Quaternary Science Reviews 96 (2014) 204–221

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Hydrothermal activity and its paleoecological implications in the latest Miocene to Middle Pleistocene lacustrine environments of the Baza Basin (Betic Cordillera, SE Spain)

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ARTICLE INFO

Article history:
Received 24 March 2013
Received in revised form
25 June 2013
Accepted 1 July 2013
Available online 1 August 2013

Keywords:
Lacustrine systems
Hot springs
Paleohydrochemistry
Large mammals
Paleoecology
Plio-Pleistocene

ABSTRACT

The continental sedimentary record of the Baza Basin (Guadix–Baza Depression, Betic Cordillera, SE Spain) shows six sedimentary units of lacustrine origin deposited from the latest Miocene to the Middle Pleistocene. Depending on the interval considered, the lacustrine deposits are mainly composed of marls, carbonates or gypsiferous evaporites, showing lithological, mineralogical and geochemical features (i.e., magnesium, strontium and sulfur contents, celestine deposits and travertine growths) that are evidence of intense, tectonically-induced hydrothermal activity. According to the high concentrations of strontium and sulfur as well as the abundance of travertines and magnesium clays, the supply of hot waters was greater during the Zanclean, the Gelasian and the Calabrian, as a result of tectonic activity. Hydrothermal activity has continued until the present time and is responsible of the hot springs that are nowadays active in the Guadix–Baza Depression. The paleoenvironmental consequences of these sublacustrine hot springs were that during some intervals the lakes maintained a relatively permanent water table, not subject to periodic desiccations in the dry season, and warmer temperatures throughout the year. This resulted in a high level of organic productivity, especially for the Calabrian, which allowed the development of a rich and well diversified mammalian community, similar to those of modern African savannas with tree patches. In this mild environment, the permanent water sheet favored the presence of drought intolerant megaherbivores such as the giant extinct hippo *Hippopotamus antiquus*. The high standing crop biomass of ungulates resulted in the availability of abundant carcasses for scavengers such as hyenas and hominins, which explains the very high densities of skeletal remains preserved in the sediments distributed along the lake surroundings.

1. Introduction

During the last decades, a number of issues related to the earliest arrival of hominins in Europe have been subject to intense debate, including the chronology of the first human settlements, the dispersal routes, the techno-cultural developments of the population that dispersed out of Africa, and the ecological context and climatic conditions of the dispersal event (for reviews and references, see Arribas and Palmqvist, 1999; Jiménez-Arenas et al., 2011; Toro et al., 2013).

Up to the mid-nineties, most researchers considered that no significant habitation took place in Europe before Middle Pleistocene times, as evidenced at the Boxgrove and Mauer sites (Roberts et al., 1994; Wagner et al., 2010). However, this was soon overturned by the discoveries of Early Pleistocene human remains and tools in a number of Western European sites covering a chronological range of ~1.4 to ~0.7 Ma. These findings include Barranco León and Fuente Nueva-3 in the Baza Basin, southeast Spain (Martínez-Navarro et al., 1997; Palmqvist et al., 2005; Espigares et al., 2013; Toro et al., 2013); Sima del Elefante and Gran Dolina TD-6 in Atapuerca, northwest Spain (Carbonell et al., 1995, 2008; Bermúdez de Castro et al., 1997, 2010; Falguères et al., 1999), and Happisburgh-3 and Pakefield in England (Parfitt et al., 2010). In addition, an earlier dispersal of *Homo* out of Africa is well

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http://dx.doi.org/10.1016/j.quascirev.2013.07.009

documented in Dmanisi, a Caucasian site at the gates of Europe dated at ~1.8 Myr (Vekua et al., 2002; Lordkipanidze et al., 2007; Ferring et al., 2011; Mgeladze et al., 2011).

The comparative analysis of the large mammal assemblages from these circum-Mediterranean sites, particularly the ones located in the Guadix–Baza Depression (Betic Cordillera, Southeast Spain), with those from Africa, the Near East and Asia has provided increasing evidence of continued faunal turnover during the Early Pleistocene (Palmqvist et al., 1996, 1999; Arribas and Palmqvist, 1999; Viseras et al., 2006; Arribas et al., 2009; Martínez-Navarro et al., 2011; Ros-Montoya et al., 2012). Specifically, the study of the huge assemblages of large mammals from the Baza Basin has shown that hominins did not disperse alone out of Africa, but were accompanied by other immigrants such as the saber-tooth felid *Megantereon whitei*, the short-faced hyena *Pachycrocuta brevirostris*, the hippo *Hippopotamus antiquus* and the giant gelada *Theropithecus oswaldi* (Martínez-Navarro and Palmqvist, 1995, 1996; Arribas and Palmqvist, 1999; Martínez-Navarro, 2004, 2010; Rook et al., 2004; Palmqvist et al., 2007, 2011). Faunal dispersal was a major subject of research for the late Professor Alan Turner, whose seminal work on carnivore taxonomy and paleoecology focused on establishing the patterns of large mammal turnover during the Neogene–Quaternary, as well as on evaluating the changing interactions between carnivores and hominins (e.g., Turner, 1990, 1992, 1999, 2007; Turner and Anton, 1996; Palmqvist et al., 2007; Turner and O'Regan, 2007; Dennell et al., 2008; O'Regan et al., 2011).

