The Rock Art Stability Index

A New Strategy for Maximizing the Sustainability of Rock Art

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Abstract In order to identify those petroglyph and pictograph panels most susceptible to damage, we propose a field-friendly index that incorporates elements of existing strategies to characterize the stability of stone. The Rock Art Stability Index (RASI) has six general categories: Site Setting (geological factors); Weakness of the Rock Art Panel; Evidence of Large Erosion Events On and Below the Panel; Evidence of Small Erosion Events on the Panel; Rock Coatings on the Panel; and Highlighting Vandalism. Initial testing reveals that training of individuals with no prior background in rock decay can be conducted within a

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two-day period and yield reproducible results. RASI's use as a tool to promote cultural resource sustainability includes the use of a Geographic Information System to store, display and analyze rock art.

Resumen Para identificar los paneles del arte rupestre pintado y engrabados más vulnerables a daños, proponemos un fácil-por-el-campo indexo que incorporan elementos de estrategia que existen para la estabilidad de piedras. El Indexo de Estabilidad de Arte Rupestre (RASI) tiene seis categorías en general: el disposición de sitio (factores geológicos); debilidad del panel de arte rupestre; evidencia de grandes episodios de erosión en y debajo del panel; evidencia de pequeños episodios de erosión en el panel; capas de rocas en el panel; y el punto culminante de vandalismo. Exámenes iniciales revelan que personas con no bases anterior en desmoronamiento de roca formara en dos días con resultados reproducibles. Como una herramienta de la sostenibilidad de recursos culturales, RASI se incluyen una pieza de Sistema de Información Geográfica para amontonar, manifestar, y analizar arte de roca.

Archaeological sites worldwide are imperiled. Cultural resource management (CRM) has developed as a professional specialization and career path in response to this fact and, overall, CRM has made great strides in slowing the loss of heritage resources in the U.S. Almost all archaeologists, applied and academic, are quick to accept disciplinary responsibility for the well-being of the archaeological record. For example, both CRM and academic archaeologists use phrases such as "saving the past for the future" as sound bites to illustrate the relevance and goals of the profession.

While portable surface remains and subsurface artifacts remain in danger, perhaps the greatest risk to the archaeological record comes from the daily loss of rock art. There can be little doubt that human activities and natural erosion lead to the destruction of countless numbers of engraved or painted motifs on rock surfaces (Bertilsson 2002; Hall, Meiklejohn et al. 2007; ICOMOS 2000; J. Paul Getty Trust 2003; Keyser et al. 2005; Varner 2003). Many academic archaeologists in the U.S.A. omit rock art from their teaching curricula based on the belief that little can be achieved through its study, raising questions such as: What tools can be used to study this heritage resource? Why is rock art important? What can be learned from it that will advance our insight into culture? An explosion of rock art research over the past two decades has answered this challenge (e.g., Boivin et al. 2007; Clottes 1997; Hays-Gilpin 2004; Lewis-Williams 2001, 2006; Novell 2006; Vandenabeele et al. 2007; Whitley 2001, 2005; Whitley and Keyser 2003; Whitley et al. 2006), making untenable this traditional bias. Perhaps more important, however, is the fact that legislation and regulation, worldwide, now require management of *all* aspects of the archaeological record, rock art included. Yet unanswered is a critical problem: How can we identify rock art that is endangered by natural and human activity, especially those sites needing immediate conservation?

Rock art commonly is intrinsically fragile (especially pictographs) and, often, much more visible than other aspects of the archaeological record (particularly in the hunter-gatherer record). Archaeologists have long recognized this fact and, in the U.S. at least, have adopted a management strategy almost exclusively directed towards one issue: visitor control (Whitley 2005). Although human actions certainly are important, sometimes critical, in long-term rock art preservation, they are only one factor in the sustainability of the sites. We have documented cases where sites literally have disappeared in only two decades, despite very controlled human visitation. Their disappearance occurred not from vandalism but due to natural weathering processes that, typically, are never considered in site management. Perhaps worse, these sites disappeared with no real knowledge of or reaction from the archaeological community, for the simple reason that no one at that time recognized the natural threat that imperiled them. Long-term sustainability of the rock art record requires a systematic tabulation of the processes, human *and* natural, that threaten the sites, combined with an evaluation and ranking system that identifies those sites that are most gravely endangered, allowing us to allocate our scarce management and conservation resources as efficiently as possible.

This paper is a response to this need. It is a collaboration of weathering specialists, a CRM archaeologist and rock art researcher, a specialist in Geographic Information Science (GIS), and a specialist in the assessment of environmental education. Together, we have developed the Rock Art Stability Index (RASI). This is intended to provide quick and replicable assessments of the natural and human factors that are potentially endangering rock art sites. It is usable by public volunteers and requires only minimal training (e.g., a week-end workshop), but otherwise no specialized prior expertise in rock weathering or geomorphology.

We start by explaining why most existing conservation approaches to stone stability do not adequately address the challenge posed by naturally decaying and vandalized rock art panels. We turn next to our proposed field classification system, outlining how this can be used as an index for management purposes.

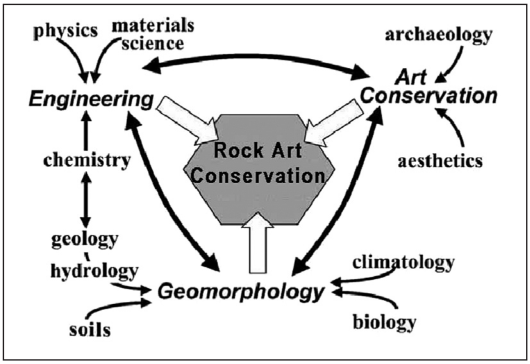

Figure 1. Interdisciplinary nature of studies of stone for the purposes of conserving rock art resources. *Modified from Pope et al. 2002.*

We then demonstrate the replicability of our approach, illustrated by a learning assessment analysis of individuals who had no prior experience in the examination of rock art panels. We conclude with an explanation of how RASI can be easily linked to a GIS useful for cultural resource managers.

