Munjan Valley, several lateral moraines also occur on the lower slopes of the southern part of the slope failure. These moraines came from the main glacier from the southeast part of Kohi Bandakha along the Tagabe Munjan tributary past the main Lower Munjan landslide.

Fig. 8. Sketch map of Upper Munjan slope-failure complex showing pronounced upper-most, main-scarp slip surfaces of Kohi Nawi to the south and Kohi Khoghesi to the north separated by the upstanding remnant peak of Kohi Peregoshti (5109 m). The toe of the slope-failure complex is marked by several zones of apparently seismically generated ground cracks that trend across an alluvial fan whose front is entrenched by the Sakhi River.
3.2.4. **Lower Munjan slope-failure complex (#5)**

The Lower Munjan slope-failure complex of multiple landslide events descended the southwest part of the Wuris (4691 m) mountain foothill of the Kohi Bandakha massif, itself a prominent mountain ridge with peaks of 6171–6843 m, rising above the Tagabe Munjan tributary to the Kokcha River into which the landslide elements descended (Figs. 7D and 9). The main mass of the failure appears to have come from rocks that were mapped (Bohannon and Stoeser 2005) as siltstone and sandstone of Late Triassic age, but which are probably low-grade metasediments. The highest parts of the main scarp seem to be diorite and plagiogranites of Oligocene age. The head of the main scarp is at about 4160 m altitude and the toe is ~2600 m. The toe of the failure is trenched by Tagabe Munjan to show a thickness of ~0.5 km that gives a volume of perhaps ~12 km³ (Table 1).

This large mass of rock fragments, with its mapped depression contours (Fairchild Aerial Surveys, 1960) and close proximity to the large glaciated Kohi Bandakha massif was recognized, mapped, and submitted for publication three decades ago by the senior author (JS) for the USGS but not published until recently (Shroder and Bishop, 2010). Because of lack of collateral information at the time, the deposit was originally mapped as a diamicton of uncertain genesis, although the choice to be made was known to be due either to glaciation or mass movement. The advent of high resolution satellite imagery has now made more precise genetic definition of mass movement possible.

The landslide mass (Figs. 7D and 10A and B) has a pronounced hummocky topography with a number of depressions >100 m deep, some of which have either water in them, or dry-lake remnants of former water bodies. At least three generations of movement (lobes A–C) have occurred here, and probably more. Thus in addition to the main lobate A mass in the east and center (Fig. 9), an intermediate lobe B moved directly south and is conspicuous with its emplacement lineations that give evidence of high speed. The small westernmost lobe C also flowed due south to the Munjan River and by cross-cutting superposition relationships, obviously failed last (Fig. 9).

The landslide seems to have dammed the Tagabe Munjan and its Ris tributary
for several km upstream so that it produced extensive buff lacustrine sediment deposits several tens of meters thick up to an altitude of ~2800 m (Figs. 7D and 9). The existing 500 m deep canyon of the main landslide cut by the river through the mass (Fig. 10A) indicates the possibility of a catastrophic breakout flood of the Munjan-Riss lake, which is also indicated by flights of scoured terraces directly adjacent to the lake’s outlet downstream at the landslide’s lower edge on the west.

Prominent lateral or medial moraines exist on the Noghulbeh ridge between the confluence of the Munjan and Sakhi Rivers (Fig. 9). These moraine ridges have been truncated by the Munjan slope failure lobe C, and their fresh appearance, coupled with their 10–15 km distance from existing glaciers on Bandakha indicate the probability that they are Last Glacial Maximum (LGM) and late Pleistocene in age. It is therefore also likely that as the LGM ice melted away, the debuttressing, fault shattering, and locally exceptionally high seismicity were proximal causes of this multiple failure.

