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High resolution magnetostratigraphy and radio-isotope dating of early Pleistocene lake sediments from southern Armenia

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ABSTRACT

The Pleistocene geology of Armenia is dominated by widespread occurrence of sediments recording recurring rapid and drastic changes of the environmental conditions during at least the last 2 million years. These sediments, predominantly diatomites, contain a huge variety of various fossil remains, allowing the reconstruction of flora, fauna as well as the climatic conditions especially during dispersal of early man into Eurasia 1.8 Ma. Radio isotope dating of pumice levels as well as a detailed magnetostratigraphic study have been carried out in Syunik Province near the town of Sisian, southern Armenia, in order to establish a temporal correlation of all major outcrops of paleo-lake sediments and to provide a timeframe for paleoenvironmental studies within this lake sediment succession.

A total of 455 oriented drill cores was sampled at six large and four short sections with a sampling resolution between 5 and 20 cm. Detailed paleomagnetic experiments reveal the presence of a characteristic remanent magnetization (ChRM) pointing either to the north and down or south and up. A positive reversal test suggests the primary character of this magnetization component. Combining the normal and reverse polarity directions results in an overall sample mean direction of $D = 354.8^\circ$, $I = 51.5^\circ$ with a Fisherian precision parameter k of 14.6 and the associated α_{95} of 2.9°, combining demagnetization data of 169 samples. In addition, ash layers were sampled for $^{40}Ar/^{39}Ar$ geochronology at five of the sections studied paleomagnetically and three additional small outcrops. The resulting ages range between 1.31 Ma and 1.08 Ma, with two samples yielding ~1.65 and 1.90 Ma. The latter are characterized by extremely low abundances of radiogenic ^{40}Ar, suggesting that the mineral system has not been closed since the time of eruption, leading to substantial loss in Ar. Integration of these radio-isotope dates with the polarity data suggests that the normal polarities can be linked to the Jaramillo subchron within the Matuyama reversed polarity chron. Based on the longest interval of normal polarity identified at Ashotavan-2, a lower limit for the sedimentation rate of ~37 cm/ky can be estimated. Therefore, we infer the duration of lake sedimentation as ~350 ky, starting at ~1.4 Ma.

1. Introduction

At the beginning of the Pleistocene, the first representatives of the genus *Homo* appeared in Eastern Africa. The most impressive example of the earliest documented hominins in Eurasia is the findings in Dmanisi, Southern Georgia (Gabunia et al., 2000; Lordkipanidze et al., 2007; Ferring et al., 2011). Findings of hominins in Southern Europe are clearly younger, and it seems that they appeared there only since 1.2, or 1.4 Ma (Spain: Atapuerca, Cuenca-Bescós and Garcíá (2007); Orce, Scott et al. (2007); Scott and Gibert (2009); Italy: Pirro Nord, Arzarello et al. (2007)). The extent to which climate and environmental changes influenced the history of hominin occupations is, however, highly controversial (Dennell, 2003, 2010; Bar-Yosef and Belmaker, 2011; Leroy et al., 2011).

To assess the environmental constraints of early human expansion(s) into Eurasia, reconstruction of the palaeoenvironmental setting in areas with known hominin presence such as the Southern Caucasus is of fundamental importance. Reconstructions can be obtained by analysis of palaeontological proxies including animal and plant fossils. However, the interpretation of environmental

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data strongly depends on a detailed and reliable age control. Unfortunately, however, many extremely detailed studies, aiming at reconstructing and quantification of early Pleistocene climate and landscape development, are hampered by the lack of precise numerical ages or by the lack of climatically significant biotic assemblages, as is the case for the Dmanisi fossil site itself (e.g., Messager et al., 2010, 2011).

Other early Pleistocene records from that region, from marine sections in western Georgia (e.g., Shatilova et al., 2002) suffer from imprecise numerical ages of the assemblages analysed. Others are not yet studied with respect to environmental reconstructions, as in Northern Iran (Vincent et al., 2010; Sharma et al., 2013) or Azerbaijan (Baak et al., 2013).