Existing Strategies for Assessing Rock Stability

Studies assessing the longevity of worked stone are carried out by many different disciplines (Figure 1). Analyzing potential future instability requires clear and replicable methods of classifying rock decay (weathering) as it relates to future erosion. Consider just the myriad of ways to measure the chemical decay of rock; the literature a decade ago contained more than fifty methods (Dorn 1995). Active research on rock art panel weathering utilizes more than six dozen methods of measuring stone decay (Barnett et al. 2005; Benito et al. 1993; Campbell 1991; Dolanski 1978; Fitzner 2002; Fitzner et al. 2004; Hall et al. 2007; Hoerle 2005, 2006; Hoerle and Salomon 2004; Pineda et al. 1997; Pope 2000; Pope et al. 2002; Prinsloo 2007; Tratebas et al. 2004; Van Grieken et al. 1998; Wasklewicz et al. 2005). One research group's methods (Fitzner 2002) include over twenty field metrics and over forty laboratory procedures. Needless to say, weathering researchers can contribute to heritage management through a wide variety of approaches to analyze the decay of stone (Table 1). But in analyzing this literature, we conclude that no single existing strategy will adequately assess the thousands of rock art panels endangered in the western U.S. alone because of cost concerns and the extensive training they require.

In the existing rock weathering literature, research analyzing the decay of building stone would seem to have a logical potential for rock art applications (Ashurst and Dimes 1990; Fitzner 2002; Price 1996; Siegesmund et al. 2002; Smith and Warke 1995; Warke et al. 2003; Winkler 1994). We conclude, however, that the strategies currently used to understand building stone weathering are not appropriate for rock art, for the several reasons.

The first problem is that rock art rests on panel faces that are often heavily weathered prior to engraving or painting. Long before exposure at the surface, panel faces weather deep under the ground (Battiau-Queney 1996; Ehlen 2005), even before the artist painted or engraved the panel face. In contrast, building stone was typically selected for construction use precisely because it is not weathered, and all existing analytical approaches focus on examining only the surface that is undergoing decay (Fitzner and Heinrichs 2002; Fitzner et al. 2004; Moropoulou, Kouloumbi et al. 2003; Moropoulou, Polikreti et al. 2003; Pininska and Attia 2003; Salvadori, Errico et al. 2003; Smith et al. 2005; Striegel et al. 2003; Turkington et al. 2005; Vicini et al. 2004; Warke et al. 2003). Whereas building stones suffer mostly from surficial degradation, rock art often suffers from the problem of entirely rotted rock.

The second problem is that rock coatings are historically considered to have a negative effect (Sharma and Gupta 1993; Smith et al. 2005; Striegel et al. 2003; Urzì et al. 1993; Van Grieken et al. 1998; Young 1996). For example, "black varnish" in the building literature can be a mix of iron oxide and carbonaceous matter (Thomachot and Jeannette 2004), fungi (Diakumaku et al. 1995) or other materials (Moropoulou, Polikreti et al. 2003) that must be eliminated to improve building appearance. In rock art, rock coatings often stabilize the panel by creating a case hardening effect (Conca and Rossman 1982; Dorn 1998; Tratebas et al. 2004; Turkington and Paradise 2005; Viles and Goudie 2004). Rock coatings are also integral to the original creation and subsequent dating of engravings (Dorn 2001). Even the lichens and other lithobionts that weather the underlying material (Gordon and Dorn 2005; Stretch and Viles 2002) are not simply erosional (Viles 1995; Viles and Pentacost 1994) but often protect the weathered material underneath (Souza-Egipsy et al. 2004).

The third problem with building-stone methods for the management of rock art is the polarization of specialists. Many of the individuals involved have different academic training; attend different conferences; contribute to and read different publication series; and have very different attitudes

Table 1. Examples of strategies used to classify rock decay.

Strategy	Synopsis	References
Chemical indices	A comparison of more than 30 chemical indices reveals the importance of microenvironment and abundance of clay minerals and validity complications for different rock types	(Duzgoren-Aydin et al. 2002)
Color and surface disruption	This field friendly scheme helps map large numbers of units (blocks of stone)	(Antill and Viles 1998)
Damage diagnosis	Hierarchy of feature classification, combining field observations, weathering simulation and laboratory analysis	(Fitzner 2002)
Durability index	The index is used by the Building Research Establishment (UK) combining knowledge of the structure with weathering to define damage zones	(Viles et al. 1997)
Fractals in microscopic analysis	A multistep fractal approach links scales in analyzing microscope weathering patterns at different scales, for different rock types, and different environmental conditions	(Oleschko et al. 2004)
Geo-engineering classification	The classication incorporates rock mass strength, the Deere and Miller engineering classification, joint factor, uniaxial compressive strength and modulus, and rock aspects such as geological strength index.	(Ramamurthy 2004)
GIS	Geographic information science frameworks can integrate spatially and non-spatially referenced data on a variety of weathering forms and processes	(Inkpen et al. 2001; Mottershead et al. 2003)
Graphical classification	Time dependent changes in strengths of different rock types uses simple field observations in rating compressive strength, discontinuities and decreases in strength over engineering timescales	(Palicki 1997)
ICA	Integrated computerized analysis relates different types of information about weathering in a common framework	(Zezza 1996)
Lithological sequences	Different lithologies, for example sandstone, can experience chronological progressions of morphological changes	(Turkington and Paradise 2005)
Micro-environment	Discriminant analysis classifies function coefficients to predict weathering type based on microenvironmental conditions	(Moropoulou et al. 1995)
Paleoweathering classification	The weathering history of a rock art panel can greatly complicate any future treatments, requiring an understanding of "inheritance" of paleoweathering	(Battiau Queney 1996)

