Comment and Reply on "Range fires: A significant factor in exposure-age determination and geomorphic surface evolution"

COMMENT

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Bierman and Gillespie's (1991) paper is a nice reminder to those who use surface-exposure dating methods to be aware of fire spalling. Here I emphasize omitted issues.

First, many who collect samples for surface-exposure dating methods are aware of surface degradational processes (e.g., Dorn, 1989, p. 580–587; Cerling, 1990, p. 154–155). Whether the sampled material is a rounded river cobble, ventifact groove, or glacially abraded boulder, there are textural clues evident to experienced field observers which reveal a lack of surface degradation. When textures not influenced by fire are sampled, positive results are found. Nishiizumi et al. (1989), for example, sampled from glacially polished bedrock to assess ^{10}Be and ^{26}Al production. Morainal boulders sampled from Tioga-age till at Pine Creek yielded varnish radiocarbon, cation-ratio (Dorn et al., 1990), ^{10}Be, and ^{26}Al ages (D. Lal et al., unpublished) that correspond to a new conventional radiocarbon age on charcoal collected from Tioga till matrix (A. J. Bach and D. L. Elliott-Fisk, unpublished).

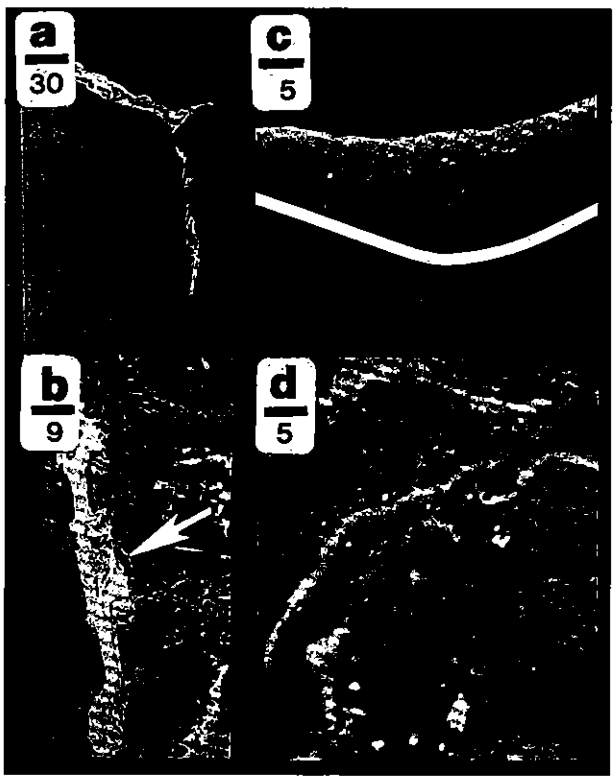

Figure 1. Backscatter electron micrographs; scale bars in micrometres. a: Crack varnish (arrow) penetrating in widening fracture in quartz, Mojave Desert. b: Crack varnish (arrow) rich in Ba (electron microprobe analysis 2.9%). c: Mn-poor (darker) under Mn-rich (brighter) varnish exposed by fire spalling at Pine Creek. Bright lines are fractures filled with reprecipitated $BaSO_4$. Line shows varnish-rock boundary. d: Porous texture (formed by leaching of Mn oxides and mobile cations) adjacent to layered varnish, from Bishop Creek moraines.

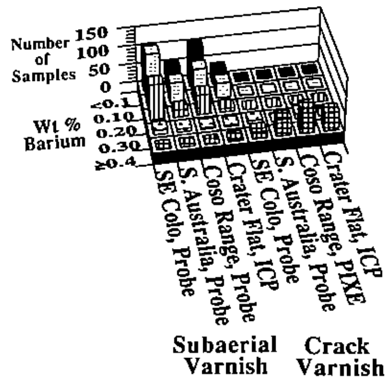

Figure 2. Concentration of barium in crack varnish as opposed to varnish formed only in subaerial environment. Methods of analysis are elaborated in Dorn et al. (1990): inductively coupled plasma (ICP), wavelength dispersive electron microprobe (Probe), and PIXE.

Second, granodiorite boulders that have undergone spalling by fire have two types of textures: (1) a very rough surface where individual crystals protrude, giving a "sandpaper feel," and (2) smooth texture on a planar surface of a joint exposed by spalling. Nowhere have I observed fire-spalling textures with smooth concave surfaces similar to those produced by boulder abrasion during glacial transport. (A positive contribution would be made for those who wish to collect samples for surface-exposure dating methods if Bierman and Gillespie would modify or add to this list of spall textures.)

Third, rock varnish can be used to assess whether a former joint was exposed by spalling or by the geomorphic process of interest. A rock-crevice environment is favorable for the colonization and spread of Mn-oxidizing organisms that catalyze the formation of rock varnish, and the best looking rock varnishes on granodiorite are commonly found in unexposed joints (Fig. 1, a and b) or in joints recently exposed by spalling (Fig. 1c).

Crack varnish is different from varnish formed only in a subaerial environment. Crack varnish is characteristically higher in certain trace elements—e.g., barium (Fig. 2). Crack varnish characteristically lacks the porous texture produced by cation leaching in a subaerial environment (Fig. 1c vs. Fig. 1d). Crack varnish lacks subvarnish lichen remains that can only be found in a subaerial environment. Crack varnish typically has an inner layer that is not enriched in Mn and lacks pieces of detritus encapsulated by the clay–Fe-oxide matrix. As the rock crevice gradually opens, a layer enriched in Mn forms on top (Fig. 1c). More criteria are available to distinguish crack varnish (Dorn, unpublished). The key is that if crack varnishes are found at the surface, the investigator using surface-exposure dating methods knows that surface degradation has occurred.

