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The Campanian Ignimbrite (Y5) tephra at Crvena Stijena Rockshelter, Montenegro

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ABSTRACT

Clearly defined distal tephras are rare in rockshelter sediment records. Crvena Stijena, a Palaeolithic site in Montenegro, contains one of the longest (>20 m) rockshelter sediment records in Europe with deposits ranging in age from Middle Pleistocene to mid-Holocene. A distinctive tephra is clearly exposed within the well stratified record approximately 6.5 m below the present land surface. We present geochemical data to confirm that this tephra is a distal equivalent of the Campanian Ignimbrite deposits and a product of the largest Late Pleistocene eruption in Europe. Originating in the Campanian volcanic province of southwest Italy, this tephra has been independently dated to 39.3 ka. It is a highly significant chronostratigraphic marker for southern Europe. Macrostratigraphic and microstratigraphic observations, allied with detailed particle size data, show that the tephra layer is in a primary depositional context and was transported into the rockshelter by aeolian processes. This site is unique because the tephra forms an abrupt boundary between the Middle and Upper Palaeolithic records. Before they can be used as chronostratigraphic markers in rockshelter and cave-mouth environments, it is essential to establish the stratigraphic integrity of distal tephras and the mechanisms and pathways involved in their transport and deposition.

Introduction

Distal tephras can provide archaeologists and geoscientists with valuable chronostratigraphic markers (e.g. Vitaliano et al., 1981; Narcisi and Vezzoli, 1999; Pyle et al., 2006; Giaccio et al., 2008; Lane et al., 2011). These markers become especially important when they are found in relation to Palaeolithic material that lies close to or beyond the range of radiocarbon dating (Pawlikowski, 1992; Fumanal, 1997; Farrand, 2000; Fedele, 2002; Fedele et al., 2003; Pyle et al., 2006; Giaccio et al., 2006, 2008; Anikovich et al., 2007). Geological and archaeological records can be directly compared – even over large distances – should the same tephra layer be identified *in-situ* in both records. Research in the central and eastern Mediterranean region over many decades has produced one of the richest databases of Quaternary volcanic activity. Distal tephras now provide an important link between the marine and terrestrial records across this region (Narcisi and Vezzoli, 1999; Wulf et al., 2004) and high-resolution analysis has also highlighted the potential of microtephras in this area of research (Lowe et al., 2007). In this paper we report a significant new tephra exposure within a long archaeological record spanning the Middle to Upper Palaeolithic at Crvena Stijena rockshelter in Montenegro. Rockshelter and cave sediment records are important archives of environmental change and much of what we know about the Middle and Upper Palaeolithic records in southern Europe and the wider Mediterranean region has been recovered from these depositional environments (Woodward and Goldberg, 2001).

Chronological markers that are not reliant on radiocarbon assume particular importance when an archaeological sequence is thought to date to around 40 ka ,— a period of intense interest to Quaternary scientists and archaeologists, as it broadly correlates with a number of important periods in climate history and human evolution including: i) the Middle to Upper Palaeolithic transition in Europe when anatomically modern humans spread across the continent and the Neanderthals disappeared from the fossil record (Mellars, 2004; Finlayson et al., 2006; Conard, 2006); ii) the global cooling of Heinrich Event 4 (HE4) (Paterne et al., 1999; Fedele et al., 2008); iii) the Laschamp Excursion (40.4 ± 2 ka), which marks a profound reduction in the strength, and change in direction, of the geomagnetic field (Guillou et al., 2004; Lund et al., 2005); and marked increases in cosmogenic ^{10}Be and other nuclides such as ^{14}C and ^{36}Cl (e.g. Mazaud et al., 1991; Voelker et al., 2000).

