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Vegetation and palaeoclimatic reconstruction of the Sousaki Basin (eastern Gulf of Corinth, Greece) during the Early Pleistocene

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ABSTRACT

Pollen analysis was performed on a Lower Pleistocene lacustrine sedimentary sequence outcropping in Sousaki Basin, eastern Gulf of Corinth, Greece for the first time. The palynological assemblages revealed a stable climate, with regard to the glacial/interglacial climate variability timescale, with minor fluctuations in humidity, expressed as a relatively wet phase between 13.1 and 19.3 m and some transient increased aridity and humidity events. A Mediterranean type of vegetation presenting altitudinal zonation was evidenced for the first time in this region. *Pinus* and *Quercus* dominate, accompanied by other arboreal and non arboreal plants. The presence of rare taxa such as Taxodiaceae, *Engelhardia*, *Liquidambar*, *Tsuga* and *Cedrus* in very low percentages shows that these taxa remained in the area as relicts sometime between 2.8 and 1.5Ma. Palaeovegetation patterns from the Balkan Peninsula are lacking, especially during the Early Pleistocene. Thus, in this study a palaeoclimate reconstruction of the Early Pleistocene Sousaki Basin based on palynological data, is presented accentuating the effect of global climate changes in an area where no other similar records exist.

1. Introduction

Little is known about the Mediterranean flora vegetation history during the Pliocene and Early Pleistocene, mostly because of the incompletely developed palynological record in circus-Mediterranean regions. During the Tertiary the Mediterranean Basin was mostly covered with evergreen vegetation types. During the Pleistocene, deciduous forests (*Querqus* and *Fagus*) emerged in the mountainous belts and at the same time steppe-like vegetation developed along the coasts. Climate was the main driving factor for these changes. (Pignatti, 1978).

Mediterranean climate is characterized by a seasonal change with dry summers and mild, moist winters (Jalut et al., 2009). This type of climate is considered to have been originated at the end of the Miocene, was established at the beginning of the Pliocene and developed throughout the Quaternary, at a time when global climate became gradually much more arid (Axelrod, 1975, 1977; Spect, 1979; Vallente-Banuet et al., 2006; Sadori et al., 2013; Naidina and Richards, 2016). The dry summer conditions, combined with the climate fluctuations during Pleistocene, probably eliminated Tertiary mesophytic taxa, and thus contributed to the establishment of the Mediterranean type flora (Coleman et al., 2003). In mesic habitats, Mediterranean vegetation corresponds to evergreen sclerophyllous forests and shrubs (Coleman et al., 2003). A certain number of these species (sclerophyllous vegetation mainly) consists of relicts of the former Neogene palaeoflora that remained in the Mediterranean region, while grassland, steppe and desert biotopes/ecosystems expanded. Moreover, the development of orogenic belts across the region as a result of the collision of the African and Eurasian plates is also inferred as a factor for the high species diversity and/or endemism of the Mediterranean flora (Axelrod and Raven, 1978; Goldblatt, 1978; Quezel, 1978; Loidi et al., 2015; Sciandrello et al., 2015; Kadereit, 2017). Large foredeep basins and wetland areas extend along the rising orogenes and allow the development of altitudinal vegetation zonations (Kovar-Eder, 2003).

Pollen records have long been used to infer past climate changes across Europe (Lona, 1950; Zagwijn, 1960, 1975; Menke, 1975; Suc and Zagwijn, 1983; Wijmstra and Groenhart, 1983; Suc, 1984; Okuda et al., 2002; Tzedakis et al., 2006; Popescu et al., 2010;

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Fletcher et al., 2013; Pross et al., 2015; Sadori et al., 2016). The major vegetation changes that occurred during the Pleistocene have been imprinted in sedimentary sequences throughout the Northeastern Mediterranean region (e.g. Bertini, 2010; Bertini et al., 2015 and Combourieu-Nebout et al., 2015 and references therein for Italian sites, Okuda et al., 2002; Joannin et al., 2007a; Pross et al., 2015 for Greek sites). However, especially for the Early Pleistocene there are a limited number of Mediterranean palynological records, which are essential for the completion of the Pleistocene vegetation history. The study area is located at the northwesternmost end of the South Aegean volcanic arc, within the eastern prolongation of the Gulf of Corinth. The Gulf of Corinth as a rift zone has been established during the post Alpine evolution of Greece (Kokkalas et al., 2006) and the Sousaki Basin has been developed among other basins in the area (Collier and Dart, 1991). Sousaki volcanic rocks constitute the basement of the Basin and can provide a lower age constrain for the long sedimentary sequences of the Basin (Pe-Piper and Piper, 2005). Moreover, the study area lies between well-known palaeovegetation study sites in Italy and Turkey (Biltekin, 2010; Biltekin et al., 2015; Magri et al., 2017) and thus covers the passage from the European to the Anatolian provinces. For all the above reasons Sousaki Basin is considered a hot spot for palaeovegetation studies.

In this study, pollen analysis has been carried out on a Lower Pleistocene sedimentary sequence in the Sousaki Basin. The scope of this study is the reconstruction of the local palaeovegetation and palaeoclimate history during the Early Pleistocene, in an area affected by global climate changes and orogeny and where similar studies have not been implemented until now.

