



Multidimensional GIS modeling of magnetic mineralogy as a proxy for fire use and spatial patterning: Evidence from the Middle Stone Age bearing sea cave of Pinnacle Point 13B (Western Cape, South Africa)[☆]

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ABSTRACT

This paper aims to identify the spatial patterning of burning and occupation within an early Middle Stone Age (MSA) sea cave in the Western Cape Province of South Africa by creating a multidimensional model of archaeomagnetic data recovered from all excavated units. Magnetic susceptibility and other mineral magnetic parameters are shown to provide an excellent proxy for the anthropogenic alteration and spread of burnt material into the surrounding unaltered cave deposits. The identification of combustion features and areas of occupation or different activities within the site can be determined because the movement of people throughout the cave mixes magnetically strong hearth material with magnetically weak unaltered sediments. This is also indicated by micromorphological analysis. The degree of enhancement is also shown to indicate the extent to which a deposit has been altered, and therefore, intensity of occupation, because multiple heatings of deposits are needed to form the concentrations of iron minerals occurring in some layers. This is further supported by a comparison with artifact density for the layers. Variation in the magnetic values between different areas of the site is noted with major occupation or fire building occurring in the front of the cave during earlier MIS 6 periods, while during later MIS 5 periods the entire cave is occupied intensively. The oldest, MIS 11 deposits at the rear of the cave indicate no evidence of enhancement and an apparent absence of any anthropogenic signature.

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Introduction

The identification of spatial patterning in archaeological sites and any inherent behavioral implications remain a difficult thing to access in many Paleolithic sites. This paper aims to identify spatial patterning in an early Middle Stone Age (MSA) sea cave (Pinnacle Point Cave 13B [PP13B]) on the southern cape coast of South Africa, by creating a multidimensional model of mineral magnetic data recovered from all excavated units. Magnetic susceptibility (MS) is the most widely used mineral magnetic parameter in archaeological studies. MS is essentially the ease with which a material can be magnetized and an indicator of the bulk iron concentration within a sediment/soil/material. MS has been shown to be a powerful tool

for identifying evidence for human occupation, mainly due to the use of fire at archaeological sites (Peters et al., 2000, 2002; Peters and Batt, 2002; Marwick, 2005; Church et al., 2007).

LeBorgne (1955, 1960) demonstrated that burning leads to an enhancement of the MS of soils. MS enhancement occurs because burning causes the formation of magnetically stronger, fine to ultrafine, ferrimagnetic minerals (magnetite, maghemite) that dominate the signal and mask any weaker antiferromagnetic (goethite, hematite) or larger grained ferrimagnetic phases (Morinaga et al., 1999; Peters and Thompson, 1999). While MS is often a good proxy for burning, only detailed mineral magnetic characterization will explain the complex mineralogy of natural samples and associated reason for MS enhancement or variation (see [Supplementary Online Material \[SOM\]](#) for a detailed review of methods). An understanding of the variation of the different mineral populations can elucidate a number of processes including sediment input, alteration, human occupation, and climate change (Herries, 2009).

In cave sites, where pedogenesis does not alter the deposits after or during deposition, MS variation is normally related to

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variation in sedimentary input, and in archaeological sites, anthropogenic alteration. Complex magnetic transformations can still occur in caves due to natural processes such as waterlogging and reactions related to deep guano deposits. Examples of this are the colored MSA deposits of Rainbow Cave and the Earlier Stone Age (ESA) deposits of the Cave of Hearths at Makapansgat, originally interpreted as being hearths (Mason, 1988; Latham and Herries, 2004). However, detailed magnetic mineralogical studies have identified such deposits as entirely natural and not related to burning (Herries and Latham, 2009). Variations in sedimentary input can also show evidence for climatic change in many circumstances as this changes the magnetic minerals deposited in the caves, as is the case at Rose Cottage Cave (Herries and Latham, 2003, 2009). However, when intense human occupation occurs, such as at Sibudu Cave, this natural signature is partly overprinted by anthropogenic alteration related to fire use (Herries, 2006). In such situations, layers or areas with relatively high MS values (hot spots), when compared to base sediments, should primarily represent combustion features where sediments have been altered by heat with the formation of highly magnetic mineral phases (Herries, 2009).

MS alone is generally unable to unequivocally identify *in situ* burnt material as high MS areas may represent dumped burnt material from behavior such as the raking out of hearths. However, mineral magnetic studies can be a powerful tool when integrated with micromorphology and paleomagnetic studies of burnt rocks (see Herries [2009] and Brown et al. [2009] for methodology; Fig. 1). These can identify both the maximum temperature that the rocks have experienced and whether they are *in situ* or not. Unless post burning alteration or scattering has occurred, burnt deposits should always have higher MS values than the surrounding sediments, and in many cases in South Africa *in situ* combustion features appear to have a distinct mineral magnetic signature consisting of high MS values and low frequency dependence of magnetic susceptibility (see [SOM]). Exceptions occur where deposits have been heated to high temperatures that are generally

only found in kilns. (Such temperatures are rarely, if ever, generated by prehistoric campfires), or if altered by secondary natural processes such as extensive waterlogging (Herries and Latham, 2009).