Fig. 9. Sketch map of Lower Munjan slope-failure complex showing three macro-lobes of the failure mass (A–C) that appear by the principle of superposition to have failed successively from east to west (drawn from Google Earth™ image at latitude 36°01.050.4700 N; longitude 70°52.022.9200 E centered on Puzhak Pass at ~3160 m in the middle of lobe A). Cross-section NE–SW is shown in Fig. 10B.
3.3. Bandakha and upper Sanglech slope-failure complexes

All of the topography along the north sides of the Sanglech Valley from Kohi Bandakha to Zebak, and from Zebak along much of the east side of the Upper Warduj Valley is underlain by what is mapped by Bohannon and Stoeser (2005) as Archean gneisses, which are not lithologies known for extensive mass-movement failure. The axes of these valleys, however, are clearly fault trained, as well as having extensive unmetamorphosed and friable conglomerates and sandstones of Miocene, Pliocene, and Quaternary ages in them that either overlie the gneisses, or which were down-faulted into fault-shattered zones within them. Certainly along the lower sides of most of these valleys are till deposits left by Pleistocene or LIA ice, although only a small percentage were ever mapped as such. Coupled with the commonly steep slopes, higher precipitation and pervasive frost shattering normal to
the middle of the Hindu Kush, and the well known high seismicity, these weak lithologies have set up areas of extensive slope failure in which hummocky topography, small lakes, and flow lineations down-slope abound that attest to the common slope failure. Only the largest and most massive of the many slope failures in this region are mapped and described below (Figs. 11A–D).

3.3.1. Dashmiakh slope-failure complex (#6)

The Dashmiakh slope-failure complex on the south slopes of Kohi Bandakha is a roughly oval mass of thick (~100 m) colluvial deposits incorporating prior tills that appears to constitute a volume of ~1.5 km³ (Table 1), below a main-scarp cliff 300–400 m high with peak altitudes along it of 4900–5200 m (Fig. 11A). The main scarp is bisected through by an ice-cored rock glacier that issues out onto the main body of the slope failure. A strong (~100 m deep) gully occurs downslope from the steep front of the rock glacier that bisects the main mass movement into two lobes. Several other ice-cemented rock glaciers issue from the base of the main scarp on both sides to cover upper parts of the mass movement. The two main lobes of the feature are characterized with a profusion of subsidiary small lobes ranging 50–200 m across. The toes of both landslide lobes have numerous springs that flow out of several zones up to 200 m above the river valley bottom, which may be evidence of basal slip surfaces.

3.3.2. Audan slope-failure complex (#7)

The Audan slope failure on the east slopes of Kohi Bandakha is another example of a massive slope failure of likely prior tills and slope deposits bisected by a rock glacier, in this case, however, an ice-cemented rock glacier derived from the profuse rock debris that ravel off the massive triangular cliff face of the main scarp that rises ~900 m above it (Fig. 11B). In this example the main central rock glacier seems to have produced enough meltwater diffusely or in small amounts so that minor vegetation and apparent fluvial smoothing of the slope has occurred below the terminus of the rock glacier. The failure overall is at least 0.7 km³ (Table 1). The south lobe of the mass has another smaller ice-cemented rock glacier that flows across it, whereas the larger north lobe of the failure is bulbous and streaked with various
layers of differential movement and flow lobes.

Fig. 11. Large slope-failure complexes on south and east slopes of the Kohi Bandakha massif in southern Badakhshan: (A) Dashmiakh slope-failure complex SIODEM; (B) Audan slope-failure complex SIODEM; (C) Dzhurmdara slope-failure complex SIODEM; (D) Armazdon slope-failure complex SIODEM. The upper main scarps below which occur streaked and flowed topography and landslide blocks are obvious.

Proceeding northeast from Kohi Bandakha into the uppermost reaches of the Sanglech Valley and the first major mountain ridge of Dzhurmdara northeast above the Sanglech Glacier, or the Damanany–Livzakhm massif, is largely in place and has not extensively failed. From there northeast down the Sanglech Valley, however extensive additional areas of slope failure occur along the northwest wall of the Sanglech Valley, and one in a tributary valley to the Sanglech.
3.3.3. **Dzhurmdara slope-failure complex (#8)**

This slope-failure mass is a complex collection of convex slump and flow lobes of bedrock and till overlain by several large rock-glacier lobes on its north and south sides (Fig. 11C). The main scarp is a triangular-shaped peak as much as 5178 m high, with a 700 main-scarp cliff below it. The length from the bottom of the main scarp to the toe in the Sanglech River at ~3900 m altitude is ~1.7 km. The mass is at least 0.1 km thick, which calculates to a volume of 0.3 km³ (Table 1).

