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Oxygen and carbon isotopic composition of modern terrestrial gastropod shells from Lipari Island, Aeolian Archipelago (Sicily)

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ABSTRACT

Oxygen ($\delta^{18}Os$) and stable carbon ($\delta^{13}Cs$) isotopic compositions of modern terrestrial gastropod shells from Lipari Island, in the Aeolian Archipelago (Sicily), have been analysed and compared with local meteoric water $\delta^{18}O$ ($\delta^{18}Op$) and vegetation $\delta^{13}C$ ($\delta^{13}Cv$) respectively. Results reveal that the $\delta^{18}Os$–$\delta^{18}Op$ relationship over the study area differs from those obtained on continental Europe and Italian shells, implying that even at the scale of the Mediterranean basin different relationships may co-exist. These differences have been interpreted as the increasing influence of Mediterranean vapour water on Tyrrhenian coasts at relatively low altitude (up to ~600 m asl), which compensates for the effect of the $\delta^{18}Op$, and possibly of temperature, on shell $\delta^{18}O$. The steady-state flux balance model (FBM), in agreement with previous studies, suggests that snails are active prevalently at night. Shell carbon isotope ratios reflect the $\delta^{13}Cv$, as predicted by the metabolic model and represent a valuable tool for identifying C3 plants with very distinct isotopic signatures.

1. Introduction

The Mediterranean landscape has been strongly shaped by natural (climatic) and anthropogenic forces at least since the middle Holocene (Blondel and Aronson, 1999). Understanding past evidence of natural versus human-induced environmental configuration is a challenge for environmental scientists and an essential task for management and conservation of Mediterranean environments and biodiversity. Palaeoecological records preserved in archaeological archives, although discontinuous and still under-explored as source of palaeoclimatic information, can offer additional tools for integrating the complex pattern of the relation between climate and human activity (Zanchetta et al., 2013). Late Pleistocene and Holocene archaeological deposits from central Mediterranean regions (e.g. Southern Italy and Sicily) contain abundant terrestrial gastropod shell remains (Lubell, 2004; Lubell and Barton, 2011), and stable isotope studies (O and C) have provided valuable snapshots on past climate and environment conditions (e.g. Colonese et al., 2010a,b, 2011), parallel to long-term palaeoclimatic records (Zanchetta et al., 2007, 2013; Magny et al., 2011).

These studies were based on empirical observation that atmospheric conditions are transmitted to shell oxygen isotopic composition through the $^{18}O/^{16}O$ ratio of environmental water, itself linked to precipitation (Heller and Magaritz, 1983; Magaritz and Heller, 1983; Lécolle, 1985; Goodfriend et al., 1987; Goodfriend, 1991; Leng et al., 1998; Goodfriend and Ellis, 2002; Balakrishnan and Yapp, 2004; Zanchetta et al., 2005; Baldini et al., 2007; Yanes et al., 2008, 2012). However the imprinting of atmospheric conditions on the shell oxygen isotope ratio is not straightforward, and distinct regional patterns have been observed (Lécolle, 1985; Leone et al., 2000; Zanchetta et al., 2005; Yanes et al., 2009), along with contributions from other variables, such as the temperature (Lécolle, 1985), relative humidity (Balakrishnan and Yapp, 2004), and other ^{18}O-enriched sources of oxygen (food) (Goodfriend et al., 1987). Isotopic interpretation of fossil assemblages requires, therefore, the development of regional baselines, achieved through the study of modern analogues, from well-constrained environmental condition (e.g. Yanes et al., 2008, 2009).

Stable carbon isotopic composition of terrestrial gastropod shells derives mainly from metabolic CO_2 (e.g. from plants and carbonates; DeNiro and Epstein, 1978; Stott, 2002; Metref et al., 2003; ZongXiu

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et al., 2007; Yanes et al., 2008) and may depend on feeding behaviour. In environmental studies, $^{13}C/^{12}C$ has been mainly used for identifying not only photosynthetic pathways (e.g. C3, C4, CAM) of consumed vegetation (e.g. Goodfriend and Ellis, 2002; Baldini et al., 2007), but also differences within the same vegetation photosynthetic category (e.g. Yanes et al., 2011; Stevens et al., 2012; Colonese et al., 2013a,b), although often in a very qualitative way.