REPLY

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Dorn's Comment emphasizes two ideas: uneroded rock surfaces can be recognized reliably by their texture, and rock varnish can be used to identify spalled boulders. These suggestions may appear reasonable; however, field observations and chemical analyses indicate that Dorn's specific assertions are, we believe, largely unsubstantiated and of little use in most field situations.

Implicit in Dorn's argument that texture can be used to identify uneroded rock surfaces are three assumptions that field evidence suggests are not viable: (1) distinctive textures are present on most rocks when surface exposure begins, (2) original textures can be reliably distinguished from those produced by weathering, and (3) distinctive, original textures are preserved over the range of ages for which exposure-age techniques are, in principle, useful.

Textures indicative of uneroded surfaces obviously are diagnostic if present, but these textures are found only in a few circumstances, such as those listed by Dorn. Rocks on many landforms (e.g., pediments, pavements, basalt flows, talus cones, debris flows, tuff sheets, rhyolite domes, cliff faces) either have no distinctive texture when initially exposed or have textures that are not unique to the uppermost surface (e.g., ropey pahoehoe). We developed the concerns expressed in our paper after visiting sites sampled for exposure dating (e.g., Phillips et al., 1990; Dorn et al., 1990). For example, the morphology of boulders on early Wisconsin or older moraine crests suggests that erosion of the rock surface has occurred (Fig. 1); yet, on many of these boulders, the wind-polished and silica-hardened surfaces are smooth and hard, perhaps mistakable for glacial polish. Striated tillstones, unusual even on latest Pleistocene moraines, are extremely rare on older moraines unless the boulder has recently been exhumed. In our opinion, a list of "spall textures" would be superfluous to the "experienced field observer" and would offer to others only false assurance that unspalled and continuously exposed surfaces were being sampled.

Dorn also suggests that "... if crack varnishes are found at the surface, the investigator using surface-exposure dating methods knows that surface degradation has occurred." This statement presupposes two ideas, neither of which is supported by field or laboratory observations: (1) spalls occur along preestablished (and varnished) joints or cracks, and (2) "crack varnish" has particular and readily identifiable characteristics.

Our field observations and those of Emery (1943) indicate that most spalls occur over the surface of the rock without regard for joint orientation (Fig. 2). After the Symmes and Tuttle Creek fires, we observed no varnish on the freshly spalled granodiorite. When these spalled areas do revarnish (see Bierman and Gillespie, 1991, Fig. 7), there will be no "crack varnish" present on the rock surfaces affected by spalling.

The unpublished chemical data used by Dorn to identify "crack varnish" are perplexing and contradict previously published analyses, including his own. Several studies (e.g., Dragovich, 1988; Dorn et al., 1990)

Figure 1. Heavily weathered pre-Wisconsin "cation-ratio dated" tillstone (site 8; Dorn et al., 1990). Remnants of degraded, planar joint surface appear to have survived (arrow); however, close examination indicates that even these remnants are significantly eroded. Although original varnish coat has certainly been lost, wind-polished and silica-hardened joint-surface remnants may be amenable to isotopic dating.

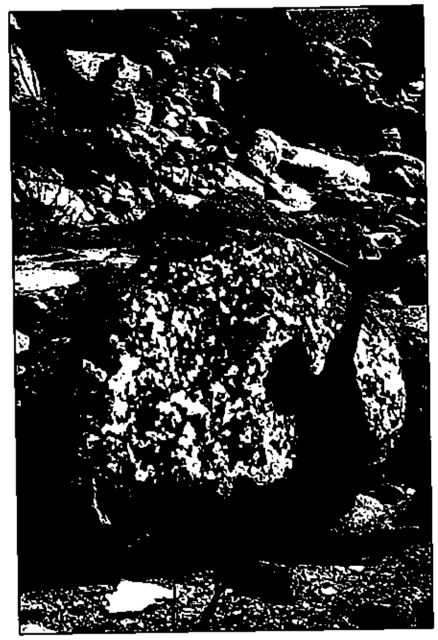

Figure 2. Granodiorite boulder (1 m high) spalled during Tuttle Creek fire. Dark areas are lightly varnished and soot covered. There is no varnish in spalled areas, and spall pattern is independent of joint orientation.

indicate that Ba is present in "subaerial" (i.e., not "crack") varnishes at concentrations between 0.5 and 2.75 wt% oxide (normalized to 100%). Recently Dorn and Dickinson (1989) published three analyses they consider characteristic of subaerial rock varnish; these varnishes contain 0.95, 0.87, and 0.53 wt% BaO (normalized to 100%). These levels are considerably higher than the ≤0.1% Ba in "subaerial" varnish implied by Dorn's Figure 2 (Comment above). The assertion that high Ba levels are associated with crack varnish appears untenable.

We are skeptical of Dorn's assertion that the porous texture shown in his Figure 1d is diagnostic of cation leaching—no chemical analyses are presented to support his claim. In fact, recent research has found no evidence of time-dependent cation leaching in rock varnish (Reneau and Raymond, 1991), thus calling into question the basis of cation-ratio dating.

Because the ideas presented in Dorn's Comment are not well substantiated, we continue to urge caution in accepting any surface-exposure date for which the assumption of zero erosion is made but not demonstrated. Even though the specific erosion history of most rock surfaces may remain enigmatic, average erosion rates may be estimated by measuring in situ-produced cosmogenic isotopes. If the concentrations of several isotopes are measured, it is theoretically possible to determine exposure ages even if erosion has occurred (Lal, 1988).

ACKNOWLEDGMENTS

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