3.3.4. **Armazdon slope-failure complex (#9)**

The Armazdon complex is a 9 km-wide mass movement (Table 1) of multiple subsidiary failures that have come down from two triangularly shaped peaks rising to as much as 5180 m above the Sanglech Valley floor at ~3300 m (Fig. 11D). The two peaks are separated by a glacial valley that rises behind them and which opens out on the slope covered with mass movement at ~4300 m altitude above the Sanglech. The main scarp cliffs on the fronts of the two peaks rise 300–600 m above the slope-failure masses below them. Below them the multiple lobate and streaked forms of flows and slides of tills and bedrock attest to many different times and types of movement. For example the main peak has a rockslide or rock-glacier form moving from it that measures ~1300 m long by 220 m wide. Approximately 1 km downslope from its front, several prominent springs flow out from lobes of other finer grained material.

3.3.5. **Farakhsheng rockslide (#10)**

This landslide is an example of a slope failure that moved largely as a single mass, probably in one of the large seismic events that are so prevalent there, that intermixed with some glacier till and ice-cored rock glacier rubble to add to the complexity of interpretation. The top of the main scarp is at ~4800 m and the toe is about 4000 m, with the total distance being about 2.4 km, with a volume of ~0.75 km³ (Table 1). The main body of the failure is a lobate mass and superficially resembles some of the ice-cored rock glaciers that are so prevalent in the region, but it has no steep front at the angle of repose, so by definition it is excluded from that designation.
In any case, the failure has also caused impoundment of a lake of ~625 m length and 130 m width. Water from this lake, and perhaps from melting ice beneath the Farakhsheng or other source, appears in springs down-valley and flows into a small stream and several other small lakes.

3.4. *Middle Sanglech slope-failure complexes*

3.4.1. *Middle Sanglech slope-failure complex (#11)*

This mass-movement complex has a triangular main scarp that heads at about 5000 m and is ~400–500 m high from the top to its north side (Fig. 12A). The toe of the mass down at the Sanglech river is at ~3050 m altitude. The volume of the failure is perhaps 1.2 km$^3$ (Table 1). The south side of the failure has numerous slump blocks, whereas the north is dominated by a large convex lobe, and both no doubt incorporate much prior glacial till. A number of ice-cemented rock glaciers with steep fronts at the angle of repose have developed at the base of the main scarp from the pro fuse rubble that accumulates there. Many of these rock-glacier forms dominate the upper part of the north half of the failure. The lower part of this north half is a large convex lobe. The south half of the slope failure is dominantly slump blocks characterized by light colors, which are perhaps the result of the weathering of the Archean gneisses that underlie the whole of the Sanglech Valley.

3.4.2. *Vashm slope-failure complex (#12)*

The Vashm mass movement is a simple rectangular lobate form with a 5098 m peak and a 500-m-high cliff at its head (Fig. 12B). The mass of till and other materials stretches some 4.3 km down to the Sanglech River at ~2950 m altitude and its volume is perhaps 1 km$^3$ (Table 1). The entire upper half of the slope failure is characterized by slump blocks and the lower half appears to be a single convex lobe that has settled down somewhat below a ~100-m high scarp that traverses the entire mass from the higher south flank to the lower north flank.
3.5. Upper Warduj slope-failure complexes

Mass movement from the highlands in the Zebak region and down the Upper Warduj Valley is unusual in highland Afghanistan because of the recognized presence of friable and unstable sedimentary rocks of Tertiary age beneath the soils and scruffy vegetation in the region. These rocks are either down faulted into the surrounding Archean gneisses, or they appear to have flowed out over the gneisses.
over which they were draped in original sedimentation in many places. In fact, the occurrence of the obvious failure and extensive flow of fine-grained clastics in this region are the chief evidence of the probable occurrence of these weak rocks. Stoesser (2005) mapped Neoarchean gneiss in the region that is rich in biotite and other mafic minerals (garnet–biotite, sillimanite–biotite, amphibole, and biotite–amphibole gneisses; and amphibolite). These mineralogies and lithologies are highly susceptible to accelerated weathering into clay minerals, most of which are unstable in wet mountainous environments. Further- more, the absence of glacial cirques on many of the nearby mountains, coupled with the rounded appearance of much of the topography and valley-side plateaus in this region, together with lineated flow-like topographic patterns, and hummocky topography with some lakes suggest extensive mass movement in this area developed from unstable sedimentary rocks, or deeply weathered mantles, or both. Some tills could be included but probably much of this mass movement occurred as permafrost melted out at the end of the LIA.

