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Letter to the Editor

Weathering phases recorded by gnammas: Comment to the paper published by Domínguez-Villar et al., Quaternary Research, v. 72, p. 218–228

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In 2009 a new theory of gnamma development (herein called "scenario 1") stated that the depth of a gnamma (*h*) increases faster than the associated spillway, but then, for no reason that is stated, the spillway begins to deepen more rapidly than the gnamma and the maximum depth of water in the gamma (called "*u*") decreases. Eventually the spillway is below the bottom of the gnamma ($u > h$) so that there is no longer a pool of water and the form has become an "armchair" (Domínguez-Villar et al. 2009, p. 219).

In scenario 1, *h* is increasing as *u* is decreasing, so we expect *h* and *u* to be negatively correlated; however, *h* and *u* are positively correlated in this paper (Domínguez-Villar et al., 2009, p. 224, Fig. 5) and two others from Chile and Minnesota (Domínguez-Villar, 2006, p. 142; Domínguez-Villar and Jennings, 2008, p. 171) and in nearby Galician granite (de Una Alvarez, 1998).

Figure 1A shows 85 field measurements of *h* and associated *u* (Domínguez-Villar et al., 2009, p. 224, Fig. 4). Figure 1B is the result of 100 numerical simulations of gnammas that were 5 cm deep at the beginning of the simulations using a model of scenario 1 in STELLA, a widely used, general-purpose, deterministic modeling language (see http://sonoma-dspace.calstate.edu/handle/10211.1/1426, the permanent digital archive of Sonoma State University). Figure 1C shows the results of 100 simulations with a simpler model in which the depth of the gnamma (*h*) deepens a little bit faster than the spillway (which is here termed "scenario 2"). This simpler scenario reproduces the natural data.

Scenario 1 suggests that the "the depth ratio" *h*/*u*, called δ, increases with time and "[d]etailed statistical analysis of gnamma depth ratios has demonstrated that for most sites, their distribution is comprised of several sub-populations that have been interpreted as phases of new gnamma formation, which could be driven by climate changes" (Domínguez-Villar et al. 2009, p. 219).

A ratio measure is a poor choice in scenario 1, however, because the spillway is deepening and *u* is decreasing and so δ becomes rapidly very large. Gnammas that have *u* value <1.5 cm were rejected because they are said to be "too mature" (Domínguez-Villar, 2006, p. 140); there must be some such rule or δ will become wildly large as the quotient approaches a division by zero. A better measure of *h* and *u* would be $(h-u)/h$, perhaps expressed as a percent.

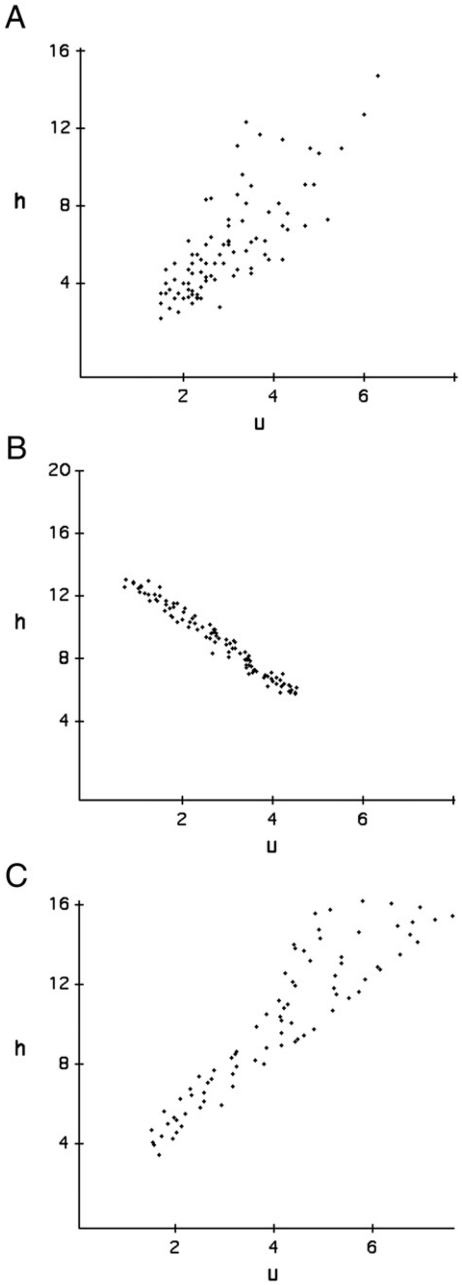

Figure 1. Fig. 1A reproduces Fig. 4 from Domínguez-Villar et al. (2009). Fig. 1B from scenario 1 is the depth (*h*) and the maximum depth of water (*u*) of 100 random modeled gnammas that were 5 cm deep when the spillway began to develop. Fig. 1C plots *h* and *u* of 100 random gnammas that developed from the simpler "scenario 2," in which the rate of the deepening of *h* is always a little faster than the deepening of *u*.