The recent growing use of oxygen and carbon isotopic analysis on shells of terrestrial gastropods for palaeoclimatic and palaeoenvironmental reconstructions (Kehrwald et al., 2010; Colonese et al., 2011, 2013a,b; Yanes et al., 2011, 2012; Paul and Mauldin, 2012; Stevens et al., 2012) requires calibration with modern regional atmospheric and environmental conditions. In this study we explore shell isotopic variability in extant terrestrial snails from Lipari Island (Aeolian Archipelago, Sicily), a small calc-alkaline volcanic island (Lucchi et al., 2010) at the south-eastern margin of the Tyrrhenian Sea. Precipitation over the study area is dominated by Mediterranean water vapour, thus shell oxygen isotopic compositions of local terrestrial gastropods provide the opportunity to investigate this dominant source of precipitation on the $^{18}O/^{16}O$ ratio of their shells in relation to previous studies on other Mediterranean populations (Lécolle, 1985; Zanchetta et al., 2005). Vegetation consists of grasslands and maquis; therefore, we also investigate their isotopic transmission to the carbon of shells. Assessing regional variability in shell $\delta^{18}O$ and $\delta^{13}C$ across the Mediterranean will certainly improve ecological interpretations of both past and modern shell assemblages in areas extremely sensitive to climate change.

2. Environmental setting

The Aeolian volcanic archipelago is located 20 km off the NE coast of Sicily and comprises a group of seven islands (Lipari, Vulcano, Salina, Stromboli, Filicudi, Alicudi and Panarea) and small islets (Basiluzzo, Dattilo, Lisca Nera, Bottaro and Lisca Bianca) (Fig. 1). Lipari (37 km^2) is the largest island and represents emergent peaks of a volcanic structure up to 602 m above sea level (asl, Monte Chirica), which has emerged since the Late Quaternary (for detailed geological discussion see Lucchi et al., 2010). The region exhibits a typical Mediterranean climate, influenced by northward and southward migration of subtropical high-pressure cells (Azores high) in summer and winter respectively (Bolle, 2003). As a consequence, air masses from North Africa prevail during spring and summer, whereas frontal depressions from the North Atlantic and North Europe regions circulate in autumn and winter. This atmospheric circulation is responsible of a strong seasonality of precipitation, with 75% of the total rainfall occurring from October to March (Liotta et al., 2013). In 2009, the mean monthly temperature at Messina (~40 km SE from Lipari) ranged from 11 °C in winter (February) to 28.8 °C in summer (August), the monthly precipitation ranged from 4 mm (August) to 309 mm (January), with an annual rainfall amount of 1,255 mm (Fig. 2; data UCEA see later). The mean annual oxygen-isotopic composition of precipitation <100 m asl for the years 2003 to 2005 was ~−5.5‰ (δ^{18}Op relative to V-SMOW; Liotta et al., 2006). The δ^{18}Op over Stromboli suggests the absence of a direct contribution of volcanogenic O (Liotta et al., 2006).

Vegetation structure and communities at Lipari are strongly influenced by its volcanic origin and by human occupation since the Neolithic. Vegetation is typically Mediterranean, dominated by perennial xeric grasslands (with *Hyparrhenia hirta* or *Brachypodium retusum*) and more or less thermophilous maquis, referred to as Oleo-Ceratonion (with *Euphorbia arborescens*, *Pistacia lentiscus*, *Calicotome infesta*, *Genista thyrrena*) or Cisto-Ericion (with *Erica arborea* and *Arbustus unedo*). Plant communities now widely occupy neglected fields, due to the decline of agriculture which has occurred since the second half of 20th century. Nevertheless, the whole archipelago hosts an outstanding biodiversity: 900 plant species, which include some endemics, have been reported for the Aeolian Islands, representing 17% of Italian flora (Lo Cascio and Navarra, 2003).

