ARTICLE IN PRESS

Quaternary International xxx (2018) 1–13

Contents lists available at ScienceDirect

Quaternary International

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

Discrimination of Holocene tephra units in Lake Van using mineral magnetic analysis

Özlem Makaroğlu [a,*], M. Namık Çağatay [b], Norbert R. Nowaczyk [c], Lauri J. Pesonen [d], Naci Orbay [a]

[a] Istanbul University, Faculty of Engineering, Department of Geophysical Engineering, 34320, Avcilar, Istanbul, Turkey
[b] Istanbul Technical University, Eastern Mediterranean Centre for Oceanography and Limnology EMCOL and Faculty of Mines, Department of Geological Engineering, 34469, Maslak, Istanbul, Turkey
[c] Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Section 5.2 – Paleoclimate and Landscape Evolution, 14473, Potsdam, Germany
[d] University of Helsinki, Department of Physics, Division of Geophysics and Astronomy, FIN-00014, Helsinki, Finland

ARTICLE INFO

Article history:
Received 15 September 2017
Received in revised form
14 March 2018
Accepted 15 March 2018
Available online xxx

Keywords:
Lake Van
Magnetic properties
Holocene
Tephra
Environmental magnetism
Geochemical

ABSTRACT

Detailed magnetic analysis of the four sediment cores from Lake Van, Eastern Turkey dating back to 9.4 cal ka BP were carried out for discriminating and correlating tephras and laminated sediments in four different cores. Six tephra units (T0, T1, T2, T3, T4 and T5) with distinct magnetic properties were identified in the cores. The tephra units are characterized by ferrimagnetic material, with a grain size in the pseudo single domain (PSD) range. There is no significant correlation between magnetic susceptibility peaks of the different tephra units except for the tephra T1 and T2. On the contrary ARM profiles show significant correlations as remanent magnetization indicators. The tephra units T1 and T2, have a higher magnetic susceptibility and a higher intensity of remanent magnetization, and finer grain size than the other tephra units. The results suggest that there is a clear difference between the magnetic properties of the different tephra units and the lake sediments. Our findings show that also differential deposition of volcanic material including magnetic mineral occurs during the transport with distance from the volcanic source.

1. Introduction

The term "tephra" comes from the ancient Greek word *τέφρα (ash)* which is the pyroclastic solid material ejected into the air by an erupting volcano and then settling down in the surrounding area. It is possible to find tephra up to thousand kilometers from its volcanic source in the case of Plinian eruptions. Tephra units are useful time markers in sedimentary sequences and are useful for stratigraphic correlation over wide regions, once their compositions are matched with the source volcanoes, and ages are ascertained by their chronostratigraphic position, or by Ar/Ar dating. Such a use of tephra in stratigraphy is called tephrochronology. Establishing the tephrochronology of depositional records is important in mapping the geographical extent of a particular volcanic ash fallouts, and studying the impact of volcanic events on natural ecosystems and human communities (Develle et al., 2009; Weiss et al., 1993; Eastwood et al., 1999, 2002; Grattan, 2006; De Klerk et al., 2008; Wulf et al., 2002, 2004; Çağatay et al., 2015).

Volcanic eruptions have always played a crucial role in the evolution of human civilizations and societies in western Anatolia, Mediterranean and Mesopotamia (Grattan, 2006; Issar and Zohar, 2007; Cullen et al., 2000; Weiss et al., 1993; Di Vito et al., 2009 Marinatos, 1939; Friedrich, 2013; Pararas-Carayannis, 1974; Mellaart, 1967). Detailed tephrochronological studies from these areas have provided important information about timing of and source of the eruptions. However, we still have insufficient knowledge of the distribution and effect of the eruptions on major civilization such as Urartu (860–590 BCE), Seljukian (1100–1400 AD), Byzantium (395–1453 AD) and Ottoman (1200–1900 AD) in the Eastern Anatolia.