Permeability spatial variation	Geostatistical analysis of spatial variation in permeability yields important insight on stone durability	(McKinley et al. 2006)
Porosity analysis	Calculating rates of such factors as anthropogenic weathering and decay is possible with electron microscopy	(Gordon and Dorn 2005; Pope and Rubenstein 1999; Stretch and Viles 2002)
Process susceptibility	Systems exist to evaluate a stone's susceptibility to a particular weathering process, such as salt weathering	(Moropoulou, Kouloumbi et al. 2003)
Ratings system	A ratings system classifies weathering in terms of engineering significance	(Price 1993)
Recording	Strategies to record the physical dimension of the art offer potential to generate quantitative metrics of change	(Barnett et al. 2005; Simpson et al. 2004; Wasklewicz et al. 2005)
Rock care	A mostly European research group is in the process of comparing systems for documenting panel damage.	(Bergqvist 2001; Fredell 2000)
Surface recession mapping	Assessing surface weathering features and measuring surface recession in the field provide rates.	(Pope et al. 2002; Trudgill et al. 2001; Turkington and Paradise 2005)
Thin section analyses	In slightly weathered volcanic rocks such as tuffs, thin section analyses of phenocrysts indicate weathering	(Topal 2002)
TNM staging system	A condition assessment of stonework strategy that is adapted from the TNM Staging System model used in medical classification systems. The purpose is to establish priorities for intervention	(Warke et al. 2003)
Weathered mantle classification	Spatial position of weathered rock and joints in relation to the weathering front is of critical importance in all classifications	(Ehlen 2002, 2005)
Weathering-rind modeling	A porosity-based diffusion model calculates rates of weathering-rind development	(Oguichi 2004)

about publishing proprietary conservation insights (Smith et al. 2005). This divergence of viewpoints is seen clearly in papers about same archaeological site written from different perspectives — for example at Petra in Jordan (Fitzner and Heinrichs 2002; Paradise 2005). As discussed below, we have devised a complementary strategy that combines the best elements from different sides in this academic divide.

The fourth and most critical problem for rock applications with the methods designed to monitor building decay involves funding. Working with building stones requires a fiscal base well beyond the vast majority of budgets allocated to rock art heritage management. A case in point is the Bangudae petroglyph site in Ulsan, Korea that was analyzed by techniques requiring hundreds of thousands of U.S. dollars (Fitzner et al. 2004). The damage diagnosis at Bangudae is an ideal to shoot for in future rock art heritage studies, but the funding required to undertake that level of analysis is simply not available for the vast numbers of rock art sites globally imperiled.

A Field Classification System Usable by Nonspecialists

We turn next to our field-based classification system that can be utilized by site managers and their assistants to quickly assess the condition of their rock art sites (Table 2). This assessment process normally begins with a training session that can be conducted over a week-end. Sites are then assessed, and scored, in terms of the physical and human factors identified in our classification system that may be affecting them, using a standardized quantitative index, RASI. This is designed for incorporation in a GIS, thereby placing information about site condition into a much larger resource data base. We start here with a description of our field classification system, and how an archaeologist/volunteer would evaluate a rock art site following this classificatory scheme to create a RASI score (discussed in more detail subsequently).

At the outset we note that the terminology we have developed is a compromise between our desire to minimize jargon with the contrasting need to easily relate our classification system to the existing technical literature. Additional explanation of our field classifications, with illustrations, is presented in supplementary on-line materials (Cerveny et al. 2007; Dorn et al. 2007). Our online *Atlas of Petroglyph Weathering Forms*, for example, can be downloaded with any Internet browser and used in field settings with a portable electronic notebook.

We have classified three-dozen weathering forms, in terms of six broad categories. These are organized to facilitate volunteer training and also to correlate with the weathering literature.

Site Setting (geological factors)

The first issue is inherent weaknesses in the substrate of the sites—the bedrock. The indexer first examines the rock art panel from a distance of tens of meters to look at the pattern of jointing and bedding (Figure 2). Visible fissures (or joints) present in the rock may result from such processes as calcrete wedging and frost weathering. These physical weathering processes open-up latent fractures that depend on how the rock hardened or lithified. These fractures dependent on lithification are typically seen separating sedimentary bedding planes. Other fissures result from stresses that crack the rock in patterns that cut across lithification. Simple Moh's hardness tests are taken on the freshest rock on a hidden and unpainted or unengraved back section of a panel, but never on any visible or decorated section of the panel. Some rocks also include anomalous textures, such as banding, concretions, or mafic inclusions that create the potential for differential weathering.

Weaknesses of the Rock Art Panel

There are many weaknesses that could eventually lead to erosion. This section focuses the indexer on those factors that could lead to future spalling (Figure 3). The most common visual evidence of these weaknesses are fissuresols that can wedge rocks apart (Villa et al. 1995), organic activity (roots, plant growth near panel), the peeling of rock material in scales (centimeter-thick rock pieces) and flakes (millimeter-scale rock sheets), the splintering of rock (appearance of a book that has gotten wet and then dried), undercutting, weathering rind development, and other processes.

Evidence of Large Erosion Events On and Below the Panel

Decimeter-thick and larger pieces dislodge from rock art panels instead of a generally slow, steady loss of the rock surface. These large "chunks" of missing rocks are often the most noticeable, even to the casual observer, and the first documentation of the actual erosion of a panel targets these large missing

Table 2. General categories of weathering forms and ordinal scale used to classify rock art decay on a panel.

Note: An atlas illustrating examples of these different forms can be seen at: http://alliance.la.asu.edu/rockart/stabilityindex/RASIAtlas.html.

	not present	*present*	*obvious*	*dominant*
Site setting (geological factors)				
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 -<Moh4 2-Moh4–5 1-Moh6–8, 0-Moh7+)	0	1	2	3
Weaknesses of the rock art panel				
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				
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 of small erosion events on the panel				
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
Rock coatings on the panel				
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 "creates a 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				

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	
Droppings	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	

Notations on Rock Coatings: These notes do not alter the Rock Art Stability Index Score, but they are useful in analyzing a site's context.

