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Chronology of rock falls and slides in a desert mountain range: Case study from the Sonoran Desert in south-central Arizona

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A R T I C L E I N F O

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A B S T R A C T

In order to respond to the general paucity of information on the chronology of ubiquitous small rock falls and slides that litter the slopes of desert mountain ranges, a case study in the Sonoran Desert reveals new insight into the desert geomorphology of mountain slopes. Rock falls and rock slides in the McDowell Mountains that abut metropolitan Phoenix, USA, fall in three chronometric groupings dated by conventional radiocarbon and rock varnish microlamination methods. First, the oldest events are >74 ka and take the form of stable colluvial boulder fields — positive relief features that are tens of meters long and a few meters wide. Second, randomly sampled slides and falls of various sizes and positions wasted during wetter periods of the terminal Pleistocene and Holocene. Third, an anomalous clustering of slides and falls occurred during the late Medieval Warm Period (Medieval Climatic Anomaly) when an extreme storm was a possible but unlikely trigger. One speculative hypothesis for the cluster of Medieval Warm Period events is that a small to moderate sized earthquake shook heavily shattered bedrock — close to failure — just enough to cause a spate of rock falls and slides. A second speculative hypothesis is that this dry period enhanced physical weathering processes such as dirt cracking. However, the reasons for the recent clustering of rock falls remain enigmatic. While the temporal distribution of slides and falls suggests a minimal hazard potential for homes and roads on the margins of the McDowell Mountains, this finding may not necessary match other desert ranges in metropolitan Phoenix or mountains with different rock types and structures that abut other arid urban centers.

1. Introduction

The talus of rock falls and rock slides covers the steep slopes of desert mountain ranges throughout arid North America and desert ranges in general (Bryan, 1922; Melton, 1965a; Cooke et al., 1982, 1993; Oberlander, 1994; Goudie, 2003; Parsons et al., 2009). Chronometric studies provide important insight into the frequency of mass wasting as a geomorphic hazard (Ibsen and Brunsden, 1996; Hungr, 1997; Aleotti and Chowdhury, 1999; Dussauge-Peisser et al., 2002; Crozier, 2013). With some exceptions (e.g., Gutiérrez et al., 1998; Matmon et al., 2005; Stirling et al., 2010; Rinat et al., 2014) desert geomorphology largely currently lacks systematic research on the chronology of rock falls and rock slides in arid mountain ranges. This is true even in metropolitan Phoenix, where urban expansion (Gober, 2005) results in the placement of homes at the bottom of steep slopes (Fig. 1).

Geomorphologists have theorized on broad chronologies of erosion on desert slopes, arguing that the last period of extensive hillslope erosion in the Southwestern USA took place during the transition from the wetter late Pleistocene to the Holocene (Huntington, 1907; Eckis, 1928; Melton, 1965b; Knox, 1983; Wells et al., 1987; Bull, 1991, 1996; McDonald et al., 2003) with a typical generalization being: "[t]hus, it appears that the initiation of hillslope erosion, fan building, and valley deposition was associated with a climatic shift from moister to drier conditions and a significant change in the nature of uplands vegetation." (Miller et al., 2001, p. 385). A few studies have examined the Pleistocene antiquity of mass wasting features such as desert colluvial boulder fields (Whitney and Harrington, 1988; Friend et al., 2000) or large landslides such as the Blackhawk (Shreve, 1968; Stout, 1977) and Marcus (Douglass et al., 2005) sturzstroms. Still, little is known about the frequency or even general timing of rock falls and rock slides in desert mountain ranges.

As urban expansion in metropolitan Phoenix — and elsewhere globally (Cooke and Warren, 1973; Cooke et al., 1982) — continues to thrust infrastructure at the base of steep desert slopes (Fig. 1), an important step in assessing hazards associated with falls and slides involves understanding the frequency of mass wasting. This paper presents the results of one effort to characterize the timing of rock falls and rock slides in one desert mountain range surrounded by cities.