Identification of tephra units in sediment core sequences and soil profiles and their assignment to their source and time of eruption allows them to be used for correlating and dating of paleoenvironmental events in the region where traditional dating methods cannot be applied because of the lack of suitable datable material and reservoir age problems in the case of the radiocarbon method. Differences in mineralogy, concentration, and grain size of the magnetic particles which control the values of the magnetic

* Corresponding author.
E-mail address: ozlemm@istanbul.edu.tr (Ö. Makaroğlu).

https://doi.org/10.1016/j.quaint.2018.03.012
1040-6182/

parameters can be used to identify and characterize different sedimentary units and their source rocks (Evens and Heller, 2003). In particular, mineral magnetic analyses which include measurements of magnetic concentrations and grain sizes have proven to be very useful in identification and differentiation of different tephra units since such units often have enhanced and different magnetic components compared to their host deposits and to each other. Therefore, it is important to find and characterize ferrimagnetic component of tephra deposits that are successfully used in dating of lacustrine and marine sediments (Brewster and Barnett, 1979; Oldfield et al., 1980, 1983; Robinson, 1986; Robertson, 1993; Lozano-Garcia and Ortega-Guerrero, 1994; Van den Bogaard et al., 1994; Pawse et al., 1998; Gonzalez et al., 1999; Dunsheng et al., 2004; Lagroix et al., 2004; Xia et al., 2007; Vogel et al., 2010).

Terminal lakes with large drainage areas, such as Lake Van in Eastern Turkey, are often characterized by high organic and inorganic carbon accumulation rates and are therefore extremely sensitive to past environmental changes (e.g., Litt et al., 2009; Litt and Anselmetti, 2014). Being located close to several Quaternary volcanic centres such as Nemrut, Suphan and Tendurek (Fig. 1), Lake Van's annually laminated (varved) sedimentary sequence is intercalated with frequent tephra units and hence provides an important archive of volcanic activity and paleoenvironmental reconstructions (Kempe and Degens, 1978; Landmann et al., 1996a, b; Wick et al., 2003; Litt et al., 2009; Sumita and Schmincke, 2013a, b; Stockhecke et al., 2012, 2014; Çağatay et al., 2014). In these studies, the chronology was mainly based on varve counting and tephrochronology. Radiocarbon dating of the lake material was an inadequate method for dating the bulk sedimentary organic carbon in Lake Van sediments because of the reservoir (hard-water) effect, which is variable between 2.5 and 3.3 ka for the last 8 ka (Makaroğlu et al., 2016), and the 50 ka upper limit of the method.

The volcanic source of the tephra units in Lake Van sediments are mainly from the Nemrut and Süphan volcanoes ejecting magma of paralkaline and calc-alkaline affinities, respectively (Landmann et al., 2011; Sumita and Schmincke, 2013a, b; Schmincke et al., 2014).

The first study on tephra units in Lake Van sediments was performed by Kempe (1977). Landmann et al. (1996a), who made the detailed geochemical analysis of 12 tephra units in two cores from the Tatvan Basin and dated them by varve chronology. Later, Landmann et al. (2011) refined the chronology of the Lake Van sediments and the tephra units, studied by Landmann et al. (1996a) and Landmann and Kempe (2005). According to Landmann et al. (2011), over the last 15 kyr, the volcanic activity during the period from 2.6 to 7.2 kyr BP originated from Nemrut Volcano but the source for the tephra units deposited from 11.9 to 12.9 kyr BP remained unidentified. These earlier studies were followed by others covering the late Pleistocene-Holocene period (Litt et al., 2009; Makaroğlu, 2011; Schmincke et al., 2014; Vigliotti et al., 2014; Makaroğlu et al., 2016). Litt et al. (2009) documented the stratigraphy and tephra units in sediment cores from the Ahlat ridge covering the late Glacial-Holocene period. Schmincke et al. (2014) identified six peralkaline rhyolitic tephra units (V1-V6) of Nemrut Volcano origin in the Holocene Lake Van sediments. These units consist predominantly of anorthoclase, hedenbergite, and lesser amounts of augite, Fe-rich olivine and minor quartz and chevkinite. Vigliotti et al. (2014) found that the tephra units and the volcanoclastic material deposited over the last 350 ka showed the highest magnetic concentrations whereas the minimum values occurred in the laminated clayey silt. This difference in the magnetic properties was also the finding of Makaroğlu (2011), which is due to the presence of carbonate laminae in the varved Lake Van sediments with very low magnetic mineral concentrations compared to the tephra units with ferromagnetic minerals (e.g., Baumgarten et al., 2014; Landmann et al., 1996a; Stockhecke et al., 2012; Çağatay et al., 2014). This difference in the magnetic properties can be used to an advantage for detecting the tephra units in lake sediments. Makaroğlu et al. (2016) identified the tephra units previously varve-dated by Landmann et al. (2011) and determined the radiocarbon reservoir age of Lake Van over the last 8.4 ka BP, using the varve dates and radiocarbon ages obtained from total organic carbon.

