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Fire induced rock spalls as long-term traps for ash

N. Shtober-Zisu[a,*], A. Brook[b], D. Kopel[b], D. Roberts[c], C. Ichoku[d], L. Wittenberg[b]

[a] Department of Israel Studies, University of Haifa, Mt. Carmel, Haifa, Israel
[b] Department of Geography and Environmental Studies, University of Haifa, Mt. Carmel, Haifa, Israel
[c] Department of Geography, UC Santa Barbara, Santa Barbara, CA 93106-3060, USA
[d] NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

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ABSTRACT

Severe fires accelerate rock weathering by spalling and exfoliation, creating abundant peels, flakes or spalls. In the following years, these spalls serve as physical traps which accommodate fine particles of dust, ash, organic matter, etc. We searched for traces of ash trapped under the spalls, after four major fires: 1989, 2005, 2010 and 2015 in Israel. Samples were collected beneath the spalls that formed on the rock outcrops, and in the immediate vicinity above and below them. Three laboratory analyses were performed: pH, EC and color. Five mineral/organic compounds were measured across the Mid-Infrared (MIR) spectral region at diffuse reflectance infrared Fourier transform mode: Hydroxylapatite (HAp), charcoal, organic carbon, montmorillonite and kaolinite. Several statistical analyses were performed: MANOVA, PCA and silhouette analysis on K-means clustering.

The results show evidence of ash trapped under the spalls formed during the 2005 and 2010 fires, 6 to 11 years after the fires. Charcoal presence is evident, as well as increased amounts of HAp and organic carbon. In the exposed soil above or below the burned rock outcrop, these values are lower. Negligible amounts of ash were measured 27 years after the fire. In the 2015 burned outcrop, large amounts of charcoal were found above and below the outcrop, but not under the spalls. It seems that on the carbonate slopes of Israel and under Mediterranean climate, the time required for spalls to begin functioning as traps is longer than one rainy season, while ash traces are preserved in these traps for a period of two-three decades.

1. Introduction

Severe forest fires accelerate rock weathering by spalling and exfoliation, both during the fire and during the subsequent cooling of the rocks. The high temperatures achieved during the fire cause a sudden heat shock to the ground surface and rock faces that rapidly expand, leading to cracking, spalling and flaking (Goudie et al., 1992; Dragovich, 1993). Large rock outcrops lose several millimeters, even centimeters, of their surface whereas smaller boulders may totally fracture and disintegrate (Ollier and Ash, 1983). After the fire is extinguished, most spalls remain in place and cover the rock, or fall adjacent to the parent outcrop exposing new rock surfaces to the atmosphere and erosion (Fig. 1a, b) (Dorn, 2003; Shtober-Zisu et al., 2015).

Several mechanisms are responsible for the process: uneven heating and thermal expansion, rapid vaporization of endolithic moisture, rock microfracturing due to rapid heating that may cause the loss of fluids from inclusions, significant increase of thermal diffusion, and accelerated loss of gases such as argon, helium, and neon from the rock (Bierman and Gillespie, 1991).

The effects of the fire depend to a large extent on the physical properties of the rock and vary with lithology, outcrop size, and water content (Allison and Goudie, 1994; Allison and Bristow, 1999). Fire-spalling affects almost all types of rigid and coherent rocks, especially hard, brittle igneous rocks, quartzite, flints and limestone (Blackwelder, 1927; Zimmerman et al., 1994). Moreover, spalling is favored by preexistent weathering rinds or fractures within the rock that formed long before the fire (Cooper and Simmons, 1977; Tratebas et al., 2004), such as in laminar calcretes (Goudie, 1996) or along rock coatings (Dorn, 2003). Preexistent dirt infill inside fissures enhances dirt-cracking which appears to be a wedging process (Ollier, 1965; Watanabe and Sato, 1988; Moores et al., 2008). It starts by precipitation of laminar calcrete inside fissures, and then it is expanded by wetting and drying of expansive clays that exert pressure on fracture sides (Dorn, 2011). When heated, these cracks will in turn accelerate spalling and exfoliation. The process produces clasts mostly as flat spalls of 10–20 cm in diameter, which in subsequent years will be subjected to gravitational and fluvial transport (Shtober-Zisu et al., 2015).

Subsequently, geomorphic slope processes act to reestablish a new

* Corresponding author.
E-mail address: nshtober@research.haifa.ac.il (N. Shtober-Zisu).

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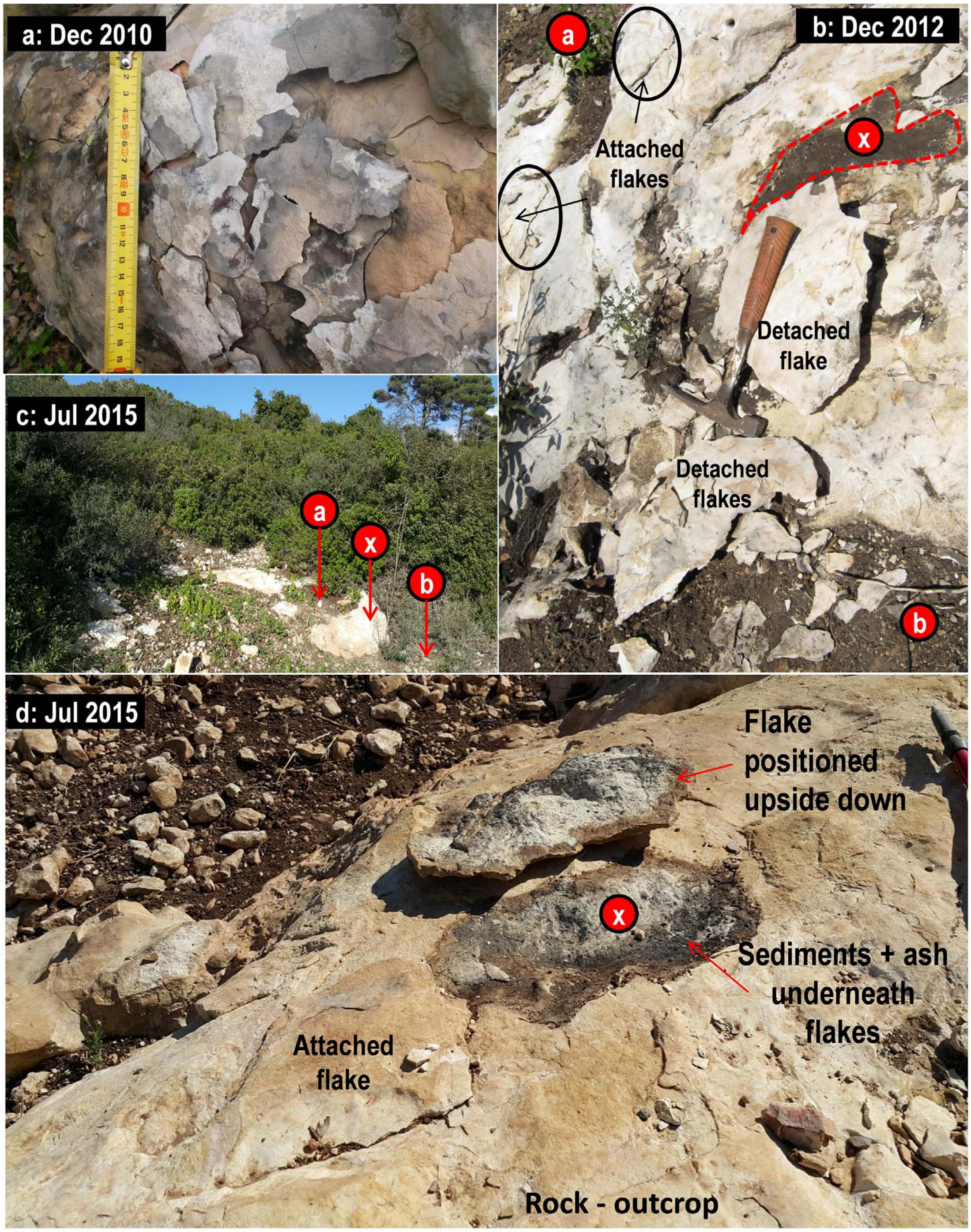

Fig. 1. Typical spalls detached from the rock outcrops. Encircled letters "a, x, b" refer to the sampling spots around and on the outcrop. See further explanation in Fig. 2b. (a) December 2010, several days after the fire ceased. The rock is spalled to a depth of several cm, forming flakes and spalls in a typical onionskin-like structure, parallel to the surface; (b) Two years after the fire, the disintegrated and detached spalls have fallen and a new, fresh rock face is now being exposed to weathering. Other spalls remain attached to the parent rock, permitting sediment accumulation underneath, such as dust, living organisms, and seeds. The red dashed line marks a sediment pocket filled with dust and ash accumulated under a large flake we manually removed; (c) Typical sampling spots (a, x, b) in an area burned in 2010; (d) Chalk outcrop and flake positioned upside down. Note the ash beneath. Photo captured in July 2015, from an area burned in 2010. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

steady-state: precipitation, infiltration, runoff, regrowth of vegetation and the returning fauna affect the rock surface and slope properties (Certini, 2005; Shakesby and Doerr, 2006). The evidence of fire on the rock outcrops decreases during the following years. Ash particles formed during the fire and those accumulated over the slopes are blown away by the wind or washed away by runoff. The abundant spalls, so prevalent right after the fire are either removed by gravity and runoff, covered by new sediments or vegetation, or assimilated into the topsoil as new rock surfaces are exposed to weathering. However, not all the spalls are removed. Some remain in place, attached to the parent rock, and separated one from another by mm-size fissures. These spalls act as sediment traps able to accommodate fine particles of dust, micro-organisms, small-scale roots and other materials that physically penetrate beneath the spalls and continue the detaching process from the bedrock (Shtober-Zisu et al., 2015).

Fires serve as excellent mineralizing agents of vegetation leading to immediate modifications in the physical and chemical properties of the soil. Among other changes, there is an increase in oxides, hydroxides