2. Study site

Metropolitan Phoenix, southwestern USA, envelops a number of small ranges that host abundant rock falls and rock slides. The early

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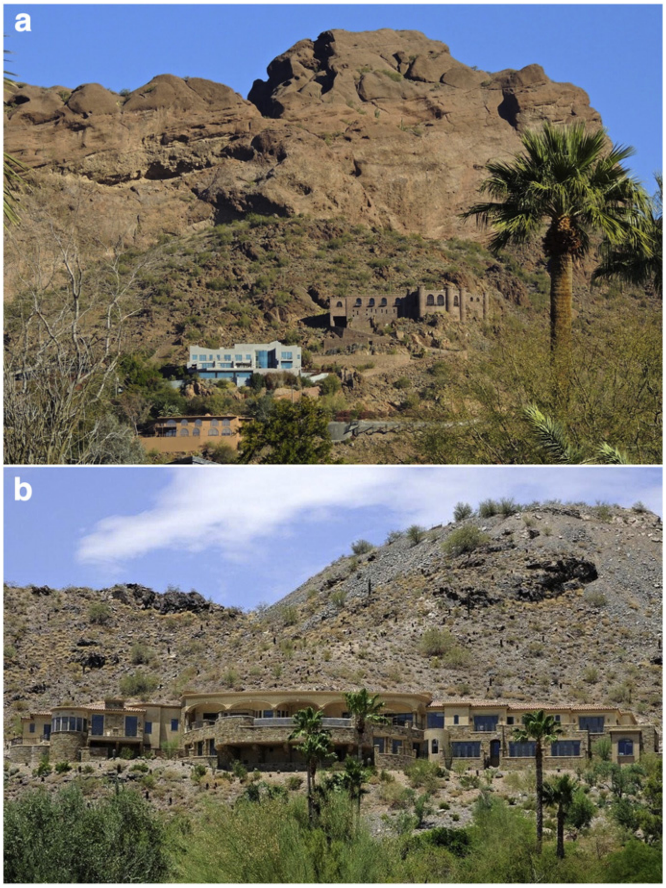

Fig. 1. Urban infrastructure at the foot of desert mountains. Expansive homes, water towers and other urban features often occur directly at the base of steep mountain slopes, exemplified here for mansions in (a) Phoenix and (b) Paradise Valley locations in central Arizona. Note construction of mansions on (a) a talus cone and (b) underneath scree.

Proterozoic metavolcanic and granodiorite McDowell Mountains (Richards et al., 2000; Vance, 2012), bordered by the cities of Scottsdale and Fountain Hills (Fig. 2) form the main field area. The latest major tectonic event, mid-Tertiary extension, created brittle normal faults through the range (Vance, 2012). The McDowell Mountains is an appropriate study area for an initial investigation of the timing of rock falls and rock slides, because it hosts a fairly typical mix of metamorphic and granitic lithologies with a relative ease of access provided by a trail network.

The McDowell Mountains varies in elevation from 600 to 1250 m. Slopes on the southern 90% of the range supply Proterozoic metamorphic quartzite and volcanic rock to the fluvial system through a mixture of debris flows, rock slides, rock falls and some channeled overland flow. Drainages in this metamorphic portion of the range debouch into alluvial fans. In contrast, course-grained Proterozoic granite dominates the northern 10% of the range where the predominant landform consists of domed inselbergs, flanked on the margins by such features as koppies, nubbins, pedastals, tors, a sturzstrom (Douglass et al., 2005), and extensive rock pediments.