3. Material and methods

3.1. Sampling procedure and preparation for stable isotope analysis

Well-preserved empty shells (n = 85) of 6 species of terrestrial gastropods were collected in April 2009 from the ground surface in 6 areas around the island, at elevations between 2 and 560 m (Fig. 1B; Table 1). Vegetation associated with the shells was also collected for isotopic analysis (Table 2). Collected shells belong to species widespread at Lipari and at other islands of the archipelago (Giusti, 1973). Snail species are herbivorous and opportunistically omnivorous in the western Mediterranean: *Trochoidea pyramidata* and *Mastus pupa* are thermophilic and xeroresistant species typically inhabiting coastal and inland areas (Giusti et al., 1995; Manganelli et al., 1995); at Lipari they were collected from shrubs and perennial–annual grassland habitats, composed of *Carpobrotus acinaciformis*, *Limbarda crithmoides*, *Pelargonium*

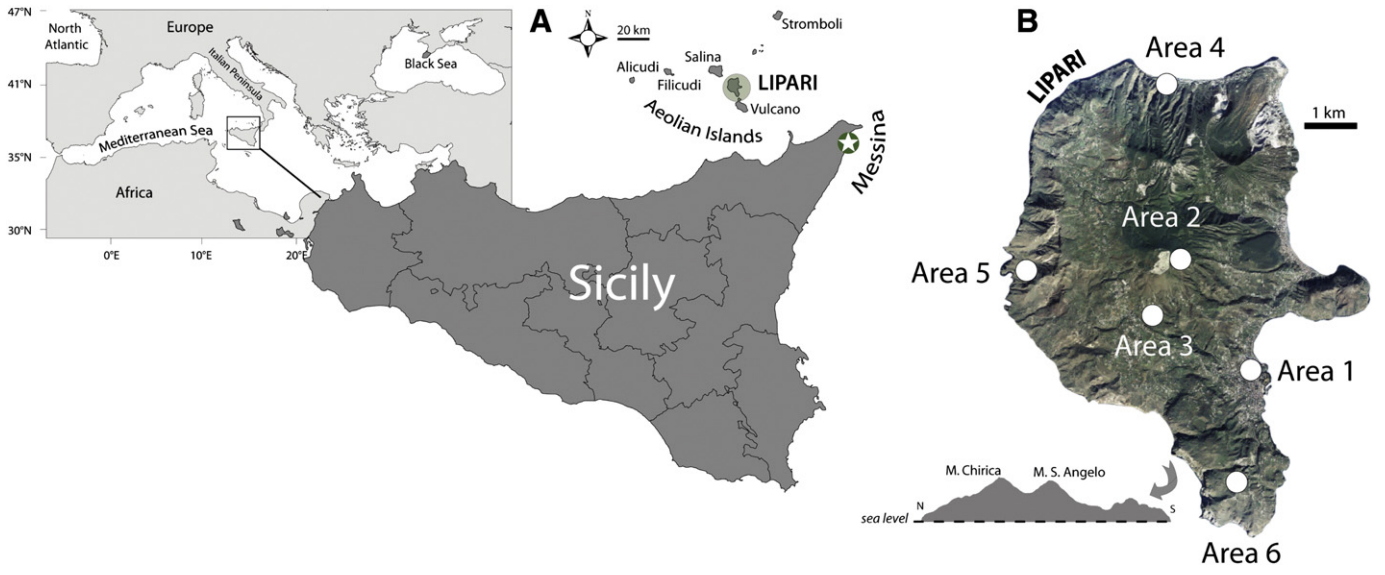

Fig. 1. (A) Geographic position of Aeolian Archipelago (Sicily, Italy) in the central Mediterranean; Messina meteorological station (star). (B) Detail of Lipari and sampling areas and the schematic profile of the island (Lucchi et al., 2010).