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Stable isotope composition of Late Pleistocene-Holocene *Eobania vermiculata* (Müller, 1774) (Pulmonata, Stylommatophora) shells from the Central Mediterranean basin: Data from Grotta d'Oriente (Favignana, Sicily)

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A R T I C L E   I N F O

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A B S T R A C T

This paper presents stable isotopic results (oxygen and carbon) from both modern and Late Pleistocene-Holocene shells of the land snail *Eobania vermiculata* (Müller, 1774) from Favignana Island (Sicily). It aims to contribute to the understanding of climate and vegetation history of this region during formation of Upper Palaeolithic, Mesolithic and Meso-Neolithic deposits of Grotta d'Oriente (ORT). Results from both an evaporative model (FBM) and an empirical regional isotopic model (i.e. linear relation between oxygen isotopic composition of shells (δ^{18}Os) and those of local precipitation (δ^{18}Op)) indicate that the δ^{18}Os values of modern specimens are mainly controlled by local temperature, relative humidity and δ^{18}Op at the time of snail activity. Data also suggest that the modern snails are nocturnally active almost all-year round in the study area. The carbon isotopic compositions of shells (δ^{13}Cs) of the same specimens indicate a diet prevalently (or exclusively) composed of C3 vegetation.

The δ^{18}Os values of Late Pleistocene specimens suggest that climate conditions at ~14.2 ka cal BP were similar to the present day, in agreement with additional δ^{18}Os records from southern Italy. By contrast, early-middle Holocene shells are notably ^{18}O-depleted and suggest wetter conditions, possibly combined with a decrease in isotopic composition of precipitation source, compared to the present day. When compared with regional palaeoclimatic records a large-scale isotopic response to millennial-scale changes in atmospheric and hydrological conditions (e.g. enhanced rainfall) in the central-eastern Mediterranean is observed during the early-middle Holocene. The δ^{13}Cs of Late Pleistocene and Holocene specimens are consistently higher than those of modern ones. For the Late Pleistocene, this could be reasonably explained in terms of water-stressed vegetation. On the other hand, this seems to be less valid for Holocene counterparts when the climate was wetter. Probably δ^{13}Cs values result from the combination of distinct competing factors, involving atmospheric CO_2 concentration, seasonal water budget, vegetation type-cover and other carbon sources. Results reveal coherent relationships between regional δ^{18}Os and δ^{13}Cs, demonstrating that Late Pleistocene-Holocene land snail shell remains from archaeological sites may provide useful snapshots of past seasonal climate conditions.

1. Introduction

In the last three decades there has been a growing interest in the mechanisms controlling the oxygen and carbon isotope composition of extant land snail shells from different parts of the world (e.g.

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Goodfriend and Magaritz, 1987; Goodfriend and Ellis, 2002; Stott, 2002; Metref et al., 2003; Balakrishnan and Yapp, 2004; Balakrishnan et al., 2005a; Zanchetta et al., 2005; Baldini et al., 2007; Yanes et al., 2008, 2009), with analogous studies attesting to their value as a source of palaeoclimatic and palaeoenvironmental information in both natural (e.g. Goodfriend, 1990, 1991; Bonadonna et al., 1999; Abell and Plug, 2000; Leone et al., 2000; Li et al., 2007; Chiba and Davison, 2009; Kehrwald et al., 2010; Yanes et al., 2011) and archaeological deposits (e.g. Goodfriend, 1990, 1991; Goodfriend and Ellis, 2000; Balakrishnan et al., 2005b; Colonese et al., 2007, 2010a, b). Shell $^{18}O/^{16}O$ ratio have been mostly related to the isotopic composition of environmental water ingested by snails (e.g. water vapour, dew, local meteoric precipitation: e.g. Heller and Magaritz, 1983; Magaritz and Heller, 1983; Lécolle, 1985; Goodfriend and Magaritz, 1987; Goodfriend et al., 1989; Leng et al., 1998; Goodfriend and Ellis, 2002; Zanchetta et al., 2005; Baldini et al., 2007; Yanes et al., 2008, 2009), temperature (Lécolle, 1985) and relative humidity (Yapp, 1979; Balakrishnan et al., 2005a), which in turn influence the extent of kinetic isotopic fractionation of body fluids (e.g. Balakrishnan and Yapp, 2004). Shell $^{13}C/^{12}C$ ratios are principally a function of the isotopic composition of the ingested food (e.g. Goodfriend and Ellis, 2002; Stott, 2002; Metref et al., 2003; Baldini et al., 2007; Balakrishnan and Yapp, 2004; Liu et al., 2007; Yanes et al., 2008, 2009; Chiba and Davison, 2009). Since land snails are predominantly herbivorous (Cook, 2001), shell $\delta^{13}C$ may provide indications of consumed plants with distinct photosynthetic pathways (e.g. C3, C4, CAM; Farquhar et al., 1989) and the effect of environmental conditions on plant carbon isotope discrimination (e.g. Arens et al., 2000). Additionally, there is evidence suggesting a contribution to the carbon isotopic signature from ingested carbonates (Goodfriend and Hood, 1983; Yates et al., 2002; Yanes et al., 2008), exchange with atmospheric or soil CO_2 and metabolic rate (Yates et al., 2002; Balakrishnan and Yapp, 2004).

