Quaternary Science Reviews xxx (2014) 1–10

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Noble gases in the sediments of Lake Van – solute transport and palaeoenvironmental reconstruction

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ARTICLE INFO

Article history:
Received 20 August 2013
Received in revised form
3 September 2014
Accepted 5 September 2014
Available online xxx

Keywords:
ICDP
PaleoVan
Deep drilling
Terrestrial He emission
Palaeosalinity

ABSTRACT

Sediment samples acquired in 2010 from the long cores of the International Continental Scientific Drilling Program (ICDP) PaleoVan drilling project on Lake Van for noble-gas analysis in the pore water allow determination of the local terrestrial He-gradient as a function of depth within a sediment column of more than 200 m. These measurements yield first insights into the physical transport mechanisms of terrigenic He through the uppermost part of unconsolidated lacustrine sediments overlying the continental crust.

In line with our previous work on the spatial distribution of the terrigenic He release into Lake Van, we identify a high He concentration gradient in the uppermost 10 m of the sediment column. The He concentration gradient decreases below this depth down to approx. 160 m following in general the expectations of the modelling of radiogenic He production and transport in a sediment column with homogeneous fluid transport properties. Overall the in-situ radiogenic He production due to the decay of U and Th in the mineral phases of the sediments accounts for about 80% of the He accumulation. At approx. 190 m we observe a very high He concentration immediately below a large lithological unit characterised by strong deformations. We speculate that this local enrichment is the result of the lower effective diffusivities in the pore space that relate to the abrupt depositional history of this deformed unit. This particular lithological unit seems to act as a barrier that limits the transport of solutes in the pore space and hence might "trap" information on the past geochemical conditions in the pore water of Lake Van.

The dissolved concentrations of atmospheric noble gases in the pore waters of the ICDP PaleoVan cores are used to geochemically reconstruct salinity on the time scale of 0–55 ka BP. Higher salinities in the pore water at a depth of about 20 m suggest a significantly lower lake level of Lake Van in the past.

1. Introduction

In the last few decades, noble gases in aquatic systems have become a well-established geochemical tool for investigating physical transport and exchange processes in lakes, oceans, and ground waters and for reconstructing past climate conditions (for reviews see Kipfer et al., 2002; Schlosser and Winckler, 2002; Aeschbach-Hertig and Solomon, 2013; Brennwald et al., 2013; Stanley and Jenkins, 2013).

The varved sediments of Lake Van have been identified as an important palaeoclimate archive, storing information on the past environmental conditions prevailing in eastern Anatolia. Therefore, the sediments of Lake Van have been targeted by a deep-drilling project of the International Continental Scientific Drilling Program (ICDP, www.icdp-online.org) to reconstruct the glacial and interglacial cycles during the last 600 ka (Litt et al., 2009, 2011, 2014; Baumgarten et al., 2014; Çağatay et al., 2014; Cukur et al., 2014a, 2014b; Kwiecien et al., 2014; Litt and Anselmetti, 2014; Randlett et al., 2014; Stockhecke et al., 2014a, 2014b; Vigliotti et al., 2014). In 2010 the ICDP drilling project PaleoVan recovered sediment cores of up to 220 m in length with the aim of studying this unique high-resolution sedimentological archive not only in terms of palaeoclimatic reconstruction, but also to constrain

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http://dx.doi.org/10.1016/j.quascirev.2014.09.005
0277-3791/

terrigenic fluid transport processes in the deep sediment column using noble gases (Litt et al., 2009, 2012), as Lake Van is known to accumulate terrigenic He enriched in ^{3}He from a mantle source (e.g., Kipfer et al., 1994).

In this work we present He, Ne, Ar, Kr, and Xe concentrations as well as the ^{3}He/^{4}He, ^{20}Ne/^{22}Ne, and ^{36}Ar/^{40}Ar isotope ratios measured in sediment pore water samples of Lake Van acquired during the drilling operations of the ICDP PaleoVan project at Ahlat Ridge (Fig. 1; Litt et al., 2009, 2011, 2012). Our previous research on the mixing dynamics and on the He emanation in Lake Van (Kipfer et al., 1994; Kaden et al., 2010; Tomonaga et al., 2011a), as well as the newly parameterised noble-gas solubility equations for its alkaline water (Tomonaga et al., 2012), set the basis for our evaluations. He concentrations are discussed in terms of fluid transport properties of the sediment column and terrigenic He emission from the solid earth. Atmospheric noble gases are interpreted, whenever possible, in terms of past environmental and hydrochemical conditions in Lake Van.

1.1. He and the fluid transport in the pore space

Terrigenic He is known to emanate from the solid earth into the atmosphere (see e.g., O'Nions and Oxburgh, 1983; Mamyrin and Tolstikhin, 1984; Ballentine et al., 2002). Pore waters of unconsolidated sediments in lakes and in the oceans represent an ideal geochemical environment for assessing the local He emission, thus allowing fluid transport in the uppermost part of the Earth's crust to be studied (Chaduteau et al., 2009; Lan et al., 2010; Tomonaga et al., 2011a, 2013). The transport of He within the sediment column can be described by advection and diffusion, where He migrates through the connected pore space of an unconsolidated sediment column (e.g., Berner, 1975; Imboden, 1975; Strassmann et al., 2005). In contrast to the open water body, the pore water in lacustrine and oceanic sediments records the spatial variability of the He emission. The pore waters of unconsolidated sediments are therefore a suitable system to analyse the rates and the spatial variability of He transport and release (Brennwald et al., 2013).

