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# Advances in rapid condition assessments of rock art sites: Rock Art Stability Index (RASI)

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ABSTRACT

The Rock Art Stability Index (RASI) is a rapid, quantitative approach to rock art condition assessment. Research carried out at Petrified Forest National Park, USA, demonstrates that, following a 2-day training session, site evaluators obtained replicable results, facilitating a condition assessment of over 3500 engraved panels.
Two electron microscopy case studies allowed us to identify the specific rock decay processes and major causes of destruction on panels that were RASI-scored as in high threat, suggesting potential avenues for future conservation interventions. This approach illustrates a holistic strategy for rock art conservation.
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## 1. Introduction

Rock art sites are especially vulnerable to human and natural damage, and they are difficult to manage and conserve (ICOMOS, 2000; Loubser, 2001; Whitley, 2001, 2005; Bertilsson, 2002; J. Paul Getty Trust, 2003; Varner, 2003; Keyser et al., 2005; Berltilsson, 2015; Haubt, 2015). They are also more common than often recognized: there are over 1500 recorded rock art sites in California alone, e.g., representing literally millions of individual motifs. One result is an unmet conservation need, partly exacerbated by the fact that traditional conservation approaches, involving individual conservators each using their preferred assessment approach, are time consuming and idiosyncratic. Another is that rock art conservation commonly reduces to crisis-management: conservation interventions undertaken only after serious threats to the art are observed. The long-term sustainability of rock art requires rapid, replicable analytical assessment techniques that are efficient and inexpensive, allowing for practical management planning. One approach that meets these goals is the Rock Art Stability Index (RASI; Dorn et al., 2008; Allen, 2011; Allen et al., 2011; Allen and Lukinbeal, 2010; Allen and Groom, 2013; Cerveny et al., 2016), which provides a quantitative evaluation of rock panel decay.

Most panel decay analyses involve specialized equipment and training (e.g., Fitzner et al., 2004; Campbell, 1991; Vogt and Edsall, 2010; Plisson and Zotkina, 2015; Hoerle and Salomon, 2004; Hoerle, 2006; Guo and Jiang, 2015; Yun et al., 2015; Hall et al., 2007; Mol and Preston, 2010; Linderholm et al., 2015; Tratebas et al., 2004; Pillans and Fifield, 2013). While valuable, these specialized analyses logically should follow a holistic management strategy directed first at identifying relative degrees of site vulnerability (e.g., Loubser, 2001; Warke et al., 2003; Giesen et al., 2014; Carmichael, 2016), such as RASI. We present here new data demonstrating that the RASI approach is replicable with minimal training, and that its results are supported by electron microscopy studies.

## 2. The RASI method

RASI provides a rapid assessment of rock art site condition. It was designed for use by college students, volunteers and archaeologists, following a minimum amount of training. It provides a replicable rank ordering of various aspects of panel physical condition, yielding a score of relative site vulnerability. When used regionally and comparatively, it identifies those sites in greatest threat, thereby establishing priorities for detailed site management and conservation interventions. It is not intended as a method for conserving individual rock art sites. Instead, it promotes logical management planning and conservation resource allocations.

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**Table 1**
General categories of weathering forms and ordinal scale used to classify rock art decay on a panel.