3.5.1. **Amari-Pira slope-failure complex (#13)**

The Amari-Pira Plateau directly northwest of Zebak above the confluence of the Sanglech with the Upper Warduj valley is characterized by gently east dipping (~30°) foliation planes of Archean gneisses that resemble monoclinic-ridge landforms (Fig. 13A). The sloping plateau surface is a roughly triangular area 3.5 km on a side covered with hummocky topography, small lakes, and flow lineations. No main scarp exists but instead the entire failed mass appears to have moved off to the east and northeast, leaving no remnant in its wake. Two prominent and separate debris flow/earthflow features issued from its margins and descended into the Warduj and Wazling valleys northwest and northeast of Zebak.
3.5.2. *Gul Khana (#14) and Zar Kahn (#15) slow debris flows*

The Zar Khan and Gul Khana slope failures (Fig. 13B and C) in these two valleys are examples of rare debris/earthflow phenomena in highland Badakhshan that most probably moved slowly and can be mistaken as results of other processes. For example, a variety of glaciers from the highest Hindu Kush and Pamir mountains once existed throughout much of Badakhshan. The Upper Warduj valley, has had glaciers in parts of it in many places, which Desio (1975) mapped and described. His map of the moraine at Aqshira on the middle Warduj is accurate and shows former
ice movement into the Warduj Valley there. Desio’s (1975) two maps of glaciers around Zebak, however, and the supposed moraines they left are incorrectly mapped because instead high resolution satellite imagery shows that the moraines are actually mass-movement features. Thus both the Zar Khan (Fig. 13B) and the Gul Khana slope failures near Zebak are derived from heretofore unmapped unstable weathered bedrock and/or overlying Mio-Pliocene clastic sediments that came from the high Amari-Pira mountain plateau on Desio’s map (Fig. 13C). Both landslides flowed down into the surrounding river valleys and probably blocked them for a time to create impoundments. The Zar Khan feature is notable in particular because it has such pronounced lateral landslide levees, which actually resemble glacial lateral moraines, but because no cirque occurs on the mountain, a glacial origin is clearly out of the question. The hypsometric diagrams of both the Zar Khan and Gulkhana debris flows show an unusual irregular pattern that seems to be reflective of the evacuation of sediment from along the course of the failures.

The unstable sediments of this region, perhaps including some tills, have contributed to a number of other failures farther downstream on the right bank of the Warduj where landslide-dammed lakes occur along the middle altitudes of the peaks on the east banks of the river in the Parkhan East, Parkhan West, and Bashun slope-failure zones between Zebak and Aqshira.

3.5.3. **Parkhan East slope-failure complex (#16)**

This slope failure is headed on the 5004 m Razak peak and flowed down the south-oriented Dargae drainage valley (Fig. 11A). The bedrock beneath the mass movement was mapped by Stoesser (2005) as extensively faulted Archean gneisses. As noted previously, friable Miocene and Pliocene sedimentary rocks occur ~10 km directly east of this location near Zebac and probably underlie this mass movement as well but are not so mapped. The main scarp itself ranges in height from a few hundred m to as much as 400 m and the volume is perhaps 0.7 km³ (Table 1).

3.5.4. **Parkhan West slope-failure complex (#17)**

The Parkhan West mass movement is one of the most complex ones in the study
in that the failure is characterized by at least three major movement directions as it is draped over a plateau and flows or slides out in several directions. For example, the farthest eastern part of the mass moved west from its source scarp above the plateau to leave a small lake in the depression the failure left, the central part of the mass moved off the plateau and flowed south downslope into the Warduj Valley, and the northwest part of the landslide slid northwest into a different part of the Warduj Valley (Table 1).

Fig. 14. Rocksides in Warduj valley: (A) vertical Google Earth™ image of Beshun rockslide; (B) Beshun rockslide on Soviet-era topographic map; (C) Yardar rockslide SIODEM; (D) photograph by Desio (1975) looking east–southeast upstream at the Yardar rockslide on the right in the valley bottom.