In this paper, we present the first 9.4 ka-long environmental magnetic record of Lake Van sediments and use it to detect and characterize tephra units in four piston cores recovered from different parts of the lake in 2008 (Fig. 1, Table 1). We analyzed the magnetic properties (magnetic susceptibility, χ_{LF}, χ_{ARM}, and hysteresis values) and μ-XRF elemental composition (K, Zr) of the four piston cores. Two of the cores were previously studied by Makaroğlu et al. (2016) for determination of radiocarbon reservoir ages and discussion of the causal variation of the results, based on ^{14}C, elemental and isotope analyses of total organic matter. The objectives of this study are to characterize the magnetic properties of the tephra units deposited in different parts of Lake Van over the last 9.4 ka and relate the properties to the distance from the main volcanic source.

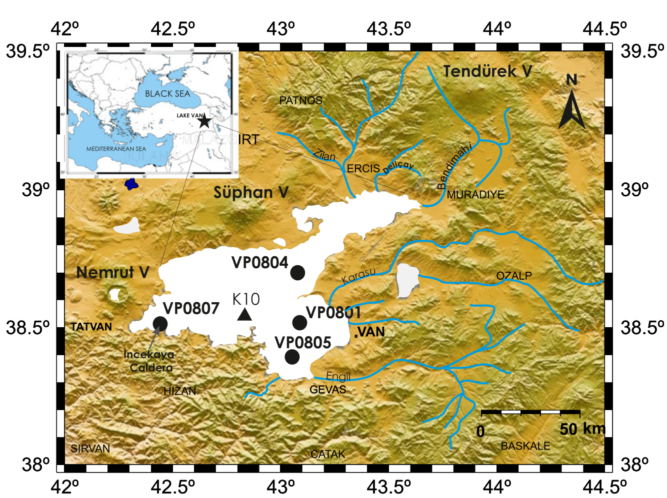

Fig. 1. Location of studied core sites VP0801, VP0804, VP0805 and VP0807 (black circles), core locations of Landmann et al. (2011) (triangle). The inset map shows location of Lake Van in eastern Turkey.

2. Regional setting

Lake Van which is located on the East Anatolian Plateau in eastern Turkey is the fourth largest soda Lake in the world and the largest lake in Turkey (Fig. 1). Lake waters have a salinity of 21.4‰ and a pH of 9.81 (Landmann et al., 1996a; Kempe et al., 2002; Reimer et al., 2009). The lake basin formed 600 ka ago, when the outflow to the Muş Basin was blocked by the growth of Nemrut Volcano (Yılmaz et al., 1998; Çukur et al., 2014; Litt et al., 2014). The lake is surrounded by Quaternary volcanoes (Nemrut, Süphan, Tendürek, etc) that appear to have been localized on north–south tensional openings formed under the north–south shortening deformation (Yılmaz et al., 1998). The volcanoes across eastern Anatolia are related to the tectonic collision (Keskin, 2007), and post-collisional volcanism at 8–6 Ma (Sumita and Schmincke, 2013a). The Nemrut volcanic center is located close to the western end of Lake Van (Fig. 1). It is the only volcano of Anatolia, which produced a historically recorded explosive eruption in 1441 CE (Oswalt, 1912). Nemrut volcano produces alkaline magma characterized by large ionic lithophile and high filed strength elements