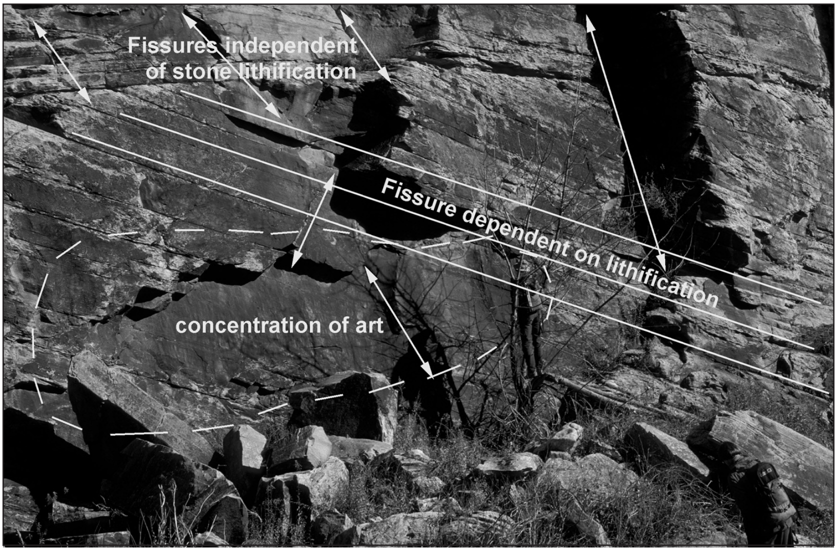

Figure 2. Indexers evaluating this Northern Arizona panel would first examine the "Site Setting (geologic factors)" from a distance of several meters, noting the abundance of fractures along sandstone bedding (dependent on lithification), the identification of joints that cut obliquely across bedding planes (independent of lithification). The indexer then moves in for closer examination to measure hardness (sample analyzed away from the art) and to look for textural anomalies that have potential to generate differential weathering, such as banding and concretions in the sandstone.

fragments (Figure 4). These large pieces may be dislodged as a result of human activity, wedging from fissuresols, fire spalling, undercutting of the surface, or other natural causes (e.g., roots, earthquakes, and other causes).

Evidence of Small Erosion Events On the Panel

After the indexers document large erosion events, they examine the surface of the panel in greater detail. This closer scrutiny reveals that the most common type of erosion occurs when smaller (millimeter-thick flakes, centimeter-thick scales) pieces spall (Figure 5). As indexers fill out this section of the RASI form, they go through a lengthy list of forms that indicate erosion has already taken place. The small but constant loss of a surface may occur as a result of abrasion from sediment transported by water, aveolization (finger-width diameter perforations), disintegration of rock into powdery crumbles and/or granules, flaking of millimeter-thick pieces, scaling of centimeter-

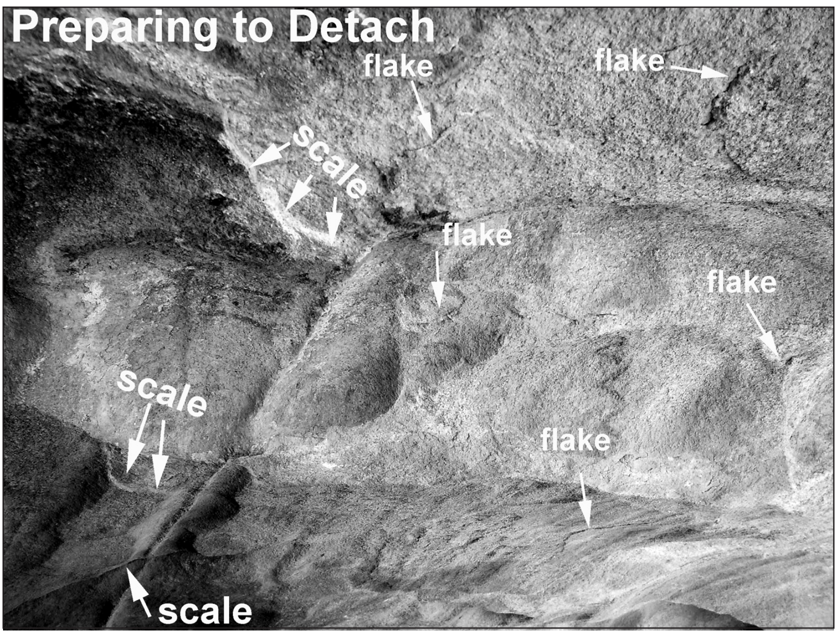

Figure 3. In filling out the "Weaknesses of the Rock Art Panel" elements, indexers identify forms strongly suggestive of future erosion. In this painted panel in a granodiorite rock shelter in southern Arizona, fingernail-thin shells are almost ready to flake off, as are thicker scales. The indexer uses the categories in the "Weakness of Rock Art Panel" section to identify future causes of erosion.

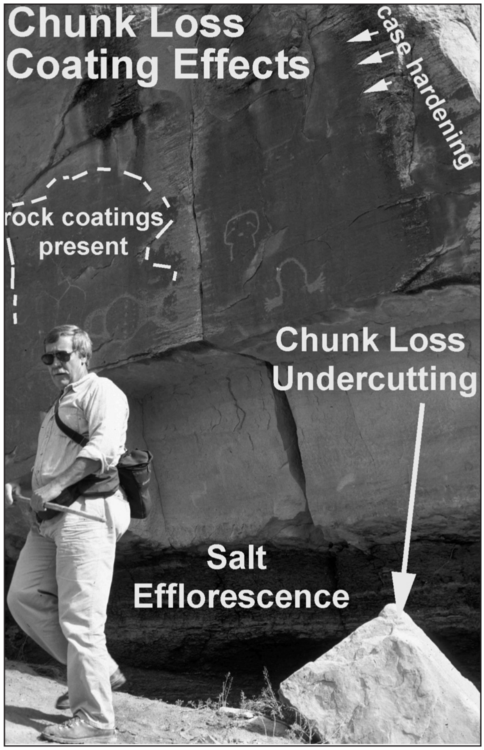

Figure 4. Use of the word "chunk" to describe large erosion events was suggested by an early trainee and quickly adopted as a highly intuitive term to orient indexers that they are looking for visual evidence of erosion of decimeter and thicker panel spalls. This sandstone panel from Utah also displays the dual effect of rock coatings that aid instability (salt efflorescence) and those that stabilize the panel (rock coatings, case hardening).

thick pieces, lithobiont pitting by biological agencies such as fungi or lichens, rounding of edges, differential loss (such as around nodules) splintering, and other forms of gradual loss.