The northwest portion of the landslide, which could be considered a separate
mass movement in its own right, is characterized by a number of linear and curvilinear crown cracks in the exposed gneissic bedrock at the head of this part of the failed mass. A number of slump blocks occur at the upper head of this part of the slope failure with at least four curvilinear shear planes daylighting around the blocks. Interesting also is the fact that a 260-m long landslide lake on the southwest portion of the plateau of the failure has been tapped by local farmers and diverted into a ditch in order to bring irrigation water around a ridge to the northwest part of the failure. This addition of water to the slope above Tergiran village, while good for the crops, is also likely to contribute to further instability there.

3.6. **Bashun rockslide (#18)**

The rockslide-generated lake, Kol Bashun, occurs in the deep tributary Bashun valley (Fig. 14A and B). The parent rockslide that dammed up the lake is ~3.34 km long from the top of the main scarp down to the toe on the opposite hillslope, ~1.04 km wide at the base of the main scarp, and ~2.13 km wide at the toe. The main scarp is a concave depression on the Kherman ridge from which the rockslide occurred, is nowhere more than 100 m deep, and most of it is much less than that. Most of the existing rockslide in the bottom of the valley does not appear to be much over 10 m thick at the present time because it has been eroded, but at the center of the original valley into which it fell it may have been as much as 100 m thick. The volume of the rockslide thus may have been as much as 0.3 km³ (Table 1). The altitude of the top of the main scarp is ~3832 m high, and the original altitude of the valley into which the landslide moved was ~2400 m. The vertical drop was therefore ~1432 so the height to length (H/L) ratio was ~0.43 m, which is not large, indicating the velocity of emplacement of the landslide was not great. Kol Bashun itself is a ~0.81-km long, ~0.25 km-wide lake produced when the rockslide dammed the valley. Waters from the lake eventually overtopped the landslide and now provide an overflow spillway across part of the toe of the landslide where a number of irrigated fields have been developed. Considerable mass seems to have been eroded from the landslide through this area.

3.7. **Yardar rockslide (#19)**
Desio (1975) photographed this rockslide in the lower Warduj River Valley near the village of Yardar just above its confluence with the Kokcha River (Fig. 14C and D). The rockslide occurs on the south side of the U-shaped Warduj Valley, with the Warduj River passing along the north side of the valley wall and isolating the landslide toe from its source cliff. The rockslide is an oval mass of rock fragments with boulders up to 30 m in length that are arranged in a curved pattern on top showing that they swept off the source cliffs to the north and piled up on the opposite side of the valley below. The Warduj Valley is a typically glaciated one with steeper slopes at the bottom of the valley walls so that the Warduj failure surface extends down from the top of the main scarp on the north side of the valley at ~1948 m, to its approximate launching point at ~1800 m altitude at least 260 m above the valley bottom where the Warduj River passes by below. Although the Warduj River could have downcut through the slide slightly since emplacement of the slope failure, with the river at ~1540 m and the leading edge of the rockslide toe at ~1650 m on the south valley-wall side, it appears that the landslide apparently was rapid enough to launch from the north valley wall enough to allow the river to maintain its course while the landslide traveled a small way up the opposite valley side.

The source rock of the Yardar rockslide was mapped as a massive pluton of granodiorite and granosyenite of Oligocene age by Bohannon and Stoeser (2005). The total length of the landslide from scarp top to toe is ~2.7 km, but the actual size of the long, narrow source scarp is ~470 m wide, to perhaps 25 m deep, by ~1460 m long to the probable launching point of the rockslide on the valley wall. The actual Yardar Rockslide itself in the valley bottom is ~1170 m wide and ~770 m wide, and the deposit is about 80 m thick at its maximum. The total volume was therefore perhaps 30–35 million m$^3$ (Table 1), which is approximately twice as big as the source scar, but of course the rock material has greatly increased its porosity, and we do not know how much rock mass existed above the present edges of the source scar.
3.8. **Lake Shewa slope-failure complex (#20)**