| Site setting (geological factors) | Not present | Present | Obvious | Dominant |
|---|---|---|---|---|
| Fissures independent of stone lithification (pressure release, calcrete wedging) | 0 | 1 | 2 | 3 |
| Fissures dependent on lithification (bedding, foliations) | 0 | 1 | 2 | 3 |
| Changes in textural anomalies (banding, concretions) | 0 | 1 | 2 | 3 |
| Rock weakness (Moh's hardness tested at control site; 3 –<4, 2–Moh4–5, 1–Moh6–8, 0–Moh7+) | 0 | 1 | 2 | 3 |
| **Weaknesses of the rock art panel** | **Not present** | **Present** | **Obvious** | **Dominant** |
| Fissuresol (future location of break–off) | 0 | 1 | 2 | 3 |
| Roots | 0 | 1 | 2 | 3 |
| Plant growth near or on panel | 0 | 1 | 2 | 3 |
| Scaling & flaking (future location of flaking — millimeter–scale, or scaling —centimeter–scale) | 0 | 1 | 2 | 3 |
| Splintering (following stone structures and oblique to surface) | 0 | 1 | 2 | 3 |
| Undercutting | 0 | 1 | 2 | 3 |
| Weathering–rind development | 0 | 1 | 2 | 3 |
| Other concerns (e.g. water flow) | 0 | 1 | 2 | 3 |
| **Evidence of large erosion events on and below the panel** | **Not present** | **Present** | **Obvious** | **Dominant** |
| Anthropogenic activities | 0 | 1 | 2 | 3 |
| Fissuresol/calcrete wedging (or dust in fissuresol, or both) | 0 | 1 | 2 | 3 |
| Fire | 0 | 1 | 2 | 3 |
| Undercutting | 0 | 1 | 2 | 3 |
| Other natural causes of break–off (wedgework of roots, earthquakes, intersection of fractures, ...) | 0 | 1 | 2 | 3 |
| **Evidence on small erosion events on the panel** | **Not present** | **Present** | **Obvious** | **Dominant** |
| Abrasion (from sediment transport by water) | 0 | 1 | 2 | 3 |
| Anthropogenic cutting (carving, chiseling, bullet impact, ...) | 0 | 1 | 2 | 3 |
| Aveolization (honeycombed appearance) | 0 | 1 | 2 | 3 |
| Crumbly disintegration (in groups of grains or powdery) | 0 | 1 | 2 | 3 |
| Flaking (single or multiple; millimeter–scale) | 0 | 1 | 2 | 3 |
| Flaking of the weathering rind | 0 | 1 | 2 | 3 |
| Granular disintegration (most frequently sandstone and granitic) | 0 | 1 | 2 | 3 |
| Lithobiont pitting | 0 | 1 | 2 | 3 |
| Lithobiont release (when the "dam" of weathered rind decayed rock erodes) | 0 | 1 | 2 | 3 |
| Loss parallel to stone structure (bedding or foliations) | 0 | 1 | 2 | 3 |
| Rock coating detachment (usually incomplete; includes paint material in pictographs) | 0 | 1 | 2 | 3 |
| Rounding of petroglyph edges (or blurring of pictograph images) | 0 | 1 | 2 | 3 |
| Scaling (centimeter–scale; thicker than flaking) | 0 | 1 | 2 | 3 |
| Textural anomaly features erode differentially (clay lenses, cementation differences, nodules) | 0 | 1 | 2 | 3 |
| Splintering (following stone structures and oblique to stone surface) | 0 | 1 | 2 | 3 |
| Other forms of incremental erosion (e.g. insects, birds) | 0 | 1 | 2 | 3 |

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**Table 1** (*continued*)

| Rock coatings on the panel | | Not present | Present | Obvious | Dominant |
|---|---|---|---|---|---|
| | Anthropogenic (chalking, graffiti, other) | 0 | 1 | 2 | 3 |
| | Rock coating present | 0 | −1 | −2 | −3 |
| | Case hardening (deposits in rock that harden outer shell) | 0 | −1 | −2 | −3 |
| | Salt Efflorescence or subflorescence | 0 | 1 | 2 | 3 |
| Highlighting vandalism and other issues | | | | | |
| Concerns | Please briefly describe the problem and why you believe that this concern endangers the panel. Put in "X" on the right to indicate whether this concern creates a "severe danger", "great danger", "urgent danger" or "problem" for the panel. | Creates a problem | Urgent Danger | Great Danger | Severe Danger |
| Graffiti | | | | | |
| Other Vandalism (describe) | | | | | |
| Trash | | | | | |
| Visitor impact (e.g. dust, trail proximity) | | | | | |
| Land use issues (e.g. livestock, off–road vehicles) | | | | | |
| Natural processes that are a major concern to you | | | | | |

| Notations on rock coatings (note: these notes do not alter the rock art stability index score, but they are useful in analyzing a site's context) less difficult to identify in the field | | |
|---|---|---|
| Rock Coating | Circle One | Notes |
| Lithobionts (e.g. lichen) | Yes / No / Uncertain | |
| Rock Varnish (desert varnish) | Yes / No / Uncertain | |
| Bird Excrement | Yes / No / Uncertain | |
| Dust Coatings | Yes / No / Uncertain | |
| Iron Film | Yes / No / Uncertain | |

| More difficult coatings to identify in the field | | |
|---|---|---|
| Rock coating | Circle One | Notes |
| Silica glaze | Yes / No / Uncertain | |
| Heavy metal | Yes / No / Uncertain | |
| Oxalate | Yes / No / Uncertain | |

After a 2-day training session, individual RASI evaluators are capable of identifying and judging the severity of the physical conditions at a site, scoring with the form presented in Table 1. Five primary analytical categories are included (Fig. 1): (1) fundamental weaknesses in the bedrock supporting a rock art site that facilitate erosion; (2) aspects of the support rock that can result in rock art panel detachment; (3) incremental erosion; (4) loss of large blocks of a rock panel; and (5) natural rock coatings and other deposits that either stabilize or promote

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instability. A final and flexible sixth category is also incorporated in the index (Table 1). This allows for the inclusion of region-specific concerns (such as human vandalism), and the differential weighting of this or any of the other categories in the calculation of an individual index score for a site.