Chronologies for this period based on radiocarbon are commonly associated with large errors and uncertainties (Pettitt et al., 2003; Blockley et al., 2008; Jöris and Street, 2008). The limited precision of this approach partly relates to elevated levels of atmospheric ^{14}C leading to younger dates, even with the use of the most recent calibration curves (Voelker et al., 2000; Beer et al., 2002; Pyle et al., 2006; Anikovich et al., 2007; Hoffecker et al., 2008). Thus radiocarbon

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chronologies have consistently underestimated the ages of well-constrained tephra layers at several sites (e.g. Giaccio et al., 2006; Sinitsyn and Hoffecker, 2006). This is a major problem because much of our knowledge of the Middle to Upper Palaeolithic transition is founded on radiocarbon-based timescales and the calibration models for this period are still under development (Conard and Bolus, 2008; Jöris et al., 2003; Hughen et al., 2004).

Crvena Stijena is a key site for understanding the nature of the Middle to Upper Palaeolithic transition in the Balkans. It preserves an exceptionally deep (>20 m) stratigraphy; one of the longest and most complete in Europe (Basler, 1975; Gamble, 1999; Baković et al., 2009). The Middle and Upper Palaeolithic periods account for most of the sedimentary record, but there is also evidence of site use during the Mesolithic and Neolithic (Table 1). The archaeological succession includes a long Mousterian sequence overlain by sediments containing lithic assemblages of Upper Palaeolithic tradition (Aurignacian and Gravettian) (Basler, 1975; Baković et al., 2009; Mihailović, 2009). A Neanderthal tooth was recovered from excavations at the site in 2004 (Baković et al., 2009). The site is also important because the eastern Adriatic coast is thought to have been an important route for the movement of anatomically modern humans from the Near East between *ca.* 50 and 30 ka (Kozlowski, 1998, 2006; Dennell, 2003; Roebroeks, 2008). It is likely that Neanderthals were still present in the region at this time, though the picture is extremely complex in terms of possible inter-species coexistence and issues surrounding technological transference (Kozlowski, 1998). Recent work on Pleistocene glacial records in this area has shed new light on the long-term palaeoenvironmental context for human settlement in this part of the Balkans. Large ice masses developed in the uplands of Montenegro during cold stages of the Pleistocene (Hughes and Woodward, 2009; Hughes et al., 2010). Well dated records show that glaciers extended down to *ca.* 500 m above sea level in MIS 12 and *ca.* 1000 m above sea level in MIS 6. The presence of large glaciers and permanent snow cover across much of the upland landscape during cold stages would have presented a very challenging environmental setting for Palaeolithic humans at these times.

Archaeological investigations at Crvena Stijena in the 1960s and 1970s generated much information on the cultural, social and subsistence activities of Middle and Upper Palaeolithic hominins in the region (Basler, 1975). Following on from this first phase of research, preliminary observations and sampling of the sediment record were carried out by Jamie Woodward and Bob Whallon in 1998 and a renewed programme of multi-disciplinary investigation was initiated at the site in 2004 (Baković et al., 2009). This included a detailed programme of geoarchaeological research to provide environmental context for the Middle to Upper Palaeolithic records (Morley, 2007). Against this background, this paper has the following aims:

1. To examine the stratigraphic and environmental context of the tephra unit at Crvena Stijena rockshelter to test the hypothesis that the tephra bed is *in situ* and has not been reworked;
2. To establish the provenance and age of the tephra unit and its wider chronostratigraphic significance.
3. In light of 1 and 2, to explore some of the key taphonomic issues associated with the transfer of distal tephra sediments into limestone caves and rockshelters and their incorporation into the sedimentary record.

Table 1
Major strata, archaeological periods and cultures at Crvena Stijena (modified from Basler, 1975). The archaeological periods follow Basler's (1975) scheme and the designations of geological context follow Brunnacker (1975).