Lake Shewa, a body of water about 15 km² in area in northeastern Badakhshan about 10 km from the Panj River border with Tajikistan, was dammed sometime in antiquity by one or more landslides (Shroder and Weihs, 2010). A large rock-slope...
failure from the fault-shattered and strongly weathered Zirnokh peaks to the north (Figs. 15A and B and 16) moved into the Arakht River valley and dammed up the river and its tributaries to a dam thickness of ~400 m and a dam volume of ~2.3 km³, producing a 12-km-long lake that is as much as 270 m deep, leaving ~80 m of freeboard to the top of the dam (Table 1). At least five separate slope failures have been mapped at the site of the landslide dam where two strike-slip faults cross each other and presumably contribute to instability (Shroder and Weihs, 2010). The uppermost part of the Lake Shewa landslide dam is a prominent rock glacier (Fig. 15C), which as a slow moving accumulation of rock debris and internal ice cement, takes centuries to millennia to form, and thus testifies to the antiquity of the dam. The water levels in Lake Shewa fluctuate several meters annually in response to variations in inflow, as well as in outflow through the open-matrix rock fragments. Progressive seepage of spring water through the dam face has caused several young subsidiary slump failures (Fig. 15D), which if continued at a large enough scale for long enough, or with additional seismicity from the active strike-slip faults that cross beneath the landslide dam, could threaten its integrity. A comparison of the world’s second largest landslide dam (Lake Shewa) to other landslide dams in the world, including the world’s largest landslide dam (Usoy) nearby in Tajikistan (Fig. 17), shows the danger associated with potential breakout floods into the Panj River and Amu Darya downstream.

3.9. **Gardzhavin Slump and rockslide slope-failure complex (#21)**

The Gardzhavin slope failure occurs along the same left-lateral strike-slip fault that passes north through the main scarp of the Lake Shewa slope failure. In the Gardzhavin example, the fault appears to constitute part or all of the main scarp above the landslide. The slope failure is constituted by a large slump block at its head that is ~0.7 km long in the direction of movement and ~1 km wide along the top of the slump block. Five boulders on its top measured 10–23 m in long axis. Overall the total volume is ~0.4 km³ (Table 1).
Fig. 16. Map of Shewa landslide and lake. Four different landslides are mapped from oldest to youngest (Qls1; Qls2; Qls3?; Qls4). Qls3? may not be the result of a separate mass-motion event, hence the query. Qls4 is recent slumping at the dam front (Fig. 15D). Qrg is the younger rock glacier at the head of the landslide (Fig. 15C).

Fig. 17. Diagram of the Lake Shewa landslide dam compared to other earth-filled and landslide dams in the world, including the large landslide dams Usoy (Tajikistan), and Bairaman (Papua New Guinea), and the man-made Oroville Dam (California), which is the tallest such dam in the US. The respective heights of Lake Shewa and Lake Sarez are shown. After the nearby Usoy in nearby Tajikistan, the Lake Shewa dam is the second largest landslide dam in the world.
Pajwar slope-failure complex (#22)

The Pajwar slope-failure complex (Fig. 18) in extreme northeast Badakhshan on the Abi Panj (river) border with Tajikistan is an example of a large slope failure preconditioned by a likely combination of high relief, glacial undercutting of the valley wall, fault-plane weakening of surrounding crystalline rocks, steeply east-dipping inclination of bedding or foliation planes into the west wall of the south-to-north oriented Pajwar Valley, and the probability of one or more strong seismic shocks, which are so common in the region. The basic bedrock geology was mapped by Bohannon and Stoeser (2005) from pre-war work done by Russian and Afghan geologists. The western source rock for the slope failure was probably mostly granite and granodiorite of Oligocene age that intruded so-called siltstone and shale of Middle Jurassic and Late Triassic age that are probably now metasediments. The landslide itself was not recognized as such by Bohannon and Stoeser (2005) but was instead mapped as conglomerate and sandstone of middle Pleistocene age, and was listed as a shingly and detrital alluvium, with gravel and sand being more abundant than silt and clay. Possibly given the description, the original mappers of the area considered the deposit to have its source from the nearby Panj River and they presumably did not recognize the mass-movement source because of its large size and unusual configuration.

Fig. 18. Pajwar slope-failure complex SIODEM, view from the north.
The greater Pajwar Basin is ~100 km² in area and is ringed by some of the Badakhshan Pamir peaks up to 5012 m in altitude around its periphery, although altitudes of 4500–4800 m are more characteristic. The main source ridge of the failure to the west of the slope-failure complex has five peaks along it that average 4138 m in altitude, which with an approximate average altitude of the average present top surface of the slope failure of ~3000 m (ten hill summits on the landslide range from 2881–3494 m in altitude and average 3263 m) gives a vertical drop of >1 km to emplace the mass (Fig. 18). Most likely, however, the pre-failure Pajwar Valley was itself >500 m deep, so the vertical drop was probably closer to 1.5 km. In the direction of travel to the east, the main rockslide moved laterally ~3.1 km length to fill the Pajwar Valley for a distance of a ~7.25 km width along the axis of the valley (Fig. 19). A conservative estimate of the total volume of the emplaced mass is therefore ~10 km³ (Table 1).