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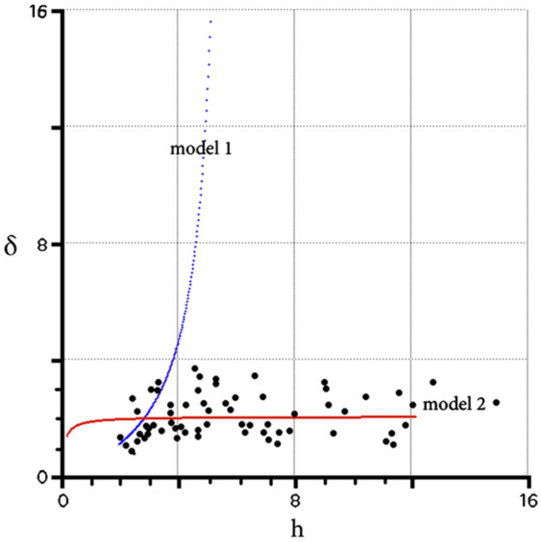

Figure 2. Simulations of scenarios 1 and 2 with *h* and δ values extracted from Domínguez-Villar et al. (2009), p. 224, Fig. 5C, left side.

Using scenario 1, eight sub-sets of gnammas were identified at Curral da Nave, and six of them were correlated with the six sub-sets at Lagoa Redonda (Domínguez-Villar et al., 2009, p. 224–5), but this may simply reflect an over-analysis of random events.

Scenario 2 is the simpler and a physically more likely hypothesis: that the gnamma and its spillway developed together, starting when the surface was first exposed by the melting of the glacier, but the gnamma is wetter and therefore deepens more rapidly. In this case, no new gnammas have developed in later times. Then we obtain an interesting and surprising result (Fig. 2).

Under scenario 1, δ is a relative time keeper (Domínguez-Villar, 2006; Domínguez-Villar and Jennings, 2008; Domínguez-Villar et al., 2009), but under scenario 2 that is true only during a short transient period, after which δ stabilizes and is time invariant. In scenario 2, the smaller the difference between the rate of deepening of the gnamma and its spillway, the larger the steady-state value of δ.

A good test of these competing scenarios is to plot δ versus *h*. Scenario 1 predicts that δ will rise exponentially as *h* increases, and that δ, a ratio measure of performance, will be wildly erratic and commonly large. Figure 2 shows that a simulation of scenario 1 can not be made to fit the field data very well, no matter what parameters are chosen, because the style of the curve is wrong. Scenario 2 can be made to fit the data very closely; it predicts correctly that δ is well-behaved, equilibrates asymptotically and is rarely over 10.

The main issue to most geomorphologists in this area of specialization is whether weathering pits are initiated continuously, episodically, or mostly at the beginning of weathering. In many cases on sea coasts in the spray zone, tafoni and gnammas form continuously or in episodes and cycles. The pits there grow faster parallel to the surface and soon obliterate themselves. A new, almost fresh rock surface is exposed, and tafoni and gnammas form for a new cycle of enlargement and obliteration (Pestrong, 1979, 1980, 1988). However, this may only be characteristic of the coastal spray zone.

In his worldwide review of gnammas, Twidale found only one site where there are two sets of gnammas (Twidale and Cobin, 1963, p. 11). Studies in temperate coastal Japan (Matsukura and Matsuoka, 1991), the Arizona desert (Norwick and Dexter, 2002), in the tropics of southeast India (Achyuthan et al., 2010), and periglacial surfaces in Scotland (Hall and Phillips, 2006), show that tafoni and gnammas often initiate after a few centuries, and after that there are few if any new tafoni or gnammas. The photographs in the papers of Domínguez-Villar, and especially his dissertation (Domínguez-Villar, 2007), show numerous outcrops that seem to show large gnammas and armchairs with no small gnammas or tafoni between them, strongly suggesting that gnammas initiated when the surface was exposed, but not since that time.

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