Several online resources facilitate RASI's use. A series of online presentations are available:

- Introduction to RASI
- Site Setting (geological factors)
- Weaknesses of the Rock Art Panel
- Evidence of Large Erosion Events On and Below the Panel
- Evidence on Small Erosion Events On the Panel
- Rock coatings on the Panel
- Highlighting Vandalism and other Issues

An atlas illustrating examples of the different physical conditions and variables can be seen at: http://alliance.la.asu.edu/rockart/stabilityindex/RASIAtlas.html.

In addition, brief 1-page handouts on each RASI component can be downloaded from this site: http://alliance.la.asu.edu/rockart/NSF/RASI_Tidbits.html.

## 3. Petrified Forest National Park Case Study

In an interdisciplinary field based research experience for undergraduates, first and second year college students were trained to conduct RASI analysis on sandstone petroglyph panels. Training typically spanned 4 h in an interactive seminar and another hour working together on the same rock art panel in the field. The first individual assessments took approximately 45 min with expert consultation, decreasing in time as terminology and field observations became more familiar. Students participated in field research lasting from 2 days to 2 weeks, 7 h per day, assessing total of 100–150 panels per day. Two to three trips per academic semester were conducted between 2009 and 2012. In all over 3500 panels were analyzed by students. Assessment of student RASI scores for specific panels resulted in <5% variance on their scores.

Testing groups of trained college students demonstrates that the results for any given site are replicable between evaluators (Allen and Lukinbeal, 2010; Allen, 2011; Allen et al., 2011; Allen and Groom, 2013). A video presentation illustrating the RASI evaluation of engraved panels at Petrified Forest National Park can be viewed here: https://www.youtube.com/watch?v=QbhRahgRzg4. In all over 3500 panels were analyzed by students.

The total RASI scores provide site managers with a quick measure of the overall condition of a panel (e.g., Fig. 2). Total RASI scores of >30 alert conservation resource managers to panels that have multiple conservation problems. In addition, each specific RASI scoring element also has value in evaluating panel instability. For example, Fig. 3 presents the data gathered by students for panels that lack support at the base or undercutting, where mass wasting could topple the panel. In another example, Fig. 4 presents observations related to anthropogenic impacts on a panel, regardless of cause. The power of RASI, as exemplified by its use at just one U.S. National Park, is its ability to provide widespread, replicable and rapid condition assessment. To our knowledge, no other rock art condition assessment strategy has yet been applied over such a large area.

## 4. Comparison of RASI with electron microscope studies

After RASI identifies a panel in potential danger, a next step would be to carry out more detailed studies to evaluate the process(es) that could