Diffusion of burnt material throughout archaeological deposits by occupation causes dilution of the magnetic hot spots and enhances the surrounding weakly magnetic, unburnt material with the addition of highly magnetic altered material. In theory, the MS data combined with other methods have the ability to identify *in situ* combustion features and the area of occupation used by humans around these features (or over time in vertical layers). This is because human movement spreads combusted material into the surrounding weaker deposits as humans move around the cave after having built a fire. However, other mechanisms (fluvial, aeolian) can also be responsible for diffusion of burnt material, and therefore other analyses such as micromorphology are useful for understanding general processes occurring in the deposit (see Karkanas and Goldberg, 2010). A comprehensive survey of the MS of sediments excavated from an archaeological site can expand the interpretive range of other bulk point sampling methods (micromorphology, Fourier transform infrared spectroscopy [FTIR]) to easily include every excavated lens and feature at the site. Such microsampling is possible because MS measurements have the advantage of being cheap and easy to undertake and sample sizes are small, on the order of 10 g of sediment.

One of the main limitations in interpreting MS data has been visualization, which has mostly relied upon two-dimensional sections or occasionally areal surveys (Ellwood et al., 1997; Herries and Latham, 2003; Herries, 2006, 2009). To visualize the MS of every single excavated unit from an archaeological site, as attempted in this study, multidimensional visualization is necessary. Multidimensional visualization and analysis are more popular than ever now because of cheaper, more powerful software and newer techniques and equipment to record data precisely in 3D. As digital data are increased, multidimensional visualization is becoming a naturally useful tool to efficiently and intuitively interact with and

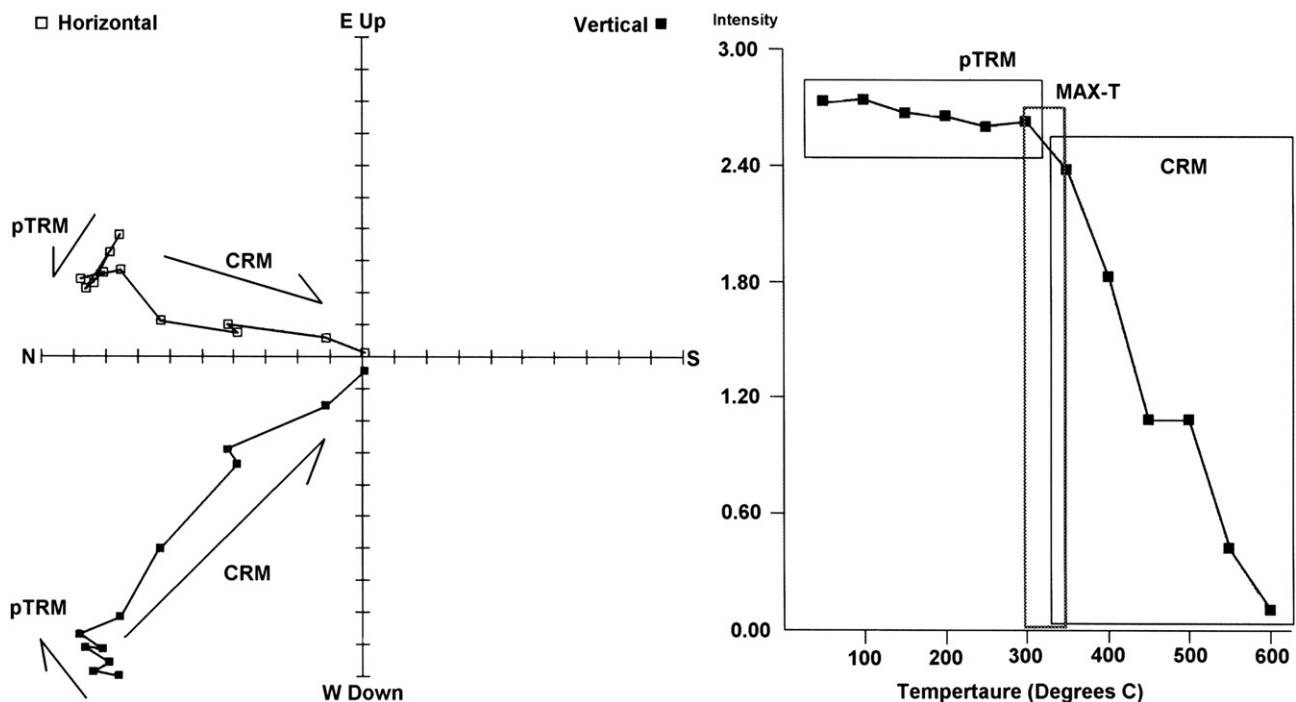


Fig. 1. Paleomagnetic analysis (zijderveld and intensity plots [A/m^2]) of sample 46660 from the LC-MSA (Northeastern area excavation). The pTRM from the heating is removed by between 300 and 350 °C to reveal the primary geological remanence (CRM).

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