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Loess failure in northeast Afghanistan

John F. Shroder [a,*], Megan Jensen Schettler [a], Brandon J. Weihs [b]

[a] Department of Geography and Geology, University of Nebraska at Omaha, 60th & Dodge St., Omaha, NE 68182, United States
[b] Department of Geography, Kansas State University, Manhattan, KA 66506, United States

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ABSTRACT

Mass movements in northeastern Afghanistan include large-scale rockslides and complex slope failures, as well as failures in loess. The loess region in northeastern Afghanistan occurs in the Badakhshan and Takhar provinces and was likely created by dust blown to the east from the Karakum Desert and the alluvial plains of northern Afghanistan. This loessic dust was deposited against the Hindu Kush mountain range which rises up along the eastern half of Afghanistan as a result of transpressional tectonism. It overlies less permeable crystalline and sedimentary bedrocks such as Triassic granite, Proterozoic gneiss, and Miocene and Pliocene clastics in the area with the largest concentration of slope failures. Thirty-four loess slides and flows were mapped and analyzed using remote satellite imagery over digital elevation models on Google Earth™. This source enabled location, classification, and measurement of failures. Findings revealed that most failed slopes faced north, west, and northwest. This trend can be explained possibly as different moisture contents resulting from the primarily westerly wind direction, which may cause more precipitation to be deposited on west-facing slopes, and sun position during the hottest part of the day. Additionally, the easterly rising Hindu Kush range may cause more slope area to face west in the study region. Other contributing factors could be the very high seismicity of the area, which may cause rapid dry fluidized loess flows, and landscape modification by humans. Several loess slope failures appear to be generated by water concentration through irrigation ditches and possible rutted tire tracks, which can create tunneling between the loess and its less permeable bedrock. Causes and effects of loess failure in Afghanistan need to be investigated in more depth. Further study may lead to the adoption of more sustainable and safe farming practices and more informed housing locations, which may prevent loss of property, crop, and transport routes.

1. Introduction

As well as the larger rock slides and rock slide complexes noted by Shroder et al. (in press) there are categories of fine-grained mass movement in northeastern Afghanistan that occur where either water or seismic acceleration are the primary causes of slope failure. Of particular interest are the plentiful deposits of wind-blown dust that accumulate as loess blankets over pre-existing topography, particularly on top of crystalline or other bedrock of lesser permeability. Because of the nature of its slow accumulation, as the dust grains of fine silts and clays settle out of air-borne suspension down onto grass blades and other shrubby vegetation typical of the steppes of Afghanistan, a so-called 'card-house' matrix of loose loess grains is established. These card-house matrices are particularly subject to differential compaction and settling, to cracking when dry, and to piping, wherein larger connected openings are developed down into the ground as the loess grains are physically transported by water running downward into cracks and pipes. This commonly sets up a situation wherein water infiltrates the loesses, either as a function of the natural porosity and permeability of the loess, or where water infiltration is accelerated into cracks and pipes, all of which contributes to instability of the loess and results in slope failures. Seismic accelerations similarly can shake the loess so that the loose matrix collapses catastrophically and the dry loess is fluidized to flow outward and downward as a powdery mass moving under gravitational control alone. Loess slides and loess flows are special kinds of earth-slides or earth flows that occur in many places in Afghanistan. It is presumed on the basis of observations made elsewhere that velocities of such slope failures can be highly variable, from rapid to perhaps largely imperceptible creep.

It is the purpose of this paper to locate and describe multiple mass movements in the loess area of northeastern Afghanistan, in order to better understand distributions and primary causes of loess-slope failure in this region. By documenting these failures it is hoped that areas at increased risk for this type of fine-grained mass movement will be identified, and primary causes determined,

* Corresponding author. Tel.: +1 402 554 2770; fax: +1 402 554 3518.
E-mail address: jshroder@mail.unomaha.edu (J.F. Shroder).

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in hopes of achieving greater safety and functionality and promoting continued development in this impoverished, subsistence based area.

2. Methodology

High resolution satellite imagery draped over a Digital Elevation Model (SIODEM) in the form of Google Earth™, which implements Shuttle Radar Topography Mission (SRTM) DEM data from NASA to create a synthetic topography, was used to locate loess failures and investigate the surrounding areas. Coordinates gained from Google Earth™ were applied to Soviet topographical maps at a scale of 1:250,000 to discover the underlying bedrock, although care had to be taken with variable lithologic designations, for example because metasedimentary rocks in many places were referred to by sedimentary rock names (e.g. siltstone instead of argillite; shale instead of slate; sandstone instead of quartzite, etc.) Bohannon and Stoeser, 2005; Desio, 1975). Other data sources were USGS maps and reports, as well as declassified CIA maps (Lindsay et al., 2005; Stoesser, 2005; Ruleman et al., 2007; US CIA, 2008).

3. Results: loess slope failures

Loess regions are commonly characterized by mass wasting, which generally occurs as loess flows or loess slides that can be dry or wet, and fast or slow. The speed, size, and type of loess-slope failure depend, among other things, on the structure and amount of moisture in the loess, the type (composition) of the affected materials, and the slope of the underlying bedrock beneath the loess (Derbyshire et al., 2000).