1.1. Geological setting and stratigraphy of the wider study area

Sousaki volcano comprises the northwesternmost end of the South Aegean Volcanic arc (Piper and Perissoratis, 2003; Francalanci et al., 2005; Calvo et al., 2012) (Fig. 1). It is located about 15 km east of Corinth Canal, Central Greece. All that remains from this low-standing volcanic center are some limited volcanic outcrops, in an area 10-km-long and in an E-W direction (see also Francalanci et al., 2005). Even if it presents minor volcanic appearances, Sousaki plays an important role on the evolution of the South Aegean Volcanic arc, as it constitutes the most westerly exposed Late Cenozoic volcanic activity in the arc (Pe-Piper and Piper, 2005) and separates isolated second order basins bounded by volcanic outcrops (Collier and Dart, 1991). Furthermore our study area is located in the eastward prolongation of the Gulf of Corinth, one of the most tectonically and seismically active areas in Europe (Pavlides et al., 2004; Leeder et al., 2008). In particular the Sousaki low-standing volcano is characterized by the presence of a thicker crust than the other volcanic centers of the arc (Pe-Piper and Hatzipanagiotou, 1997).

Based on radiometric ages, the volcanic outcrops in the eastern Sousaki area bear an age of 2.8–2.3 Ma. The outcrops of the volcanics in the area are located next to the studied section providing a lower age constrain for it (Pe-Piper and Piper, 2005 and references therein) (Fig. 1). The distribution of the volcanic outcrops is controlled primarily by extensional tectonics. E-W trending faults and secondary SE-NW tectonic lineaments are found as an array of discontinuities throughout the area (Schroeder, 1976; Collier and Dart, 1991; Stiros, 1995; Pe-Piper and Hatzipanagiotou, 1997; Galanopoulos et al., 1998; Francalanci et al., 2005; Tsatsanifos et al., 2007). This tectonic regime has possibly affected the basin since the Pliocene (Francalanci et al., 2005; Papadopoulou, 2016).

Consequently, the volcanic rocks interfinger with severely tectonized sedimentary strata. These strata are primarily marly sediments up to 400 m thick, laterally changing into sandy-conglomeratic facies up to 250 m thick (Schroeder, 1976). The numerous and frequent changes in the sedimentary facies across the Sousaki Basin provide evidence not only for rapid palaeogeographic changes but also for intense vertical motions. The stratigraphy of the basin is provided in detail by Mettos et al. (1988) and Collier and Dart (1991). The volcano-sedimentary sequence overlies an Upper Triassic-Lower Jurassic limestone and a Post-Upper Jurassic ophiolithic nappe (possibly thicker than 1000 m), which shows intensive hydrothermal alteration (Kaplanis et al., 2013). Finally, Holocene sediments overlie unconformably above the aforementioned sequences (Galanopoulos et al., 1998).

1.2. Lithostratigraphy of the studied section

The composite stratigraphic column of the wider study area is shown in Fig. 2. The base of the column consists of the volcanic basement that is exposed southeast of the studied section. It is unconformably overlain by alterations of thick conglomerate layers and interbedded rhythmic deposition of organic rich sediments and marly/sandy layers. This Unit (Conglomerate Unit-Fig. 2) is exposed to an artificial section about 200 m east-southeast of the studied section. It is overlain by marls (Marl Unit-Fig. 2). Between the two units there is a gap in the stratigraphic data caused by the construction of the railway tracks in the area.

The studied section is located on the north side of the railway tracks of Athens-Corinth suburban railway, 3.7 km west of Ag. Theodoroi town (E 37°55′23.65″, N 23°5′42.33″) (Figs. 1 and 2). It is a well-exposed outcrop of marly sediments that lie next to the outcrops of the eastern group of volcanics. The studied section is composed mainly of alterations of white to yellow marls and marly limestones with varying thicknesses (from 0.10 m to 1 m) (Fig. 2). At the base of the section a strongly carbonated conglomerate has been found (more than 5 m thick), overlain by the typical alterations of marly sediments and by some intercalations of thin-bedded organic rich shales and gypsum beds. Organic rich shales (beds thicker than 5 cm) occur at 6.04–6.20 m, 8.97–9.31 m, 9.94–9.99 m, 13.11–13.16 m and 15.58–15.67 m. They are tabular to lenticular and extend laterally for a few tens of meters. They contain rootlets and plant debris. Upwards the section consists of alterations of marls and marly limestones, which gradually become more abundant whereas the organic rich shales and gypsum beds almost disappear. The stratigraphy of the studied section is presented in detail in the respective stratigraphic column (Fig. 2; Papadopoulou, 2016).

1.3. Present day climate and vegetation

The study area lies on the low hills of Gerania Mountains (1.351 m), in the eastern prolongation of the Gulf of Corinth, Greece. The climate of the wider area is typical Mediterranean as inferred by the Hellenic National Meteorological service. Especially in the plains the climate is semi-arid with very mild winters (mean annual rainfall 409.6 mm, mean annual temperature 18.2 °C according to the Hellenic National Meteorological service, Corinth station, 37°56′N, 22°57′E, altitude: 15 m, data mining period: 1970–1984). The vegetation type is also typical Mediterranean, presenting high endemism because of the special geological features of the bedrocks (e.g. ophiolites and volcanics) (Konstantinidis, 1997). Above 700 m, forests with *Pinus halepensis* and *Abies cephalonica* occur accompanied by *Pinus nigra* and *Querqus*. Leathery, broad-leaved evergreen shrubs or small trees (maquis vegetation) coexist (*Arbutus andrachne, Arbutus unedo, Capparis spinosa, Cotinus coggygria, Daphne jasmine, Globularia alypum, Myrtus communis, Nerium oleander, Olea europaea, Phillyrea latifolia, Pistacia lentiscus* and *Pistacia terebinthus* amongst others). On the low hills and the