The slopes of the McDowell Mountains display many of the characteristics of arid mountain ranges, in that they contain a mix of bedrock and colluvium. Rock varnish and other desert rock coatings (Dorn, 2009) cover the vast majority of the colluvial boulders. Many falls and slides, however, have a 'recent looking' appearance, where the lack of establishment of Palo Verde trees (*Parkinsonia aculeata*) and minimal rock coating development give the rock face and talus a much lighter coloration. Unlike settings with softer rock types (Migoń et al., 2005), boulder disintegration does not occur with the micaceous quartzite (Early Proterozoic), rhyolite (Early Proterozoic), purple quartzite (Early Proterozoic), mafic volcanic rocks (Early Proterozoic), and red quartzite (Early Proterozoic). However, like Migoń et al. (2005), some disintegration does occur on early Holocene and late Pleistocene colluvium with the argillite-phyllite (Early Proterozoic), schist-undivided (Early Proterozoic), and coarse-grained granite (Middle Proterozoic).

While presenting an inventory of mass wasting events in the McDowell Mountains is beyond the scope of this research paper examining the chronology of rock falls and rock slides, the general morphological characteristics are typical of desert slopes in the Sonoran Desert. Rock slide areas range from 40 to 6350 m^2 with the median talus intermediate axis of these slides being 59 cm. Talus from rock falls has a median intermediate axis of 91 cm. Course-grained granite (Middle Proterozoic) and purple quartzite (Early Proterozoic) generated the largest talus often exceeding 3 m in the intermediate axis. Run-out distances for the rock slides range from 12 to 380 m with a median of 40 m. Talus from rock falls typically come to rest within 50 m of the rock face, but the longer run-out distances reached 240 m. In summary, there is nothing geomorphically special or unique about this Sonoran Desert range — making it an appropriate setting to carry out this first investigation of the chronometry of rock falls and rock slides in the desert southwestern USA.

As the study proceeded, an anomalous finding of a cluster of events in the late Medieval Warm Period led to the possibility of a seismic trigger. This clustering generated the need to determine if this chronometric clustering in the McDowell Mountains matched another range in the local area. Thus, section 15 (N 33.34116 W 112.04016) was selected randomly from the Guadalupe Range — 30 km to the southwest — to test the hypothesis that the late Medieval Warm Period clustering might occur in multiple ranges in the Phoenix area.

3. Methods

Two distinct sampling strategies provided different perspectives on rock fall and slide chronology. One strategy involved a random selection of 30 locations in the McDowell Mountains. After gridding the entire McDowell Mountains, a random number generator identified 30 grid cells, where the center of the grid cell identified the locale for sampling. The closest fall or slide to the randomly selected spot was sampled for varnish microlamination (VML) dating and radiocarbon dating of any available Palo Verde (*P. aculeata*) wood crushed by talus.

The second strategy was not random, but subjective in that sampling focused on just 'recent looking' rock falls and rock slides visible from a trail network — a total of 17 events in the McDowell Mountains. As explained in the previous section, the clear temporal clustering of these 17 events (presented in the next section) warranted a second round of sampling from a different mountain range in the area. After random sampling identified Section 15 (N 33.34116 W 112.04016) in the Guadalupe Range, VML samples were collected from the four closest 'recent looking' rock falls and to the center point of Section 15. While many other 'recent looking' rock falls and slides exist throughout central Arizona, time and funding restrictions limited the number of samples.

For each rock fall/rock slide event sampled for dating, a small shovel excavated the edges around talus boulders to assist in finding any evidence of Palo Verde (*P. aculeata*) wood that might have been crushed by talus. Five excavations revealed samples of wood appropriate for conventional radiocarbon dating. One of the randomly selected rock slides generated a debris flow, and the matrix of this flow contained a fragment of wood appropriate for radiocarbon analysis. These six radiocarbon measurements provide estimates of fall and slide ages and also provide local calibrations for the varnish microlaminations (VML) dating method.

VML dating generates age ranges for rock varnish formed on talus boulders derived from rock falls and rock slides. Developed by Tanzhuo Liu, a growing data set links climatic events to micron-scale microstratigraphy in rock varnish (Bell et al., 1998; Liu et al., 2000; Zhou