By analysing the pore water in the uppermost 2 m of the sediments of Lake Van, Tomonaga et al. (2011a) determined a terrigenic ^{3}He/^{4}He isotope ratio range of $(2.5–4.1)\cdot 10^{-6}$ suggesting that the He entering the lake is a mixture of mantle He and radiogenic He being produced in the sediment column or in the rock basement. The study also mapped the spatial distribution of the He emission at the sediment–water interface of Lake Van and identified three distinct He concentration gradients being associated with three characteristic He fluxes (Fig. 1, for details see Tomonaga et al., 2011a): low flux ("L" cores: $(0.4–0.8)\cdot 10^{8}$ atoms/m^{2}/s), high flux ("H" cores: $(2–5)\cdot 10^{8}$ atoms/m^{2}/s), and "hot spot" flux ("S" cores: $(18–42)\cdot 10^{8}$ atoms/m^{2}/s). The highest fluxes have been identified not in the centre, but at the steep borders of the main deep basin of Lake Van (the Tatvan basin, see Fig. 1).

1.2. Atmospheric noble gases to reconstruct past environmental conditions

The equilibrium partitioning of noble gases between air and water can be approximated reasonably by Henry's Law (Ozima and Podosek, 1983; Kipfer et al., 2002; Brennwald et al., 2013). As the Henry coefficients depend mainly on the temperature and on the salinity of the water mass involved in the gas exchange, the

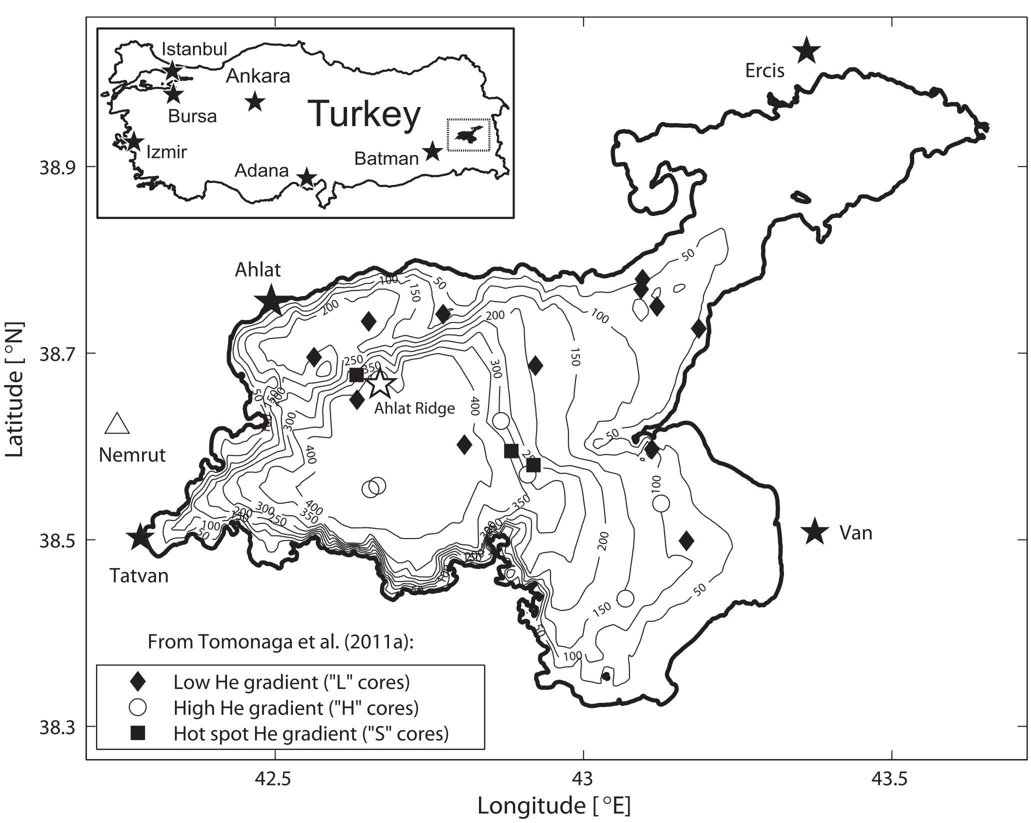

Fig. 1. Location of Lake Van (Turkey) and the main ICDP PaleoVan drill site at Ahlat Ridge (empty star) together with the position of low ("L" cores, black diamonds), high ("H" cores, empty circles), and hot spot ("S" cores, black squares) He concentration gradients determined in the pore water of short sediment cores (Tomonaga et al., 2011a). Major cities are represented by black stars. The triangle indicates the position of the Nemrut volcano (the most active volcano in the study area).

Please cite this article in press as: Tomonaga, Y., et al., Noble gases in the sediments of Lake Van — solute transport and palaeoenvironmental reconstruction, Quaternary Science Reviews (2014), http://dx.doi.org/10.1016/j.quascirev.2014.09.005