From the early seventies onwards, the models of stratigraphic architecture for the continental infilling of the Baza Basin were based on the existence of a number of lacustrine systems fed by alluvial waters (Vera, 1970; Peña, 1979, 1985; Fernández et al., 1996a; García-Aguilar, 1997; García-Aguilar and Martín, 2000; Ruiz-Bustos, 2011). Depending on the interval considered, these lacustrine systems resulted in marly, carbonate or evaporitic deposition. The lakes developed intermittently during the last 7.5 Ma of the sedimentary history of the basin and are separated by hiatuses of variable duration (García-Aguilar and Martín, 2000; García-Aguilar and Palmqvist, 2011). Up to present times, the origin of the lacustrine systems has been related to hydrological supplies of runoff waters (Vera, 1970; Peña, 1979, 1985; Viseras et al., 2005; Pla-Pueyo et al., 2011).

However, new analytical data from the lacustrine deposits as well as the review of the tectonic context of the basin for the interval between the latest Miocene and the Middle Pleistocene suggest that the lacustrine environments were also fed, at least in part, by hydrothermal supplies. In fact, many hot springs in the Guadix–Baza Depression have been known for centuries and some of them are even used today as spas due to their therapeutic qualities (e.g., thirteen are catalogued as showing various physicochemical properties; Diputación de Granada-ITGE, 1990). Pentecost et al. (2003) defined as hot springs those waters emerging with a temperature in excess of the core human body temperature (36.7 °C) and discarded the use of other terms (e.g., thermal springs or warm springs) because they cannot be defined satisfactorily for all springs. There are 13 springs in the depression that show output temperatures in excess of 18 °C. Although only two of these springs emerge with a temperature in excess of 36 °C, from a hydrogeological point of view they are considered as hot springs (Diputación de Granada-ITGE, 1990).

Peña (1979) and Sebastián-Pardo (1979) interpreted the presence of celestine and fluorspar in Plio-Pleistocene sediments from the lacustrine formations of the Baza Basin as reflecting hydrothermal activity. Later, García-Aguilar (1997) proposed that sublacustrine hot springs resulted from extensive tectonic activity in the basin during its period of continental sedimentation (i.e., latest Miocene to Late Pleistocene). The sedimentary singularity of the lacustrine formations of the Baza Basin (Arribas et al., 1988; Anadón et al., 1995; García-Aguilar and Palmqvist, 2011) and the rich paleontological assemblages unearthed from them (Arribas and Palmqvist, 1998, 1999; Palmqvist et al., 2005, 2011; Oms et al., 2011; Espigares et al., 2013; Toro et al., 2013) could be the result of the feeding of the lacustrine systems by waters from hot springs; this allows reconstructing a new paleoenvironmental and paleoecological scenario for the basin.

The main objectives of this article are two: (1) to show the main lithological, mineralogical and geochemical evidence in support of this hypothesis; and (2) to discuss the sedimentary and paleoecological consequences.

2. Geological setting

The Guadix–Baza Depression is a postorogenic, intramontane sedimentary area, ~110 km elongated NE-SO at ~1000 m elevation, which developed on the boundary region between the Internal and External Zones of the Betic Cordillera (Fig. 1). This depression was endorheic (i.e., characterized by interior drainage) from latest Miocene times (Viseras et al., 2005; Minwer-Barakat et al., 2009; Hüsing et al., 2010; García-Aguilar and Palmqvist, 2011; Pla-Pueyo et al., 2011), developing two depocenters (Guadix Basin and Baza Basin, respectively) with several depositional environments (Figs. 1 and 2).

Two successive lithological sets have been differentiated in the sedimentary infilling of the Guadix–Baza Depression, separated by an angular unconformity that may be recognized throughout the whole depression (Vera, 1970; Sanz de Galdeano and Vera, 1992; García-Aguilar and Martín, 2000; Viseras et al., 2005; García-Aguilar and Palmqvist, 2011; Pla-Pueyo et al., 2011). The oldest set (~1000 m thick) outcrops along the borders of the depression and is mainly composed of marine deposits of Late Miocene (Tortonian) age (Fig. 1B). The most modern set, latest Miocene (Turolian) to Middle Pleistocene in age, consists of a ~600 m thick sequence of continental deposits and covers the greater part of the depression, representing the thickest and most continuous record of Plio-Pleistocene continental sediments known in the Iberian Peninsula (and probably also in Europe). This set comprises the deposits that correspond to three formations traditionally defined in the depression, which show lateral changes of facies (Fig. 1B): (1) the Guadix Formation (Von Drasche, 1879; Vera, 1970), which has an alluvial and fluvial origin, and outcrops mainly in the western sector of the depression (Guadix depocenter); (2) the Gorafe-Huélago Formation (Vera, 1970), which corresponds to a carbonate lacustrine environment and is located in the northwestern sector of the Guadix Basin; and (3) the Baza Formation (Vera, 1970), which has lacustrine origin, outcrops in the eastern sector of the depression (Baza depocenter) and is mainly composed of limestones, marls and gypsum.

Six major phases of lacustrine deposition, some of them separated by stratigraphic hiatuses, are recognized in this article for the sedimentary infilling of the Baza Basin (Fig. 2), following García-Aguilar and Martín (2000): (1) latest Miocene pink marls; (2) Zanclean white and gray marls and calcilutites; (3) cyclical sequences of marls and marly limestones deposited during the latest Early Pliocene and the Late Pliocene (hereafter referred to as Piacenzian); (4) marls and gypsiferous evaporites of Gelasian age; (5) marls, marly limestones and sands of Calabrian age; and (6) Middle Pleistocene marls, pelites and limestones. In addition to these lacustrine deposits, travertine buildings of Late Pleistocene age outcrop in the vicinity of hydrothermal waters, for example those at the localities of Zújar in the Baza Basin and Alicún de las Torres in the Guadix Basin (García-Aguilar, 1997; Prado-Pérez, 2011).