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Digital imaging technology and experimental archeology: a methodological framework for the identification and interpretation of fire modified rock (FMR)

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ABSTRACT

This paper presents the results of a series of experiments for the identification and analysis of fire modified rock (FMR). FMR is a common but frequently overlooked artifact type. Experiments were conducted simulating the effects of different hypothetical burning scenarios on rocks similar to those found in a South African Middle Stone Age site. A digital imaging method was then used to quantify FMR color values, designed to limit intra-analyst bias. Statistical tests and a blind test suggest that unburned rocks and experimental FMR can be separated statistically based on physical appearance. Two burning scenario models, based on measured experimental data were applied to archaeological FMR from a South African Middle Stone Age site named Pinnacle Point 5-6 (PP5-6) and show that the archaeological samples are not statistically different from a simulated campfire and possibly a lithic raw material heat-treatment fire.

1. Introduction

Modern humans and preceding hominins have used and controlled fire since the Lower to Middle Pleistocene, with widely debated dates ranging from 0.2 to 1 Ma for the first controlled use of fire (Berna et al., 2012; Clark and Harris, 1985; Goren-Inbar et al., 2004; James et al., 1989; Karkanas et al., 2007; Rolland, 2004; Wrangham et al., 1999). The initial use and control of fire played an important role in the origins of cooking, and a role in a change in hominin nutrition and the structure of social interactions. In addition, it allowed for the conquering of darkness, thus extending activity-time of early humans (Gheorghiu, 2007; Petraglia, 2002; Wrangham et al., 1999). Further, fire is important in the generation of warmth and light, providing protection from predators and a way to signal nearby groups, and centralizing a location for economic, social, and ceremonial activities (Petraglia, 2002). Ethnographic and archaeological observations from around the globe demonstrate that heat and hearth associated artifacts can provide information about hominin landscape use, site occupation histories, and economic, social, and ceremonial activities (e.g. Black, 2003; Guernsey, 1984; Holdaway et al., 2002; Homsey, 2009; Jensen et al., 1999; McDowell-Loudan, 1983; Nakazawa et al., 2009; Odgaard, 2007; Petraglia, 2002; Schiegl et al., 2003; Smith and McNees, 1999; Stevenson, 1991; Thoms, 2003; Vaquero and Pastó, 2001; Wandsnider, 1997; Wilson and DeLyria, 1999). Some of the most numerous archaeological heat and hearth-associated artifacts at any prehistoric site are thermally altered rocks. The nature of these artifacts remains ambiguous, but they are sometimes directly related to human use of fire (Petraglia, 2002).

Thermally altered rocks are defined as pieces of rock that are discolored, reddened, darkened, cracked, or broken because of heating (Homsey, 2009; Petraglia, 2002). Fire cracked rocks (FCR) are the cracked and broken component of such assemblages, and are typically identified by one or more thermal alteration features, including irregular fracture surfaces, pot lidding, and reddening (Homsey, 2009; Petraglia, 2002). This study uses fire modified rock (FMR) as a collective term for thermally altered rock and fire cracked rock. In this study, the term FMR does not imply that human behavior resulted in FMR, only that fire acted on the rock in question. Additionally, this study does not assume intentional placement of FMR in a burning feature, only that rocks happen to be near fire and thus were fire modified. House and Smith (1975) argue that FMR is hard to link to any specific human behavior. Perhaps for this reason, FMR has received relatively little research attention compared to other artifact categories and is often described only in terms of gross counts and weights (Petraglia, 2002).

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Arguably, any suggestion of use of fire in the archaeological record from the Lower and Middle Pleistocene until present day requires experimental and actualistic studies simulating natural brush fires, hearths (defined here as combustion features resulting from human behavior), and heat and hearth-related artifacts such as FMR (James et al., 1989). Experimental recreation of FMR is the most accurate method of identification and investigation, and is vital to create a framework for the analysis of FMR associated with an archaeological context (Homsey, 2009; House and Smith, 1975; McDowell-Loudan, 1983; Odgaard, 2007; Wilson and DeLyria, 1999).

In both geology and archeology, numerous studies focusing on FMR use an experimental and actualistic approach (e.g. Allison and Bristow, 1999; Allison and Goudie, 1994; Backhouse and Johnson, 2007; Bearden and Gallagher, 1980; Blackwelder, 1927; Buenger, 2003; Chakrabarti et al., 1996; Dering, 1999; Emery, 1944; Freeman et al., 1972; Gomez-Heras et al., 2006; Goudie et al., 1992; Hajpál and Török, 2004; Homsey, 2009; House and Smith, 1975; McCabe et al., 2007; McDowell-Loudan, 1983; Ollier, 1963; Ollier and Ash, 1983; Pagoulatos, 2005; Petraglia, 2002; Shockey, 1997; Sullivan et al., 2001; Rapp et al., 1999; Thoms, 2007, 2008; Warke and Smith, 1998; Wilson and DeLyria, 1999; Witkind, 1977). A notable similarity between studies from both disciplines is the lack of an objective method used to quantify color-change caused by thermal alteration. Past studies investigating color characteristics of FMR use the Munsell color chart or other subjective measurement systems for quantifying color (e.g. Backhouse and Johnson, 2007; Pagoulatos, 2005). The Munsell color system is a color appearance system. Such systems are inadequate and inherently subjective because they are based on individual color perception, resulting in an increased possibility of inter-analyst bias (Ohta and Robertson, 2005).