Rock Coatings and Deposits

Thus far, the indexer addresses issues that would lead to a higher RASI index score, meaning that the given art panel is in greater danger. Phenomena like fissures, weathering rinds, roots, and tafoni (decimeter-scale and larger caverns in rock produced by weathering) all lead to loss of the panel surface and therefore the art that is upon the surface. Rock coatings, in contrast, can preserve the art by stabilizing the surface and protecting the art. Case hardening processes actually stabilize the surface and are therefore given a negative value in the index to represent their stabilizing role in the RASI score. Alternatively, humanly created rock coatings, like chalk and graffiti, degrade the surface and the art itself, and natural deposits like salt efflorescence lead to

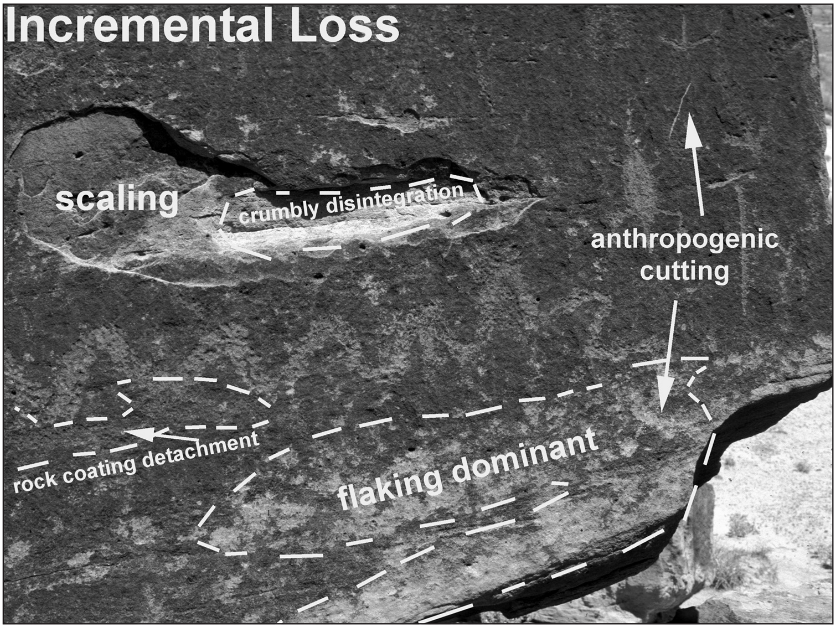

Figure 5. The longest list of weathering forms indexers categorize is when they identify visual evidence of prior incremental erosion. This sandstone panel in Petrified Forest National Park, Arizona, actually hosts far more diversity of incremental erosion than annotated here. However, the identified evidence of incremental loss are the most noticeable in the field. For example, when the case hardened shell scales or flakes away, the underlying rind has a texture that crumbles into powder as it disintegrates.

surface loss and spalling (Figure 4). Thus, these coatings are given a positive value to represent their destructive role.

Only four rock coating and deposit variables are scored by the indexer and included in RASI. The limited role of rock coatings in RASI may come as a surprise to many archaeologists and non-specialists interested in rock art. The general perspective held by those who study rock art is that rock coatings are very important to document, and some panel recording involves data gathering such as documenting Munsell color. Yet, the importance of rock coatings in the stability of a panel truly only justifies the four categories shown in Table 2.

The end of RASI includes an optional section that asks the indexer to simply note the presence or absence of different types of rock coatings. There are two reasons for including this section. First, data gathered may be useful in asking important research questions about the role of rock coatings in panel stability. Second, many rock art enthusiasts have the opinion that documenting rock coatings is an important part of documenting a panel's condition. By simply allowing the indexer to do their best at identifying rock coatings, we obtain better replicability on the actual RASI scoring related to rock coatings. Of the coatings listed in this section, lithobionts (organisms growing on rocks), rock varnish (desert varnish), droppings, dust coatings, and iron films are easy to teach. Silica glaze, heavy metal, and oxalate coatings are more difficult for novices to identify.

Highlighting Vandalism and other Issues

It is vital to document human destruction of rock art, and the last section of RASI asks the indexer to identify vandalism and other anthropogenic effects such as graffiti, dust, trail proximity, livestock, off-road vehicle use, and other aspects of human impacts. This section also allows the indexer to identify natural processes that are a major concern. The indexer is asked to judge the danger posed by the impact in a qualitative scale from 1 to 4: creates a problem; urgent danger; great danger; and severe danger, respectively.

Turning Weathering Forms into a Rock Art Stability Index

General Considerations

The ultimate purpose of RASI includes both research on and management of endangered heritage resources. To have widespread utility as a means to identify, map, and understand those panels in the greatest danger, the rock art stability index has been designed to include the following characteristics.

1. The index is scaled from 0 (perfect stability) to 100 (most unstable) in order to assist geovisualization in a dynamic GIS map display. Our proposed RASI has the following scale:
   ≤20 (Blue color): Excellent condition
   20-29 (Green): Good status
   30-39 (Brown): Problem(s)
   40-49 (Yellow): Urgent dangers
   50-59 (Orange): Great dangers
   60+ (Red): Severe dangers

2. The scoring is replicable by individuals and groups of volunteers with minimal training.

3. The index distinguishes between objective assessment elements and the eventual score. This is not a contradiction. Many volunteer indexers will hold personal concerns, such as the significance of lichens, concern over chalking, or fear of visitors climbing on panels. If these indexers are not encouraged to express their concerns in the last section "Highlighting Vandalism and other Issues," objectivity of the scoring suffers. This is because the indexer gets upset at the limitation of assigning only a "3" to a factor that is greatly important to them. RASI thus separates objective scoring from subjective adjustments in a way that allows resource managers to visualize the objective data and the subjective concerns in a dynamic mapping environment. The last section in Table 2 is scored by the broad categories of problem, urgent danger, great danger and severe danger to accommodate this issue.

4. The index is compatible with more technical analyses, should funding permit a more rigorous site stability analysis and detailed condition assessment (Fitzner et al. 2004).

5. The index is mappable in a Geographical Information System (GIS), where panel recording data (Loendorf 2001; Simpson et al. 2004; Wasklewicz et al. 2005) can also be included. As argued by Snow et al.:

   > [s]ustainability [of prehistoric knowledge] can be assured in two ways. First, data collections should be distributed and sharable. Host institutions should retain the freedom to manage their own databases for their own purposes, thereby spreading costs and maintaining institutional autonomy. Second, digital libraries and associated services should be made available to researchers and organizations to store their own data and mirror data of others [2006:959].

   This vision is advocated by national organizations responsible for managing heritage resources (Snow et al. 2006).

6. Data gathered should be analyzed through existing and future spatial analytical strategies in GIS-based geovisualization tools (MacEachren et al. 2004).

7. Data gathered can be password-protected in a way that protects confidentiality. Heritage managers must have confidence that their site records are not available to the general public, while still allowing for access by managers or researchers at other offices in order to discuss site issues.