In southern Armenia, Pleistocene lacustrine diatomites are widespread and are perfectly suited for palaeoenvironmental studies, as they yield various fossil remains (Gabrielyan, 1994; Bruch and Gabrielyan, 2002; Ollivier et al., 2010). They can carry valuable information on the ecological conditions during time of deposition. Flora and fauna documented in diatomites of the Sisian Formation in the Voratan river basin in southern Armenia have been studied intensely since 1937 (Kryshtofovich, 1939). Several thousand fossil leaf specimens were identified, yielding information about the palaeoenvironment (Gabrielyan and Kovar-Eder, 2011). However, the age constraints for these sedimentary successions for a long time were based on biostratigraphy exclusively (Takhtajan and Gabrielyan, 1948; Avakyan, 1973; Gokhtuni, 1987, 1989; Gabrielyan, 1994). More recently, palynological (Joannin et al., 2010) and geomorphological (Ollivier et al., 2010) studies added the first magnetostratigraphic and radio-isotope data for one of the sections of the Sisian Formation. The paleomagnetic data included 19 samples and show only reversed magnetic polarities. Pumice layers within the section gave $^{40}Ar/^{39}Ar$ ages of 1.25 ± 0.03 Ma and 1.17 ± 0.02 Ma, respectively (all $^{40}Ar/^{39}Ar$ ages reported here have been recalculated relative to the Fish Canyon sanidine (FCs) of 28.201 Ma of Kuiper et al. (2008)). On the other hand, a basalt flow, overlying the diatomites, yielded K/Ar ages of 935 ± 15 ka and 934 ± 20 ka, respectively. The authors concluded a deposition age of the sediments during the Matuyama reversed chron (2.581 – 0.781 Ma (Gradstein et al., 2012), constrained by the age of the basalt.

For other diatomitic, fossil bearing outcrops of the Sisian Formation, a detailed age classification has not been established. Ongoing climate and vegetation quantifications based on fossil macro and micro plant remains from these outcrops promise to give valuable information on the local response of vegetation to global palaeoclimatic changes (Bruch et al., 2011). To better constrain these data, and to establish a precise time frame for the lake sediment succession of the Syunik area, a combined radio-isotope and magnetostratigraphic study has been undertaken. It has been carried out on several mainly diatomitic outcrops in the Vorotan river area near the town of Sisian (Syunik Region, Fig. 1).

2. Geological setting and characterization of study region

Located between the Black and the Caspian Sea, two remnants of the Tethyan ocean (Adamia et al., 1981), the Caucasus was subjected to uplift during the final collision of Arabia and Eurasia (Mosar et al., 2010) starting in the Early Cenozoic and accelerated during the Plio-Pleistocene (Adamia et al., 1977; Mosar et al., 2010). This oblique collision, which is still active, is taken up by diagonal strike slip faults (Forte et al., 2010). The present day active convergence mostly occurs between the Kura basin and the Greater Caucasus (Forte et al., 2010).

Seismicity and active strike slip faults are reported in the Syunik Area (Fig. 1 in Philip et al. (2001) and references therein), where this study is located (Fig. 1). Ollivier et al. (2010) reported numerous normal faults in the region, which they interpreted to be ~819 ka.

Fig. 1. Location of the study area (black circle) in the Syunik Province (grey), which is located in southern Armenia (dark grey). Hominid bearing site of Dmanisi is marked.

During the Pleistocene, the tectonic evolution was associated with extensive volcanism and the emplacement of massive basaltic flows (Adamia et al., 1984; Karapetian et al., 2001). During the early Pleistocene, one of these flows formed a natural dam of the Paleovorotan river, one of the major drainage routes in southern Armenia. This led to the formation of several lacustrine basins in the Syunik region, which were subsequently filled by diatomites intercalated with volcanoclastic rocks (Avakyan, 1973). These sedimentary deposits, stratigraphically grouped as the Sisian formation cover an area of ~100 km^2. They overlie Cretaceous-Eocene limestones, porphyrites and granodiorites and are juxtaposed and partly intercalated with Neogene-Pleistocene volcanogenic rocks (compare Fig. 2 from Ollivier et al. (2010)). Elevation ranges between 1340 and 2100 m asl (Gabrielyan and Kovar-Eder, 2011). Only minor tilt has been observed in all sections, not exceeding 5°.

The remnants of a large paleolake occur ~25 km along the Vorotan river. Assuming lake formation to have been caused by the closure of the Vorotan river, the present day distribution of paleolake sediments in the area implies a lake of at least ~20–30 km length (Fig. 2). The maximum width of the former lake cannot be estimated because the lake sediments have been covered by younger lava flows in the northern part of the basin.

Most of the lake deposits are exposed only with a stratigraphic thickness of a few meters. Only at six locations do lake sediments exceed 6 m in thickness, and are undisturbed and well-bedded. All outcrops are predominantly characterized by silty and sandy diatomitic layers, which alternate irregularly. Their thicknesses range from several centimetres to about one meter. They are intercalated by tuff layers. The lithological pattern of individual sequences is very complex, and it is therefore impossible to correlate only based on the lithology.

The larger outcrops, Brnakot-2, Uyts-2, Ashotavan-2, Darbas-2, Sisian-3, and Shamb-2 (Avakyan, 1973; Gabrielyan and Kovar-Eder, 2011), have been sampled for paleomagnetic analysis with a sampling resolution of 5–20 cm across a maximum sediment thickness of 40 m. Four additional small outcrops (Brnakot-1, Brnakot-3, Ltsen-3 and Tolors-2) were sampled for magnetostratigraphy using three to four samples (Fig. 2, Table 1). Within six of all these sites (Table 1), volcanoclastic layers were investigated using $^{40}Ar/^{39}Ar$ geochronology.