Multiple field seasons at the Middle Stone Age (MSA) site PP5-6 (Supplementary Fig. 1) (Brown, 2011; Brown et al., 2012, 2009) yielded numerous FMR, mostly in association with gray ash, burnt black organic matter, and red-burned sediments. Some layers more isolated from burning features also yielded FMR. Excavated artifacts were classified as FMR if they were reddish and appeared 'burned', and it was assumed that the FMR was the result of human behavior. This method is qualitative and subjective; prompting a study to objectively quantify such qualities by examining FMR color characteristics and to investigate whether or not different burning scenarios produce different FMR color characteristics.

An investigative and methodological framework was designed to study FMR. This framework is reliant on the archaeological site in question, as the appearance of FMR and probability of different burning scenarios will vary by context. The framework for any site consists of four components, *first*, actualistic experiments simulating different burning scenarios with local rock materials utilized at the given archaeological site, used to create a comparative dataset. *Second*, a data-capturing framework that combines an objective digital imaging method to quantify color values, a consideration of physical FMR characteristics such as cracking and spalling, and blind tests on FMR characteristics for excavators or those classifying artifacts. This framework uses a low-cost digital imaging method (Papadakis et al., 2000; Yam and Papadakis, 2004) to quantify FMR color values, designed to limit intra and inter-analyst bias by measuring color directly from each sample. *Third*, a series of hypotheses designed to build sequentially (i.e., hypotheses 2 only follows if hypothesis 1 is supported, and hypotheses 3 only follows if hypothesis 2 is supported), and tested by a statistical framework aiming to create a strong inferential chain. Here, the following three hypotheses were tested. Hypothesis 1: experimental FMR can be distinguished from unburned rock based on color. Hypothesis 2: color can be used to distinguish different burning scenarios. Hypothesis 3 part 1: overall, the PP5-6 archaeological FMR color distribution is significantly different from the overall experimental burning scenario FMR distribution. Hypothesis 3 part 2: PP5-6 archaeological FMR resulted when rocks were exposed to a burning scenario similar to a campfire. *Fourth and finally*, the framework should consist of two burning scenario models, one each for two different color modes, and including rock cracking and spalling data that compare the experimental data to archaeological material.

2. Material and methods

2.1. Rock material sampling procedure

PP5-6 (see Supplementary text for more information about PP5-6) is a rock shelter (Supplementary Fig. 1) that is formed in the Skurweberg Formation that belongs to the Table Mountain Sandstone Group (TMS). The Skurweberg formation is a coarse-grained, light gray Quartzitic sandstone with beds of varying thickness and consolidation (Brown, 2011; Brown et al., 2012, 2009; Karkanas and Goldberg, 2010; Marean et al., 2004; Thamm and Johnson, 2006). The rock samples used in this study were collected from talus slopes below the rock face at the PP5-6 rock shelter, and below the rock face of another cave site called PP9 also within the Skurweberg formation. Boulders of quartzitic sandstone (PP5-6 $n = 15$ and PP9 $n = 6$) with different colors were sampled and subsequently broken into smaller samples (Table 1), in order to represent a wide range of unburned colors. A subset of these boulders and their smaller samples from the PP5-6 talus slope was divided among the experiment types (Table 1), so that every experiment would have the same initial color range and unburned rock color variants would be exposed to different types of burning scenarios.

Table 1
Summary of the unburned samples and four different experimental burning scenarios.

Burning scenario	Experiment type	Experiment #	Duration (hours)	Avg. temp. (°C)	Max. temp. (°C)	Avg. temperature per hour[a]	Tot. # of samples	Tot. # of color measurements
Unburned samples							125	203
Heat-treatment fire: Low temperature and very long duration	Controlled	1	36	146	367	4.1	25	39[b]
Campfire: High temperature and long duration	'Naturalistic'	2	6.3	489	951	78.2	15	29[c]
Campfire: Low temperature and short duration	Controlled	3	4	103	358	24.5	16	30[d]
Brush fire: High temperature, rapid heating and short duration	'Naturalistic'	4	0.25	753	844	3012	15	29[c]

[a] Average temperature per hour is a measurement of fire intensity.
[b] 2 Random sides of 9 samples, plus 1 random side of 8 blind test samples, 1 random side of 8 teaching samples, and the interior of 5 samples were measured.
[c] 2 Random sides of 9 samples, plus 1 random side of 6 blind test samples, and the interior of 5 samples were measured.
[d] 2 Random sides of 9 samples, plus 1 random side of 7 blind test samples, and the interior of 5 samples were measured.