Stage 1: No discretion in scoring each weathering form

The first step is for each RASI indexer to examine a panel for each weathering feature in Table 2. Each weathering form in Table 2 is scored on an ordinal scale from 0 to 3, where:

0 = not present

1 = present

2 = obvious

3 = dominant

Eschewing interval measurements was not an easy decision. However, compiling ordinal data in a replicable index is a normal approach in a field science where cost concerns inhibit the use of data-gathering methods that generate interval data (Harden 1982; Lancaster 1988).

Another issue and a reason to employ a purely visual and ordinal ranking is that many interval scales require the use of destructive devices. Use of rock hammers, rock corers, or even a Schmidt hammer (Ericson 2004) is simply unthinkable on a rock art panel. In contrast, the proposed ordinal scaling is non-destructive and relatively simple. The indexer must be able to accurately identify the weathering process and rank its prevalence on a scale of one to three. The simplicity of the ordinal scale speeds up the indexing and also improves replicability.

Figure 6 portrays six panels from different rock art settings. The raw scoring varies considerably from a basalt talus boulder in excellent condition (Figure 6A) to eolian sandstone joint faces where the art is in severe danger of natural erosion (Figure 6D).

The first question often asked about the scoring (Table 2) relates to the equal weighting of the three-dozen weathering forms. Even newly trained indexers recognize that different weathering forms pose different dangers at different sites. For basalt at Deer Valley, central Arizona (Figure 6A), talus boulders with petroglyphs spall mostly by very infrequent calcrete wedging in fissuresols (Villa et al. 1995). For silicified dolomite at Karolta, South Australia (Figure 6B), the most serious instability comes from detachment of the rock coating of rock varnish, leading to a condition where the engravings are varnished and the older panel surface is not. For a granodiorite tor along Pima Wash, central Arizona (Figure 6C), biotite oxidation and hydration drives granular disintegration. For a site in southeastern Colorado (Figure 6D), the largest concern rests in the weakness of a rock with poor grain cementation. A grid petroglyph at Petrified National Park, Arizona (Figure 6E) is most endangered by decay in the weathering rind under a case hardened surface. At a site inside Chevelon Canyon in Northern Arizona (Figure 6F) sandstone experiences abrasion from river sediment transport. At each site, vandalism may be a threat. Because each panel will have different factors reducing the health of the art, there is need for the indexer to have a means of identifying these key concerns in Stage 2.

Stage 2: Field worker discretion identifying key concerns

In our RASI the field indexer is asked to identify key concerns in the section "Highlighting Vandalism and other Issues." Some of the instability factors are intuitively obvious to anybody examining a panel, such as bullet holes, erosion of powdery material (Figure 4), or undercutting by spring sapping (Figure 5), while others may relate to a particular concern of the indexer such as lichens. We envision as commonplace a circumstance where an indexer works at a rock art site when a rock climbing class slides down a rock painting, rubbing against panels accidentally with backpacks, shoes, clothing and skin. Such an indexer would rightfully be alarmed and want to score the entire panel as in serious danger. The "Highlighting Vandalism and other Issues" encourages the field indexer to make that judgment call, and yet not invalidate data gathered in stage 1.

Similarly, an expert in rock art might look at a painted panel on granodiorite and identify granular disintegration of the grus and flaking as the two most serious issues facing a panel (Figure 3). The entire panel might be falling apart from grussification and flaking, yet these two components only add 6 points (3 each) to the total RASI score. Other examples of natural factors that could be highlighted might include: wind abrasion eroding a panel (Keyser et al. 2005); a tree too close and a wildfire that could burn the panel (Tratebas et al. 2004); roots about to pry apart a joint and erode a panel; or a river on the verge of going through an avulsion that could subject a panel to fluvial abrasion. The most common identified concern in Stage 2, however, will be vandalism.

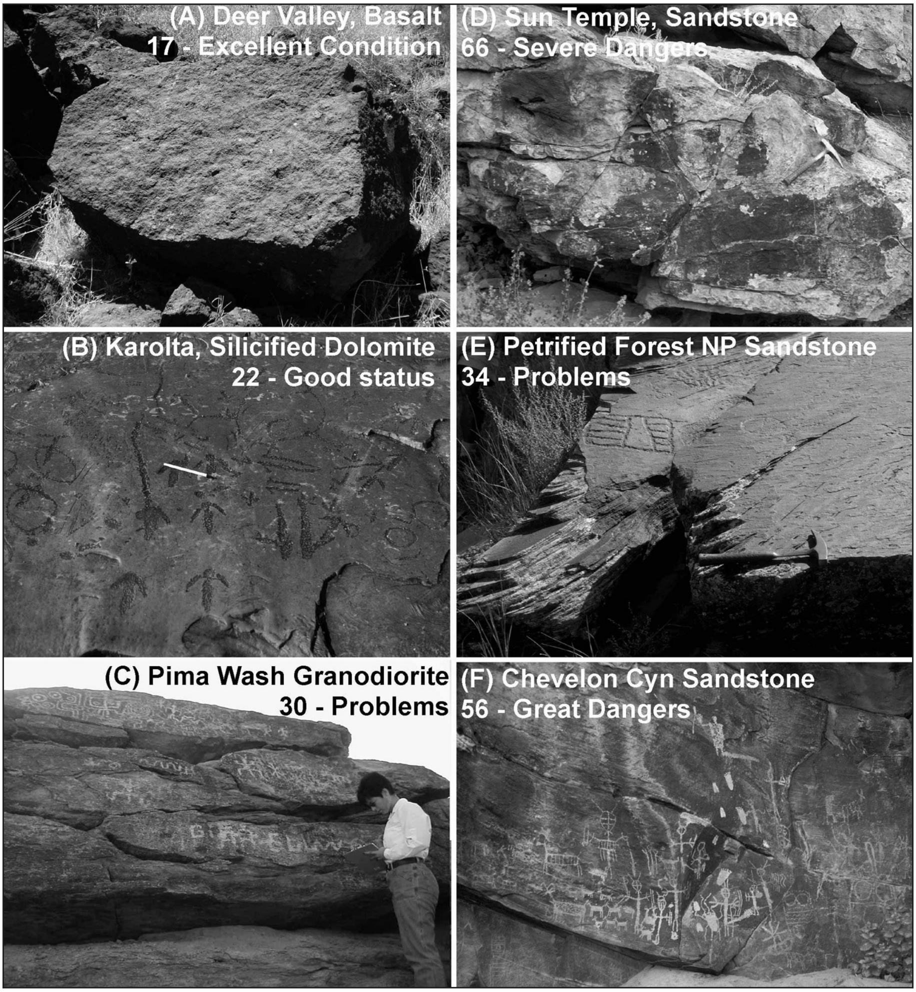

Figure 6. Rock art panels from sites with varying lithology exemplify different inherent weaknesses and different RASI scores.