The surface of the Pajwar slope failure is a distinctively mottled and streaked mass of exceptionally hummocky topography whose rolling swales can be hundreds of meters in frequency and amplitude. The dramatically rolling surface of the slope failure is variously smooth and covered with weathered soil and grass, or is comprised of huge lobate masses of strongly rock-varnished boulders. A few trails or dirt transport tracks, some houses, stock pens, and shepherd’s cabins occur on the lower altitude parts of the slope-failure surface as well. The long rectangular shape of the landslide is unusual because it seems to represent the linear col-collapse of the west wall of the valley, down into the formerly glaciated Pajwar Valley so that the landslide mass splayed out to both the south and north and came to rest in the bottom of the valley to fill it with rock rubble for over 7 km along the valley axis. Subsequently several other mass movements have served to add complexity to the interpretation of emplacement.

The original configuration of the pre-landslide Pajwar Valley, with respect to a north orientation, was an upside down Y-shape with the stem of the Y pointing north to its confluence with the Abi Panj, and with the two arms of the Y pointing south and southwest into the high Pamir. The two arms of the Y arose in glaciated cirques to the south and the stem of the Y was inclined down to the north into the Abi Panj. After the landslide had been precipitated into the stem of the Y, the emplaced mass was spread
out as a tilted ovoid mass with a *brandung* ridge (Heim, 1932; Hewitt, 2002) all along its eastern toe against the opposite valley sidewall, where two lakes (Upper Pajwar Lake at 3308 m and Lower Pajwar Lake at 2985 m) were impounded between the *brandung* and the original valley wall as well. The inclination of the landslide mass from south down to north reflects the original configuration of the pre-landslide valley itself as it passed from the upper glacier cirques down to the Abi Panj River bottom.

Fig. 19. East–west cross section through the middle of the Pajwar slope-failure complex showing conjectured internal volume based upon: (1) most likely configuration of formerly glaciated, wide U-shaped Pajwar Valley into which the left (west) bank of the valley-side mountain collapsed, and (2) the narrow V-shape of the lower Pajwar valley cross section exposed in the steep banks of the Panj River valley directly north.

The main scarp of the landslide is the arcuate western ridge of the Pajwar Valley that has a huge arcuate talus slope of fresh rock debris extending all along its lower reaches. The upper (south) parts of the landslide where the arms of the Y meet the landslide mass have a number of prominent ice-cored moraines and rock glaciers that descend from the cirques and override the emplaced landslide with strongly lobate, rock-glacier morphologies. The low-er (north) parts of the landslide that decline down toward the Abi Panj show with the presence of two fresh escarpments that cut transversely east–west across the landslide, that subsequent
failure of the northern-most toe of the landslide mass occurred into the Abi Panj River valley as well. Some of this failure may be related to subsequent bedrock fault movements, as possibly indicated by apparent ruptures in the adjacent bedrock, but without ground evaluation, this is speculative.

The water table inside the rock-rubble matrix of the Pajwar slope failure declines northward from an altitude of ~3300 m in the far southeast margin of the upper toe of the slope failure where Pajwar Lake 1 is located. A variable-level beach around the edges of the Pajwar Lake 1 shows that the lake level varies by several meters through time, presumably depending upon surface inflow variation balanced by subterranean outflow. The water table passes beneath the highly hummocky topography along the toe to Pajwar Lake 2 at an altitude of ~2970 m, and from there through the lower parts of the northeastern-most toe to the village of Pajwar on the Abi Panj where large springs discharge at ~1970 m. Pajwar Lake 2 has no surface inflow points and no variable-level beach, which indicates that its level presumably does not vary by much. Plotting the altitudes of the two lakes up on the landslide, down to the large springs at the far northern toe in the deep valley of the Abi Panj at Pajwar Village shows that the water table inside the landslide maintains an approximately ~9° slope over a distance of about 7–8 km horizontal distance.