Advances in isotope ecology of land snails are expected to have significant impact on socio-environmental studies in archaeological contexts. For example, much of what is known about Pleistocene and Holocene human-environmental interactions in Mediterranean regions derives from sedimentary successions preserved in caves and rockshelters (Woodward and Goldberg, 2001) and land snail shells are often abundant and well preserved in these cultural archives (e.g. Farrand, 2000; Lubell, 2004; Colonese and Martini, 2007; Aura et al., 2009; Rizner et al., 2009). Thus, their isotopic study offers the possibility to explore past climate and environmental dynamics (e.g. amount of rainfall, relative humidity, vegetation) at the time of site occupation in direct association with cultural remains (e.g. artefacts and fauna). In addition, isotopic analyses permit environmental reconstructions on assemblages with low numbers of species, which are sometimes found in Late Pleistocene and Holocene archaeological sites (Lubell, 2004).

In spite of the growing body of information about hydrological and vegetation dynamics in Mediterranean regions from the Late Pleistocene to the Holocene (e.g. Roberts et al., 2008; Jalut et al., 2009; and references therein), relatively few terrestrial palaeoclimatic archives supply coeval climatic and environmental data from Sicily (Sadori and Narcisi, 2001; Frisia et al., 2006; Zanchetta et al., 2007b; Sadori et al., 2008; Tinner et al., 2009). This paper investigates the climatic and environmental significance of Late Pleistocene (Late Glacial) and early-middle Holocene land snail shell oxygen and carbon isotopic composition from the archaeological succession of Grotta d'Oriente, a small coastal cave located on the island of Favignana, NW Sicily. Combined with other shell isotopic data from fossil snails in southern Italy, it aims to supply additional clues into vegetation and hydrological conditions over this region during the Late Quaternary, a crucial time interval for understanding social-environmental relations of the last Mediterranean hunter-gatherers and earliest farmers.

2. Environmental and archaeological setting

Favignana is the largest island (~20 km^2) forming the Egadi Archipelago, at about 5 km from the NW coast of Sicily, Italy (Fig. 1A and B). The archipelago also includes Marettimo and Levanzo and the islets Maraone and Formica. With the exception of Marettimo, the other islands and islets of the Egadi Archipelago were formed by the Late Pleistocene and Early Holocene sea level rise (Agnesi et al., 1993; Antonioli et al., 2002). The geology of Favignana comprises calcareous-dolomitic rocks dated from the Triassic to the Miocene, which form the main relief in the centre of the island (Monte Santa Caterina, 320 m a.s.l.). Pleistocene calcareous and arenaceous marine sediments were successively deposited on the plains to the west and east of the island respectively (Agnesi et al., 1993).

The region has a typically Mediterranean climate, characterized by hot summer droughts and wet winters. At the seasonal scale, the climate is controlled by northward and southward migrations of the subtropical high-pressure cells (Azores high) in summer and winter respectively. Precipitation occurs prevalently in winter-spring when the southern position of the Azores high increases incursions of cyclonic storms from the north Atlantic. Its northwards migration in summer coincides with scarce precipitation (mostly of Mediterranean origin) and higher temperatures (Lionello et al., 2006). Mean monthly temperature for the year 2004 ranged from about 10 °C in winter to 27 °C in summer, while mean monthly precipitation ranged from 190 mm to 0.2 mm respectively, with an annual amount of rainfall of 680 mm (Fig. 2). For the same year relative humidity (RH) displayed substantial differences between mean monthly nocturnal and diurnal values. At night the RH was higher and exhibited less pronounced seasonal variability than daytime values (Fig. 2). Intra-annual oxygen isotopic composition of local precipitation (δ^{18}Op) below 20 m a.s.l. ranged from −10.1‰ in winter to +0.6‰ in summer (years 2002–2003), with an annual average of ~−5.0‰ (Liotta et al., 2006). Inland vegetation is mostly composed of heath, scrub, maquis and garrigue (e.g. *Ampelodesmos mauritanicus*, *Euphorbia dendroides*), mixed with annual dry grassland and pseudo-steppe, mostly Thero-Brachypodietea (see site code ITA010004 at Rete Natura, 2000: http://www.minambiente.it/).

Grotta d'Oriente (ORT; Fig. 1A) is a small vertical coastal cave located on the slope of the "Montagna Grossa", at ~40 m a.s.l. (Fig. 1A). ORT was first excavated in the early 1970s (Mannino, 1972, 2002) and subsequently in 2005 (Lo Vetro and Martini, 2006; Martini et al., in press), as part of an interdisciplinary project carried out by the Università degli Studi di Firenze and the Museo Fiorentino di Preistoria "Paolo Graziosi". The more recently studied archaeological zone of the cave (~5 m^2) is located at ~2 m from the entrance and integrates the oldest studied zone. Its sedimentary succession is ~2 m thick, and radiocarbon ages obtained from charcoal reveal significant deposition with hiatuses dated to the Late Glacial and the early and middle Holocene (Fig. 1C and D; Table 1). Microstratigraphic excavations in 2005 revealed distinct phases of human occupation spanning from the Late Pleistocene to the middle Holocene. Four main phases of occupation are recorded: Late Upper Palaeolithic (Layers 7A–7E), Mesolithic (Layer 6A–6D), Meso-Neolithic transition or early Neolithic (Layer 5A–5C) and Bronze Age (Layers 4–3). Some of these phases (indicated by numbers) contained short-term occupation episodes (indicated by letters) associated with the intense exploitation of coastal resources (Colonese et al., 2009). Archaeological evidence includes structured fireplaces, pits, stone tool assemblages (Fig. 1E) and