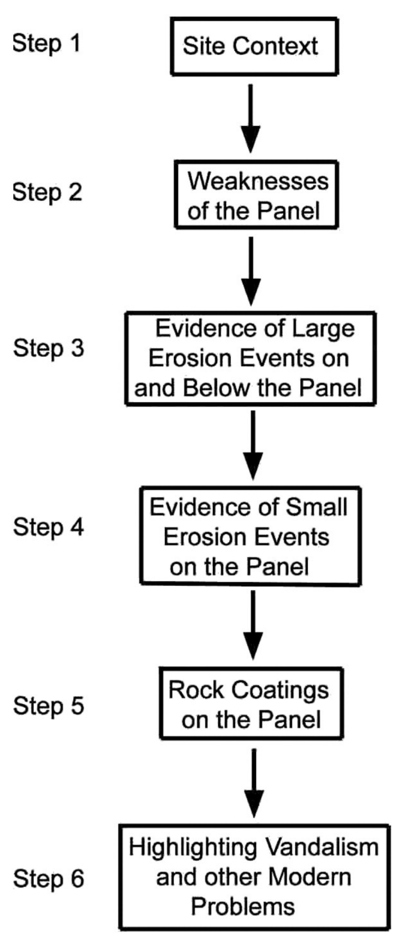


**Fig. 1.** The general sequence of field observations in the RASI index.

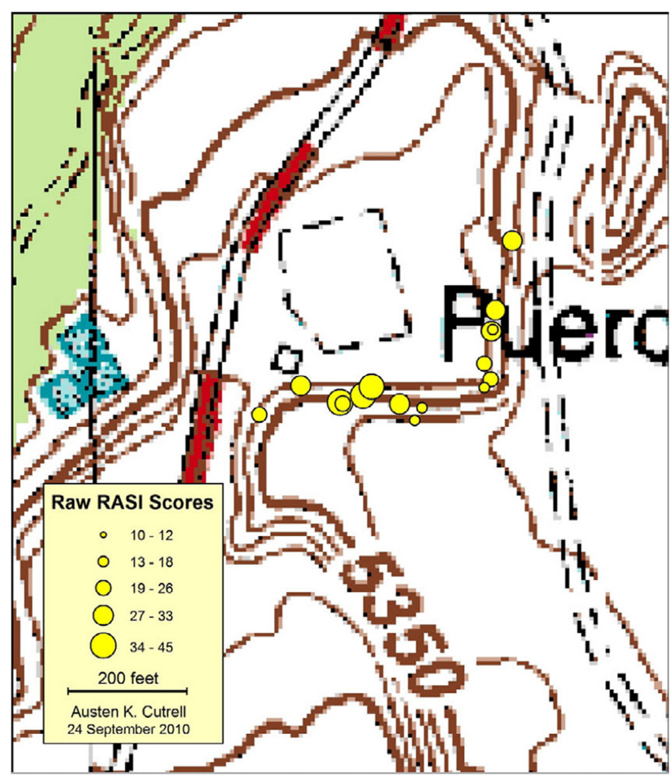


**Fig. 2.** RASI total scores for 16 panels at a public overlook at Petrified Forest National Park, superimposed on the U.S. Geological Survey topographic map. Higher scores indicate greater danger. While not cartographically appealing, this map was generated in the field after the panels were scored.

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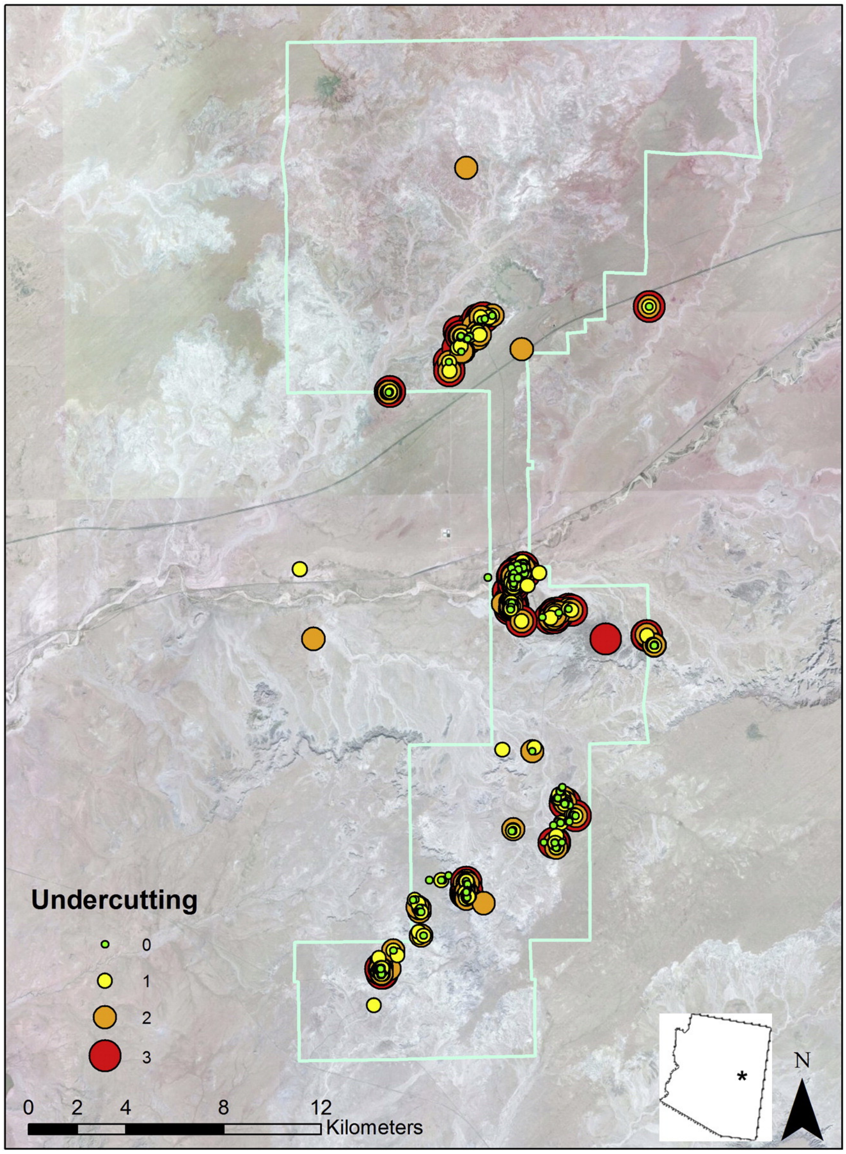