If the indexer does not have some mechanism to identify and emphasize their key issue, we have found that the objectivity of the raw data gathered in Stage 1 suffers. Indexers not given the ability to identify key concerns will adjust raw data simply to honor their heartfelt concern over the safety of a panel. This second stage must necessarily be subjective in order to promote the sustainability of heritage resources by encouraging personal concern for the indexed panel.

Stage 3: Site manager's discretion

Site managers are often aware of general concerns unknown to a volunteer indexer. There may be wildfire dangers, annual visitation issues, weekend visitation by a destructive group, or another concern. The heritage management expert should have the ability to adjust the summary RASI designation, such as changing a panel that might be scored a 25 (good status) to "Severe Danger" based on such knowledge and local conditions. Again, management discretion would not change the raw data collected in Stage 1 or the key concerns identified by the indexer in Stage 2.

Assessing RASI

We asked two questions in assessing whether RASI can be utilized in heritage management by volunteers with little prior background in the study of rock weathering. The first question is how the new indexer learns RASI. The second question is what type of training yields the most replicable scoring by the new indexer.

To identify the process by which new indexers learned RASI, we used concept maps as a way of understanding how the learner organizes a complex idea (All et al. 2003). Used in biomedical fields for years, concept maps provide a means of discovering misunderstandings (Hsu and Hsieh 2005); thus we used them to assess how the new indexer learned different levels of complexity and to examine how indexers linked physical, biological, and cultural processes. In order to gather a sufficient sample size, we analyzed the learning of 312 students enrolled in an introductory earth science class at Arizona State University, *Introduction to Physical Geography*—a sample population where 86% had never taken a college-level laboratory science course. These students were all trained in person in an introductory classroom session, trained in the field at a petroglyph panel, and then used RASI to index a petroglyph panel.

An analysis of their pre-training and post-training learning involved scoring their concept maps (Hsu and Hsieh 2005; West et al. 2002). Scoring concept maps involves assigning a value to valid propositions, examples, cross-links, and hierarchical structures. If desired, a "weight" can be added to specific elements before tallying the total (Stoddart et al. 2000).

For these 312 students, concept map scores increased 14% between pre-RASI training and post-RASI training. This indicates that by using RASI, non-weathering specialists gain a higher level of comprehension associated with weathering processes. More importantly, as part of the concept map assessment process, students were also asked a series of open-ended questions dealing with rock stability and whether they thought rock art should be preserved. Invariably, students who participated in the on-site RASI training showed a deeper understanding of overall rock stability, and they also demonstrated a more informed position regarding rock art management. From these results, it is clear that non-specialists can learn an index of the three dozen factors responsible for the stability of a heritage resource. Novice indexers were able to create their own mental integration of the complexity that mirrored the major categories of RASI. In other words, RASI training did not confuse but actually made sense to the new indexer.

The second question we asked is whether the raw data gathered by the new indexers are replicable. The answer varied, depending on the nature of the training—where smaller groups trained in person yielded the most replicable scoring. Prior to formal replication of RASI, focus groups of general education Arizona State University students discussed RASI in the context of petroglyph panels near the campus (Figure 7). These focus groups had no prior background in weathering. Over a period of four years, different focus groups discussed and refined versions of RASI, addressing such issues as: a 0–3 scale versus a 0–5, or a 0–10 scale; how much jargon to include such as lithification and lithobiont; what literature terms to use to describe loss of stone by millimeter-thick flakes and centimeter-and-thicker scales; and many other issues that went into the index compiled in Table 1.

A group of ten geography student volunteers without prior background in rock weathering agreed to learn RASI by reading instructions and by reviewing only the online Atlas (Dorn et al. 2007). These volunteers were then taken into the field to score six different petroglyph panels on andesite near the Arizona State University campus. Compared with the 'control' of the authors' RASI scoring, these students averaged deviations for these six panels of –13%, +12%, –21%, +53%, +80% and +35% (Figure 8) — revealing that online training is not a satisfactory means of introducing the RASI scoring.

In contrast to online training, a group of seventeen geography students without prior background in rock weathering or rock art were trained in RASI, first with a three hour Powerpoint introduction and discussion on a Friday. The following Monday they reviewed RASI for three hours with the Atlas of Rock Art Stability (Dorn et al. 2007). Tuesday then saw six groups rotate through six different andesite petroglyph panels near the Arizona State

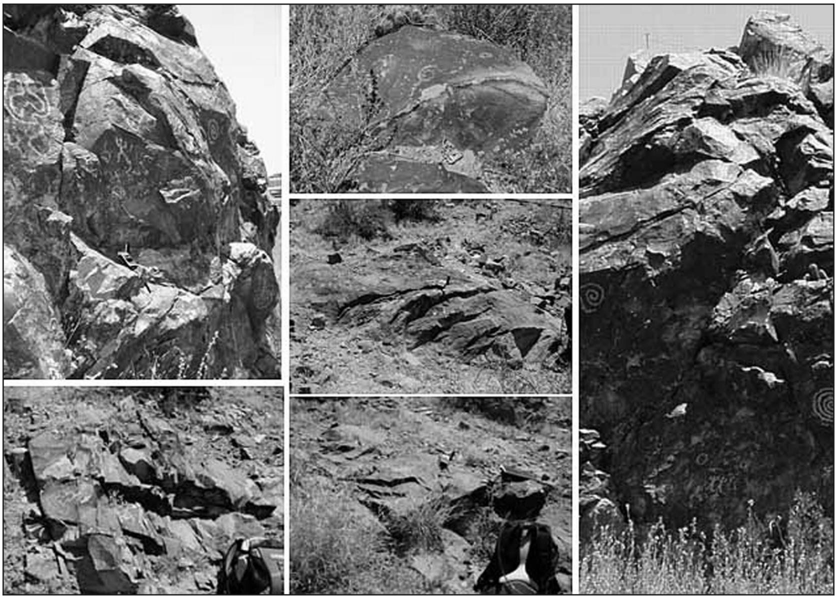

Figure 7. Petroglyph panels at Tempe Butte, central Arizona, served as the background for assessing the replicability of RASI by individuals without prior background in rock weathering with only a few hours of training.