Inasmuch as the Pajwar slope-failure complex is one of the largest landslides in Afghanistan, and is located only about 100 km west of the huge Usoy (Usoi) landslide dam and Lake Sarez in Tajikistan (Gaziev, 1984) that was produced by a seismically triggered landslide in 1911, a relationship of the Pajwar complex to the pervasive seismicity characteristic of the greater Pamir region is possible. Certainly the general high seismicity of the region, the huge size the mass movement, and the unusual linear configuration of the Pajwar landslide that was precipitated from the western ridge down into the pre-failure Pajwar valley and part way up the east-ern valley side, all argue for a massive failure of a linear mountain ridge, but there is no evidence that the mass ever even partially dammed the huge Abi Panj River that is directly adjacent. The Usoy Dam of Lake Sarez is only about 2 km³, but at 567 m high, it is the highest such landslide dam in the world and it is indeed fortunate that at the Pajwar complex only two small lakes occur with no major river trapped behind the landslide mass to threaten another
such event.

4. **Results: orientations of mass movements**

   The aspect orientation of the slope failures in northeast Afghanistan is, of course, in multiple directions (Fig. 20) but the dominance of the southeast direction is obvious. This direction is caused by the extensive southeast-facing fault scarps that are developed on the sides of large and steep mountain massifs.

![Fig. 20. Rose diagram of landslides in northeast Afghanistan. The strong orientation to the southeast is a result of major southeast-facing fault scarps, and high and steep valley sidewalls there.](image)

5. **Results: debris-covered glaciers, ice-cored rock glaciers and non-glacial ice-cemented rock glaciers**

   In the high altitude glaciated regions of Afghanistan where high magnitude, high frequency seismicity prevails, plentiful debris cover is supplied by plentiful falls and avalanches. Such thick debris covers either protect glacial ice onto which the rock
fragments and debris falls, or form open-matrix, rock-fragment aggregations into which interstitial ice will easily develop. The result in much of high altitude Afghanistan has been the development of plentiful ice/rock fragment mixtures that have developed on the upper regions of many prior slope failures. Many, if not most of the large area, slope-failure complexes extending along the Central Badakhshan Fault zone thus have ice-cored or ice-cemented rock glaciers (Giardino et al., 1987) developed across at least part of them. Because it can take many thousands of years for such debris-covered glaciers and rock glaciers to form across the prior slope failures, it is clear that many of these massive slope failures with overlying rock glaciers of different types are very old.

6. **Discussion and conclusion**

Mass movement in northeastern Afghanistan is predominantly large slope-failure complexes that include massive rockslides and slow debris flows of considerable antiquity, many of which are also overlain by mixtures of ice-cemented and ice-cored rock glaciers. One of these, the Lake Shewa slope-failure complex is the second largest landslide dam in the world and has the capacity to produce a very large breakout flood if the dam gains further in frontal instability as it has been observed to be doing recently. Many smaller and younger rockslides occur in steep-sided, formerly glaciated valleys, and a few slow debris flows have formed where downfault-ed unstable sedimentary rocks in Badakhshan have failed and flowed down into lower valleys. Causes of the extensive mass movement in northeastern Afghanistan are multiple and include: (1) unstable sedimentary lithologies; (2) pervasively fault-shattered rocks; (3) ubiquitous seismicity; (4) steep slopes; and (5) high relief. As glaciers downwasted and as permafrost came out of the ground at the end of the Last Glacial Maximum (LGM) and the Little Ice Age (LIA), the removal of lateral ice buttressing and internal frozen support from valley walls, in the close proximity of high seismicity, would have contributed to extensive instability and resultant slope failure. In conditions of ongoing global warming, and the ever present high seismicity in Afghanistan, further such failures are likely so that development agencies in the wartorn country would be advised to factor this and other similar natural-hazard situations into consideration in
their efforts.

Acknowledgments
Our thanks to Michael P. Bishop and Jeffrey W. Olsenholler for plentiful discussions and help with the graphics and preliminary analyses of this paper, as well as to the US Agency for International Development and the US National Academy of Sciences whose funding for work on capacity building and glacier ice in nearby Pakistan enabled us *en passant* to accomplish this peripheral but related work in Afghanistan as well.

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