**Fig. 3.** Scores for undercutting measured at 450 panels at Petrified Forest National Park. The score of 3 indicates panels where undercutting was considered to be dominant and of serious concern.

lead to panel loss. Then, only after these processes are understood, should conservation intervention measures (Loubser, 2001) be taken. We present here two examples of RASI case studies and how they compare with electron microscopic analyses.

Fig. 5 presents a Petrified Forest National Park panel located near Lacey Point. The scored panel has an overall RASI average score of 34 with scores of 3 (dominant issue) identified for scaling, undercutting, loss parallel to stone structure, flaking, weathering-rind development, and vandalism. Electron microscope observations on a sample collected at the white arrow in Fig. 5 indicate the cause of scaling of the panel. Motifs engraved into dark rock varnish have been lost through ongoing mineral dissolution underneath the rock varnish. The dashed white line in the SEM imagery separates two different zones in the weathering rind of the sandstone: a zone of decay underneath and a zone of enhanced porosity with organics above the rind. The next effect of decayed rock, enhanced porosity, and endolithic organisms results in scaling of the panel face.

Fig. 6 presents a McDowell Mountains, central Arizona, USA, panel with an overall RASI score of 42 and with scores of 3 (dominant issue) identified for plant growth, flaking of the weathering-rind, weathering-rind development, lithobiont (organisms directly growing on rock surfaces such as lichens, fungi or algae) pitting, lithobiont release, textural anomalies and splintering. The visual loss of the motifs is due to the action of microcolonial fungi lithobionts, as revealed by SEM imagery.

In these two cases (Figs. 5–6), RASI identified each panel as endangered. Electron microscopy next allowed us to identify specific decay process and the major causes of panel destruction, suggesting future potential conservation intervention approaches. These examples illustrate a logical and holistic approach to rock art conservation, starting first with the identification of endangered panels on a regional scale, followed by more detailed analytical studies to determine causes of destruction, from which potential corrective measures could be identified.

## 5. Conclusion

Over twenty different strategies can be used to analyze rock art panel decay (Dorn et al., 2008). Unfortunately, these approaches are too specialized, expensive, and/or time consuming to use on a regional scale. It is thus essential, for practical management and efficient resource allocations, that rapid condition assessment approaches be adopted. Our study at the Petrified Forest National Park, USA, illustrates