Stratum	Depth (m)	Archaeological context	Geological context
I	0–0.40	Bronze Age	Postglacial
II–III	0.40–1.80	Neolithic	
IV	1.80–2.90	Mesolithic	
V–VII	2.90–3.50	Late Up per Palaeolithic (Epipalaeolithic)	Würm
VIII–IX	3.50–4.90	Local UP based on Aurignacian	
X	4.90–7.60	Aurignacian	
XI–XII	7.60–8.30	Late Mousterian	
XIII	8.30–9.10	Denticulate Mousterian	
XIV–XVII	9.10–10.40	Mousterian	
XVIII	10.40–10.70	Pontinian	
XIX–XX	10.70–11.40	Mousterian with triangular points	
XXI–XXII	11.40–12.10	Pontinian	
XXIII–XXIV	12.10–15.40	Mousterian	Riss/Würm
XXV–XXVIII	15.40–17.80	Protomousterian	Riss
XXIX–XXXI	17.80–20.30	Premousterian	

The Campanian Ignimbrite eruption

The Campanian Ignimbrite tephra (also known as the Y5 tephra in the marine record) is a Late Pleistocene volcanic ash that originated from an eruption in the Phlegrean Fields region of the Campanian volcanic province in southwest Italy (Fig. 1, Thunell et al., 1979; Cramp et al., 1989; Rosi et al., 1999; Ton-That et al., 2001; Fedele et al., 2008; Sparks et al., 2005; Pyle et al., 2006; Blockley et al., 2008; Di Vito et al., 2008; Giaccio et al., 2008). This super-eruption (Sparks et al., 2005) is thought to have been the most powerful volcanic explosion in the Mediterranean region over the last 200 ka (Barberi et al., 1978; Fedele et al., 2003, 2007, 2008; Oppenheimer and Pyle, 2009). It ejected around 300 km^3 of volcanic material into the atmosphere, and its distal tephra has been found spread over an area of some 2 to 4×10^6 km^2 (Sparks et al., 2005; Fedele et al., 2007, 2008; Giaccio et al., 2006, 2008; Oppenheimer and Pyle, 2009), including locations as far away as the Palaeolithic site cluster at Kostenki, Voronezh, on the River Don in southwest Russia (Pyle et al., 2006; Anikovich et al., 2007). It may even have reached North Africa (Barker et al., 2010).

The Campanian Ignimbrite tephra has been identified in a range of environmental archives including marine cores (Vinci, 1985; Cramp et al., 1989; Vezzoli, 1991; Ton-That et al., 2001), and terrestrial contexts, including lake sediments, peat bogs, open-air archaeological sites, and cave and rockshelter sequences (Fig. 1 and Table 2). This event has also been recognised in the Greenland ice-core records as a peak in sulphate (375 ppb) at 40.12 ka $_{GISP2}$ (Fedele et al., 2007). This is in good agreement with high-precision $^{40}Ar/^{39}Ar$ dating of the tephra which has yielded ages ranging from 39 to 41 ka (Ton-That et al., 2001; De Vivo et al., 2001) and places the time of deposition within MIS 3 (*ca.* 60–30 ka) (Van Andel and Davies, 2004; Hoffecker et al., 2008).

It has been argued that the immense volume of material ejected into the atmosphere, and its widespread dispersal, may have had a profound effect on climate at this time — perhaps even at the global scale. Fedele et al. (2008) have argued that the Campanian Ignimbrite event would have subjected the Mediterranean region to a "volcanic winter," and the coincidence with HE-4 (the coldest and driest of the Heinrich Events) could have resulted in what they term a "HE4-CI crisis." High sulphur levels associated with volcanic eruptions can lead to global cooling (Self, 2006), and some researchers claim that the Campanian Ignimbrite peak in sulphur, evident in the Greenland ice-core record (Zielinski et al., 1996, 1997), may have precipitated the onset of a markedly cold climatic episode within the relatively warm, but climatically unstable, Interpleniglacial, or MIS 3 (Van Andel and Davies, 2004). It is not the purpose of this paper, however, to explore these issues and the wider environmental impacts of the Campanian Ignimbrite eruption. Instead we present new data on the tephra layer at Crvena Stijena and highlight the importance of establishing the precise stratigraphic and depositional context of such features in archaeological sites. This is a key first step before any analysis of the potential impacts of such an event on Late Pleistocene ecosystems and Palaeolithic societies can take place.