University Campus (Figure 7). Compared with the 'control' of our RASI scoring, these students averaged deviations for these six panels of –3%, +6.5%, –17%, +40%, +43% and +48% (Figure 8) — revealing that large group training yields mediocre results in replicability.

We then tried progressively smaller training groups. Ten geography students without a prior background were trained in an all-day session mixing a field introduction, PowerPoint, and a group scoring of a panel in the field. Scoring of these same six panels by individuals the day following intensive training resulted in deviations from our 'control' scores of –7.5%, +9.7%, –11%, –10%, –1%, and 14%. Later, just four geography students without a prior background were trained in an all-day session following the pattern of the group of ten. This small group then scored the six panels together. Deviations from our 'control' decreased for the total RASI score to –5%, +3.2%, –5.6%, –5%, –7.1%, and +3.5% (Figure 8).

These trials reveal several issues. First, progressively better correspondence between our scoring and those by newly trained indexers reflects both the refinement of our training procedures and the impact of progressively

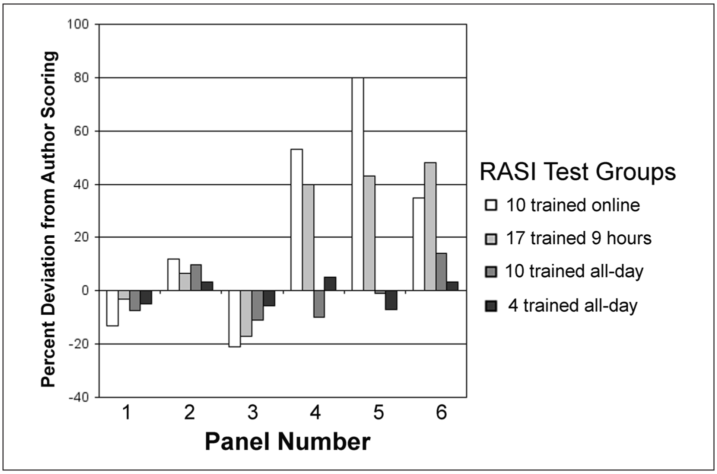

Figure 8. Arizona State University undergraduate students completed RASI for six petroglyph panels engraved into andesite adjacent to the campus. These individuals had no prior background in weathering except an introduction to physical geography class. After minimal training, composite scores compare well with the authors' scoring if the group size is sufficiently small.

smaller groups. Second, more complex panels like sites 5 and 6 were overestimated until the training was altered. Third, RASI as a tool has seen four years of thought and refinement — giving it a chance to mature before it is proposed to a larger heritage management audience.

Heritage Management with RASI and GIS

Data gathered and entered into a database can be integrated into a GIS interface, at the discretion of the heritage manager. This interface will yield a great deal of usability for heritage site managers, as well as for the general public when desirable and appropriate. Heritage managers will have the ability to password-protect any information that is included in the RASI database or that is uploaded to the RASI servers so that the general public accesses site information selected by management.

The data that will be included and considered includes information collected from the RASI assessment process. Furthermore, heritage managers will have the option to upload and include supplementary site data such as motif documentation, photographs, and additional commentary pertaining to specific sites or specific areas. Heritage managers will have the opportunity to manually specify areas of the user-facing map that will prompt the user to click for more information. The GIS administrator will have the option to include part of all of this supplemental data when creating an interface.

In addition to the RASI database and the supplemental material that heritage managers can upload, the GIS administrator will be able to select from a number of GIS layers that will be made available on the server. These layers will help users visualize the mapped rock art panels in a way that is relevant to the need at hand. Currently planned layers include: topographic information, road information, land ownership information, and aerial photography. The GIS administrator will also have the ability to determine the scale of the final map product, and to select the characteristics of the rock art panels to be included. The final user-interface will be similar in scope and usability to that of Google Earth.

As the database grows in size and scope, there exists enormous potential for future research. The information that can be garnered through the use of RASI is twofold: first, by studying the people who collect and utilize the data, and second, by studying the data itself. As RASI becomes more widely used, there will be a wealth of data to be analyzed and considered in future improvements to the process, as well as scientific research. Moreover, collecting a comprehensive database about rock art panels in one place will allow for in-depth analysis that has never before been possible. Equally important will be the information that can be gleaned by interviewing the people who take the time to perform the RASI evaluations, and the heritage managers who will transform the information that has been gathered into a living document.

Conclusions

Snow et al. (2006) have recently emphasized the importance of creating and sharing digital data-bases of archaeological resources, for their long-term sustainability.

This vision is shared by U.S. scholarly and federal organizations responsible for managing these resources. Any concern with the long-term sustainability of rock art similarly must involve a system that is compatible with "e-science" (Foster 2005), a kind of service science that promotes the use of basic spatial thinking through GIS-based geovisualization tools (MacEachren et al. 2004).

RASI, we believe, is that tool. It is designed to identify natural and cultural threats to rock art sites quickly, systematically, and objectively. It is not a conservation technique in the sense that it does not fix or rectify ongoing site problems. It instead is used to determine which rock art sites have specific problems and which sites, among the many that managers are required to safeguard, are in the greatest peril—and which sites most urgently need interventions by trained conservators. It is in this sense a management tool, made all the more useful because it can be undertaken with minimal training and funding, is replicable, and can be articulated with GIS. Critically, in this day of global electronic data change, we maintain a stable RASI website (Cerveny et al. 2007) and RASI atlas (Dorn et al. 2007) with such features as streaming video instructions on how to fill out a Rock Art Stability Index. Although we recognize that RASI does not guarantee the sustainability of our rock art heritage, we believe that, if adopted and used by cultural resource managers, it will greatly contribute to that goal.

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