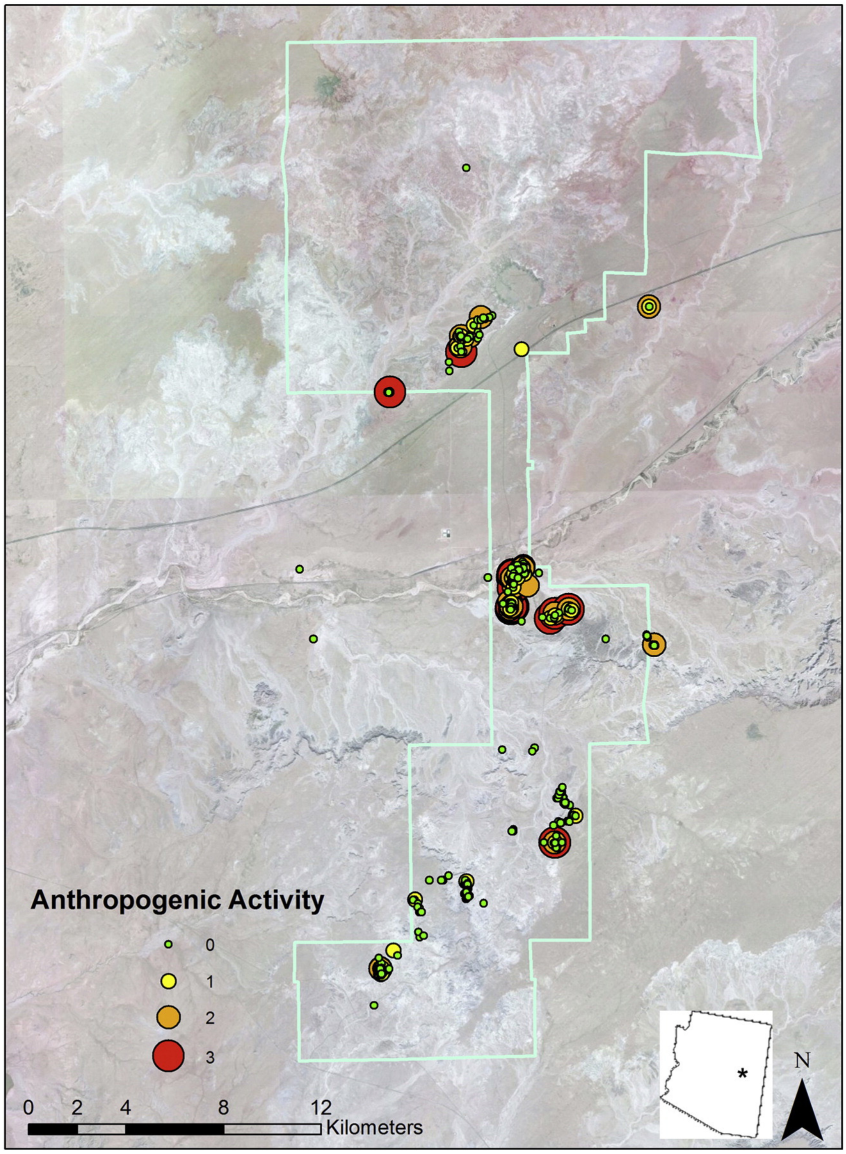


**Fig. 4.** Scores for all anthropogenic impacts measured at 450 panels at Petrified Forest National Park. The score of 3 indicates panels where scorers felt the impacts were dominant and represent the greatest danger.


**Fig. 5.** Petrified Forest National Park panel near Lacey Point exhibits panel scaling. The upper and lower SEM images are secondary electrons (showing topography) and back-scattered electrons (showing atomic number).

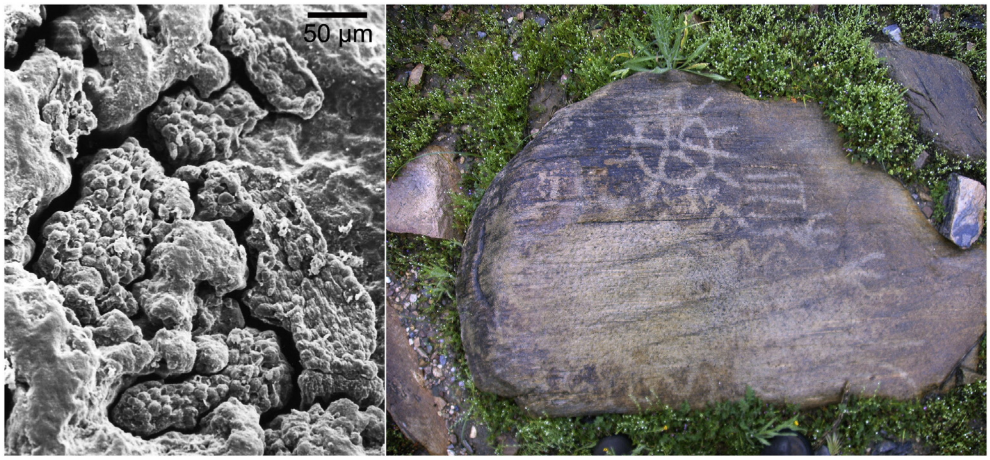


**Fig. 6.** Hohokam motifs engraved into dark rock varnish on a metarhyolite alluvial-fan boulder. The motifs are disappearing due to the secretion of organic acids by microcolonial fungi, where the rounded forms ~5 μm diameter are individual cells. The secondary electron image on the left shows an abundance of fungi dissolving the varnish away, resulting in loss of the motifs.

the power and ease of the Rock Art Stability Index as an effective management and conservation tool.

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