3.1. Loess slope-failure processes

Many mechanisms of mobilization occur, as do many different types of loess failure; organization schemes established by geologists and engineers focus variously on content and composition of the movement mass, location of the failure plane, or mobilization and type of movement. The latter types of classification focus on mobilization and type of movement so that broadly, movement can be seen to be caused by saturation and liquefaction, fluidization, hydro-consolidation, and progressive failure or loess "creep".

3.1.1. Saturation and liquifaction

Though loess can be quite stable and cohesive when dry (as when Derbyshire et al. (1994) cited a functional bridge cut into loess near Lanzhous, China), it is subject to failure when saturated. Where wet, loess has a relatively low shear strength and a thick clayey consistency like that of toothpaste, and after reaching a certain saturation level it loses the ability to support itself (Bettis et al., 1986). Pye (1995) listed several reasons for this: (1) water dissolving or deforming salts, carbonates, and other framework materials; (2) reducing grain friction; (3) dissolving clay pellets from the matrix; and/or (4) deforming clay "bridges" between grains. In addition, water adds load weight to the loess structure, increasing downward pressure (Derbyshire et al., 2000).

In many places, loess stays fairly dry and stable because of relatively low precipitation, exposure to sun and wind (evaporation), and steep slopes (Bettis et al., 1986). However, in areas that undergo heavy rain or flooding or in latitudes that experience monsoons, catastrophic loess-slope failure can be a significant problem. Loess can mobilize as a mudflow or a rapid wet debris flow on the surface, or, if saturated along the basal layers (by piping or an impermeable bedrock contact), can form a "skating surface" for slump-block slope failure and landslides (Bettis et al., 1986). Failure is especially likely after several days of torrential downpours. Many such catastrophic landslides and mud flows have occurred in the Gansu Loess Plateau region of China, which receives up to 60% of its annual rainfall in the monsoonal months of August and September (Derbyshire et al., 2000).

3.1.2. Dry fluidization

Loess can move rapidly and catastrophically when dry, in an event variously referred to as dry fluidization, soil liquefaction, rapid soil flow, or loess powder flow (Zhang and Wang, 2007). These mass movements can be triggered by high-magnitude seismicity, which causes the porous, card-house matrix of the loess to collapse and fluidize. In tectonically active earthquake zones, such as the China Loess Plateau and along the Hindu Kush loess region in Afghanistan, this can be the primary trigger for mass movement (Zhang and Wang, 2007). In a study done in China, Zhang and Wang (2007) found that these slides generally occurred on gentle, concave slopes of <15°, in contrast to saturation-induced landslides, which generally occur on steeper slopes.

Landslides mobilized by earthquakes, whether in loess or in a more stable sedimentary rock, are typically rotational, characteristically large in volume and scale, high-mobility, and can be very damaging (Derbyshire et al., 2000). In the Haiyuan earthquake of 1920 in the Chinese loess region, an estimated 100,000–180,000 people were killed by such earthquake-mobilized landslides (Zhang and Wang, 2007; Derbyshire et al., 2000).

3.1.3. Hydroconsolidation

Loess can collapse rapidly due to overburdening at certain critical moisture contents (Derbyshire et al., 1994). If overloaded, the loess will eventually collapse and settle, reducing pore space (Bettis et al., 1986). Moisture decreases the load strength of loess; Miller (1964) noted that "wet" loess, described as greater than 20% moisture, settles under light loads under 70,307 kg/m^2 (100 psi), whereas "dry" loess (less than 10% moisture) can hold heavier loads over 70,307 kg/m^2. Not all loess has the same potential for collapse. Younger loess is in general more collapsible and behaves plastically. Older loess tends to be dense and brittle, and usually has a greater bearing strength than overlying (younger) loess; it is less collapsible (Derbyshire et al., 2000; Miller, 1964). In China, engineering codes were instituted for buildings in areas with "collapsible loess". The susceptibility of the area to collapse is calculated using the heights of the loess under normal conditions, under reduced pore space (under pressure), and when saturated and under pressure (Derbyshire et al., 1994).

3.1.4. Loess "creep" or progressive failure

Loess slope failures are not necessarily always catastrophic. In a process that Derbyshire et al. (1994) called progressive failure, the loess slope is gradually weakened by groundwater, which removes soluble salts and shifts particles. Stresses slowly transfer, and the loess readjusts, deforming and creeping downhill. This type of movement can produce step-like features along the failure plane called "teracettes" or "catsteps" and arcuate cracks (crown cracks) at the crest of loess slopes (Derbyshire et al., 1994; Bettis et al., 1986). Such landforms are common in Afghanistan. Though loess appears to deform plastically for awhile, Derbyshire et al. (1994) warned that eventually, the weakened loess exceeds a weathering threshold or is triggered externally, causing rapid slope failure.

Mass movements variously occur by failure at the bedrock or paleosol contact, failure entirely within loess, or at bedding planes or joints (mixed landslides). Derbyshire et al. (2000) summarized a classification system using the composition of the slide mass and the location of the failure plane that is relevant to loess failures in Afghanistan, although too reliant upon direct field observation to make direct comparison or complete classification possible: