Documenting lichen-induced mechanical weathering of quartzitic sandstone at Kaapsehoop, Mpumalanga

Candice McKechnie[a*], **Stefan Grab**[a] **and Gillian Drennan**[b]

THE ROLE OF LICHENS IN ROCK WEATHERING is difficult to quantify and its study is still in its infancy. Here we highlight some biologically induced weathering processes observed on sandstone samples taken in a field of boulders located at Kaapsehoop in Mpumalanga province, South Africa. Light microscopy and scanning electron microscopy were used to investigate the interaction between lichen colonies and sandstone surfaces. The biological structures of lichens were observed for their effect on the rock surface, and variations in pore size, angularity and sorting of sandstone micro-granules were assessed. We demonstrate that the interlacing of lichen hyphae between sandstone grains contributes to the dislodgement and movement of these granules. We also found that lichen-induced weathering at Kaapsehoop produces smaller and more angular micro-granular sandstone surface structures than on the adjacent lichen-free surfaces.

Background

Information on the role of lichens in the disintegration of rock surfaces is limited for southern hemisphere and African environments. Although lichen-induced weathering has been examined in southern Africa,[1–3] there is limited information on the mechanisms involved. A previous study[1] conducted in the Magaliesberg, west of Pretoria, concluded that the weathering effects of lichens have been greatly underestimated. It has been proposed that lichens predominantly *alter,* rather than *remove,* the substrate.[4] Some studies have considered lichen colonies as agents of rock disintegration,[5] whereas others have argued in favour of a protective insulating role.[6,7]

Mineral grains are loosened and removed by lichens, so it is likely that biota-induced weathering and erosion (referred to as bio-weathering and bio-erosion, respectively) take place simultaneously.[5] Evidence of lichen-induced chemical weathering presents itself as grooves and pits, resulting from the dissolution of the substrate[8] and the dislodgement of grains. Physical mechanisms include thallus expansion and contraction through wetting and drying, and hyphae penetration.[9] These physical processes result in micro-fractures, surface spalls and increased porosity.[9] Once the lichen has dissolved minerals from the sandstone, the remaining precipitates accumulate and chemical weathering is further induced within these pores.[9] Robinson and Williams[5] observed thin sections of lichen and rock using a microscope to investigate the penetration of lichen between rock granules[5] and noted that weathering extends both vertically beneath the lichen cortex (outer layer of the thallus), and laterally to and beyond the thallus periphery.[5]

Several authors[1,10,11] have used scanning electron microscopy (SEM) to determine the role of microorganisms as geomorphic agents on rock surfaces. We have used this method to provide some preliminary evidence for sub-surface mechanical weathering by the lichen species, *Physica aipolia* and *Xanthoria elegans,* on quartzitic sandstone at Kaapsehoop, Mpumalanga.

Methods

Because it is difficult to observe lichens in the field and also to simulate field conditions in the laboratory, SEM is an alternative for observing the interactions of saxious lichens (those that grow on rocks) with the underlying substrate.[4]

Sandstone samples were collected in the field and later prepared as polished thin sections, cut perpendicular to the rock surface on which lichens grew. Transmitted light microscopy revealed the interactions between the lichen and sandstone at a maximum magnification of ×400 and only in two dimensions. Further investigations using SEM were conducted for more in-depth observation. The samples from the same slab of rock were cut into blocks with dimensions of *c.* 1 × 1 × 1.5 cm, which permitted observation and rotation within the microscope at magnifications between ×16 and ×13 000. Specimens were coated with gold–palladium and prepared as recommended by

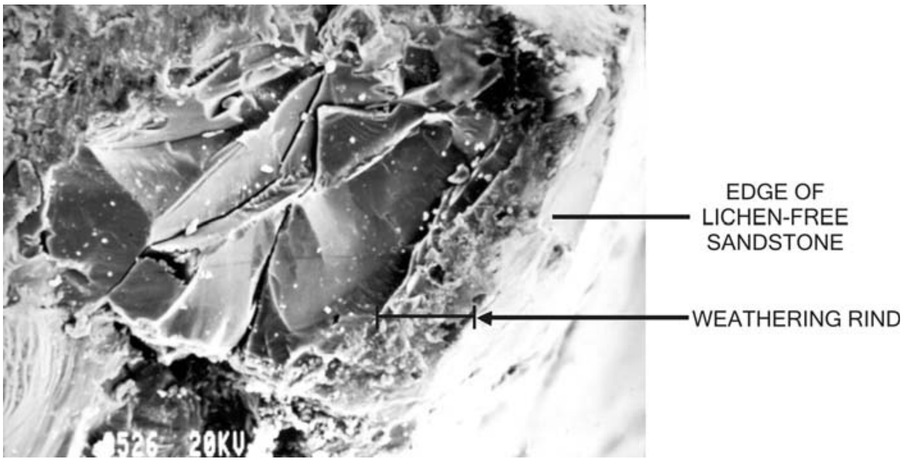
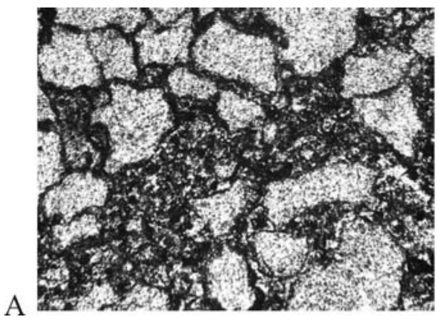


Fig. 1. SEM image of the surface of the lichen-free sandstone (450×).



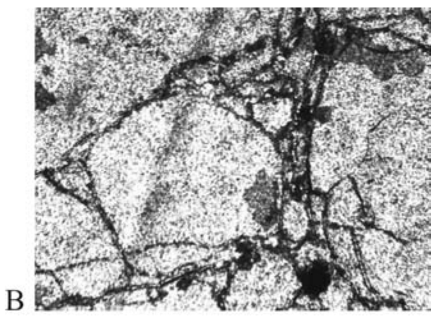


Fig. 2. Thin sections using light microscopy (400×) showing differences between granules at the surface (**A**) and 3 mm below the surface (**B**).

[a]School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, Private Bag 3, WITS 2050, South Africa.
[b]School of Geosciences, University of the Witwatersrand.
*Author for correspondence.
E-mail: candice@crg.bpb.wits.ac.za

Hale.[12] The metallic coating acted as an ion-emitting layer to avoid electron discharge that results in a flash-over and white streaking on the photographic record, and to reduce the risk of damaging the lichens.[4]

The degree of angularity of micro-granules was noted using parameters proposed by Lees.[13] A non-empirical and non-intrusive visual estimation of the degree of angularity of a particle was available in chart form. The chart places particles in categories ranging from 0–99 (representing well-rounded particles) to 1500–1599 (illustrating extraordinarily angular particles) in extreme cases.[13] Particles rated less than 300–399 were relatively well-rounded, whereas most particles with a very high degree of angularity fell into the 1000–1099 category or above.[13] A high angularity implies that these granules have been displaced from their original state and thus present an indication of the relative extent of particle weathering .

Lichens illustrate a symbiotic relationship between a phototroph (providing food) and a fungus.[14] *Physica aipolia* and *Xanthoria elegans* are both foliose lichens which are closely adnate, have narrow branched lobes and a dorsiventral cortex (that is, an upper and lower cortex).[15] They colonize specific rocks, depending on their moisture-holding capacity and the accumulation of nitrogen-rich nutrients.[16] Adjoining sandstone rock surfaces, with lichens present and absent respectively, were examined to differentiate the effects of lichen-induced mechanical features from those that were the product of other (non-lichen) weathering processes.[4]

Results and discussion

The lichen-free sandstone granules were larger and less angular than those overrun by lichens (Fig. 1). Although the lichen-free sandstone granules are likely to have been subjected to some mechanical and chemical weathering processes, they were larger (mean size = 16 μm) than those found on the adjoining surface where lichens appeared to have broken down granules into smaller size fractions (mean = 7 μm).

Light microscope images showed evidence of micro-granular sorting having occurred from the surface downwards through the lichens and weathering rind (outermost layer of the weathered zone) (Fig. 2A, B). Micro-grain size at the lichen/rock interface was *c.* 25% smaller in diameter than that at depth (*c.* 30 mm), where the lichens no longer have a direct influ-

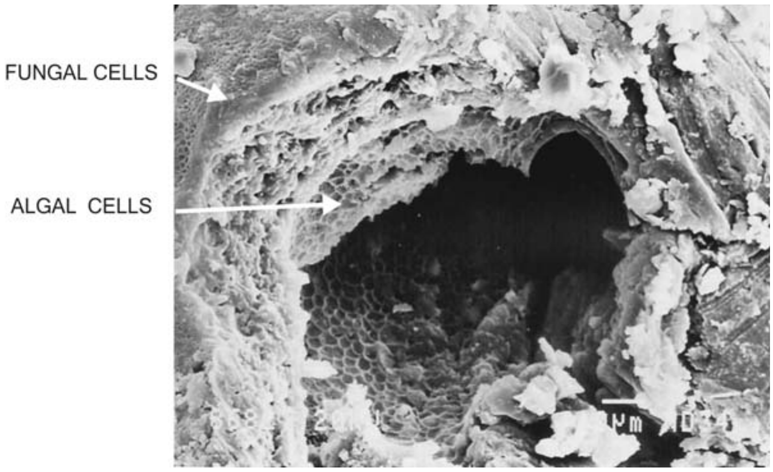


Fig. 3. SEM image of lichen fungal and algal components (800×).

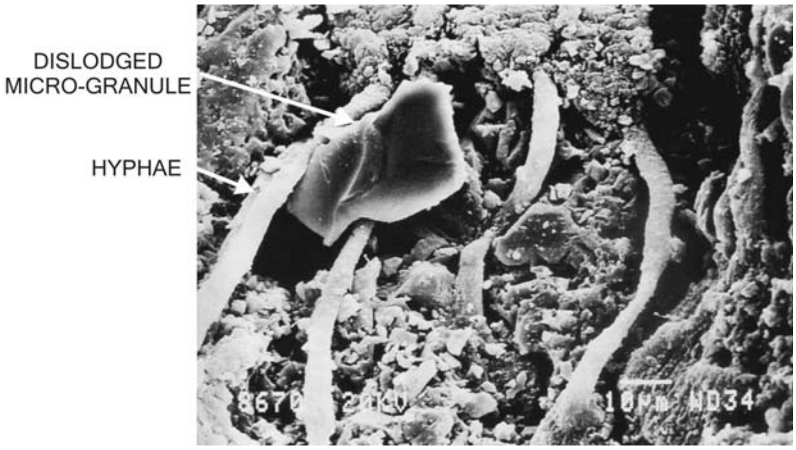


Fig. 4. SEM image of lichen hyphae interlacing sandstone grains (800×).

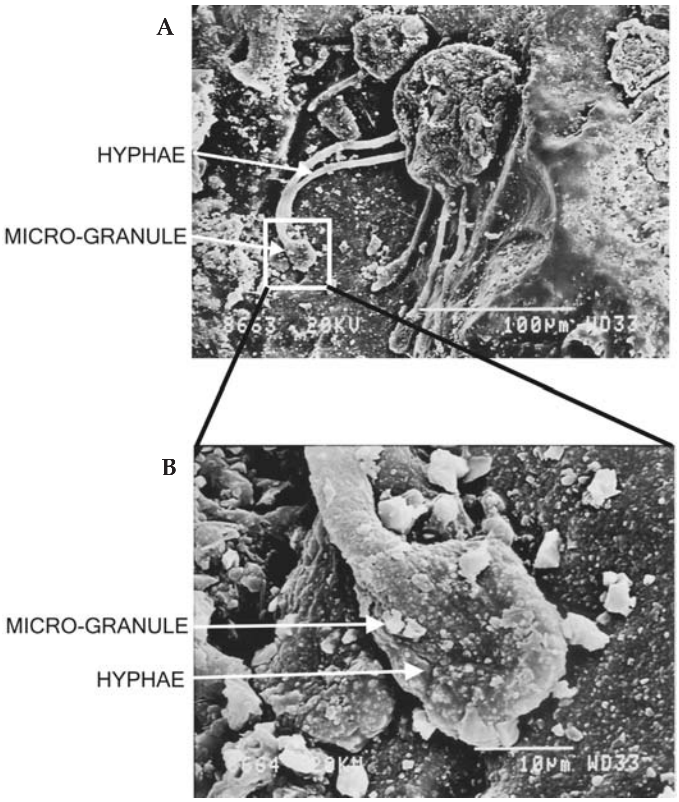


Fig. 5. **A**, SEM image of lichen hyphae attached to substrate (350×). **B**, SEM image of lichen hyphae dislodging micro-granules (1800×).

ence. At the rock surface, the pore spaces were larger (by *c.* 2 μm) than the micro-granules, thus contributing to rock porosity and increasing the potential water absorption capability. However, pore space diameter decreased from *c.* 3 μm at the rock surface to 1.5 μm at a depth of 30 mm. Lichens thus increased pore spaces and rock porosity close to the surface. The micro-granules were angular at the surface (900–999 degree of angularity),[13] becoming rounded (200–299 degree of angularity)[13] with increasing depth to 30 mm, which may reflect differences in the extent of bio-weathering/erosion effects with depth.

SEM is able to reveal lichen morphology and its associated geomorphological imprint. A cross-sectional view of a thallus indicated the protective effect of the fungal cells (cortical or condensed gelatinous hyphae) surrounding algal cells (Fig. 3). Lichen hyphae interlaced sandstone grains of up to 14 μm in diameter, and thus had the potential to remove relatively large granules (*c.* 20–30 μm in diameter) (Fig. 4). The mechanical weathering ability of hyphae (width *c.* 5–8 μm) was evident through their attachment to, and growth and extension between, micro-granules (Fig. 5A, B). This highlights the ability of the hyphae to displace micro-granules mechanically. Planar (layered) fracturing was visible within the weathering rind (upper 7 mm) where micro-fracture planes were *c.* 5.6 μm in width (Fig. 6), induced by hyphae penetration within existing fracture openings. Foliose lichens are attached to the substrate by rhizines (collections of hyphae).[16] Micro-grains are brought to the surface after dislodgement, thus also suggesting that lichens act as bio-erosional agents (Fig. 7). Whereas bio-weathering constitutes the *in situ* dislodgement or breakdown of granular structures, bio-erosion involves mechanical forces that *move* the dislodged micro-granules. We thus demonstrated that lichens are capable of both *altering* and *removing* substrate. It is possible that the micro-grains were either being abraded as they progressed towards the surface, or alternatively, that only the smaller size fractions were involved and transported to the surface. Lichen hyphae were able to penetrate the sandstone (Fig. 8) by etching their way along planes of weakness and existing open rock pore spaces. As the interlacing hyphae anchored themselves onto the substrate, they dislodged and displaced sandstone granules with their movement, thus contributing to both micro-scale weathering and erosion.

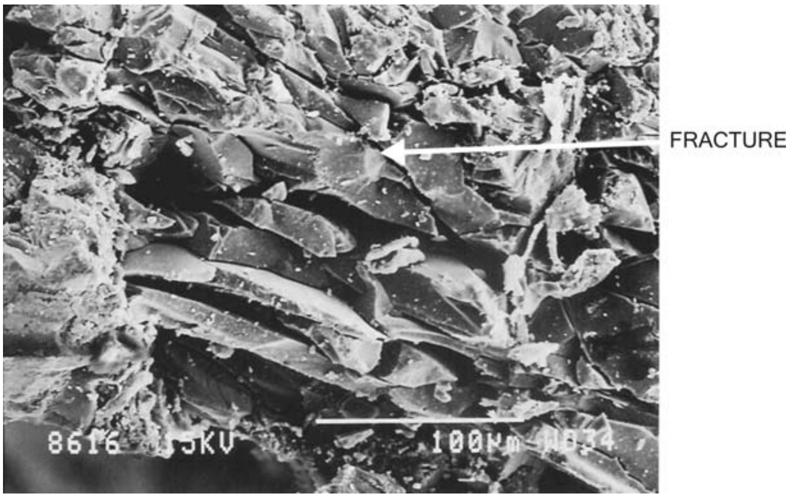


Fig. 6. SEM image of planar fractures within the weathering rind, suggesting mechanical weathering (350×).

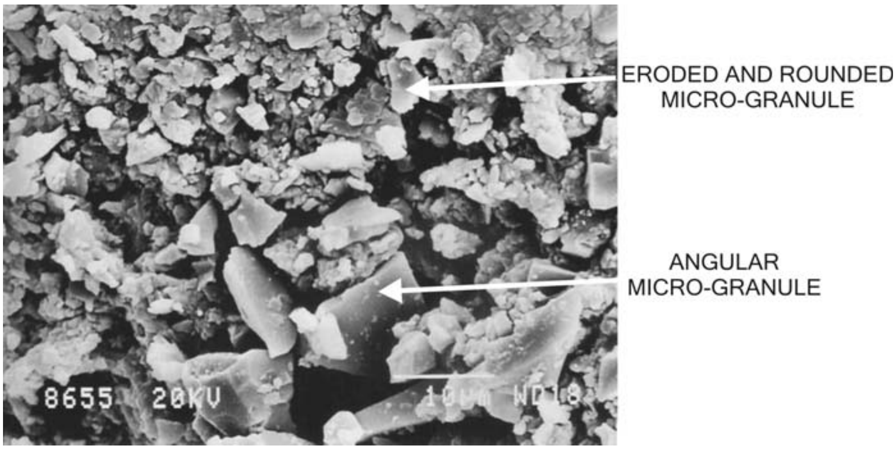


Fig. 7. SEM image of the dislodgement and transfer of micro-granules towards the surface (1800×).

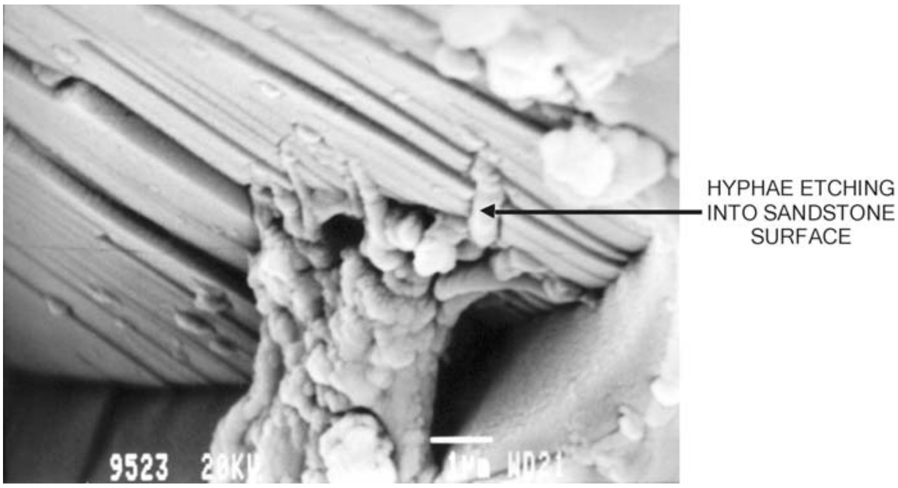


Fig. 8. SEM image of lichen hyphae etching into the sandstone (13 000×).

The challenge of such micro-scale weathering studies is to quantify the mechanisms involved, and to monitor these processes over time. This study reports the first southern African observation of microgranules involved with lichen-induced bio-weathering and erosion. The increased pore spaces associated with lichen-induced weathering are likely to enhance other weathering processes and account for differential rates of rock disintegration across sandstone surfaces.

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