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Seismic evidence of shallow gas from Lake Van, eastern Turkey

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ABSTRACT

Analysis of multi-channel seismic reflection and chirp data from Lake Van (eastern Turkey) reveals various shallow gas indicators including seismic chimneys, enhanced reflections, bright spots, mud volcanoes, pockmarks, and acoustic blanking. The enhanced reflections, suggesting the presence of free gas, are most dominant and observed at more than 200 locations. They are characterized by very-high amplitude reflections and occur in both deep and shallow sedimentary sections. Some enhanced reflections are accompanied by very subtle seafloor expressions such as mounds, which may suggest active venting activity. Seismic chimneys or columnar zones of amplitude blanking have been observed in much of the surveyed area. Seismic chimneys in the study area cannot be associated with any known faults that would act as migration pathways for deep fluids. This suggests that the observed structures in Lake Van sediments allow the preferential emission of gases which might be for a large share of biogenic origin. The acoustic blanking, characterized by transparent or chaotic seismic facies, is seen in the eastern part of the lake. The lakeward edge of the acoustic blanking largely coincides with the 100 m water depth contour, indicating that (past) changes of the hydrostatic pressure may be responsible for the distribution of these anomalies. Mound-like features, interpreted as mud volcanoes, occur in a few locations. The presence of these features may suggest active gas emission. Very strong amplitude anomalies or bright spots with negative polarity, indicating gas-charged zones, are also seen in a number of locations. Pockmarks are observed only in the northeastern part of the study area. The scarce occurrence of pockmarks in the study area might be ascribed to a higher permeability of the lake sediments or to the absence of the substrate/reservoir providing the critical mass of gases necessary to produce such features. Turbidites, tephra layers, and deltaic deposits have the potential to provide ideal conditions to allow the sediments to act as a gas reservoir.

1. Introduction

Shallow gas has been a major topic to the geoscientists for many years (Kvenvolden et al., 1981; Schroot and Schuttenhelm, 2003). The gas can pose a great hazard when drilling a borehole, as it can lead to blow-outs under over pressure conditions. The presence of shallow gas, when abundant, can also be a valuable source for the petroleum industry. In light of the globally increased demand for energy, petroleum scientists started to explore and exploit shallow gas accumulations in the world (Judd and Curzi, 2002). Shallow gas is easily accessible, significantly widespread, and underexploited, and, thus, can be an important energy resource for the future.

The evidence of shallow gas has been documented worldwide, both from marine and coastal environments (Hovland and Judd, 1988; Alavi et al., 1989; Judd and Hovland, 1992; Okyar and Ediger, 1999; Fleischer et al., 2001; Ergün et al., 2002; Garcia-Gil et al., 2002; Gay et al., 2007; Naudts et al., 2009; Dondurur et al., 2011). Seismic reflection methods have proven to be particularly useful for the identification, characterization, and mapping of the distribution of gas accumulations and seepage. The origin of shallow gas is attributed either to low-temperature biogenic production (bacterial activity) or thermogenic/abiogenic production (being essentially

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temperature and pressure dependent; Davis, 1992). In both cases the gas is derived from organic material (Davis, 1992).

Lake Van (Turkey) is the fourth largest terminal lake and the largest soda lake on Earth (Wong and Degens, 1978) (Fig. 1). The morphology and the sedimentary processes in Lake Van have been documented by seismic profiles (Cukur et al., 2013). However, the distribution and occurrences of seismic indicators of shallow gas in the lake have not been reported. This paper, for the first time, describes and maps seismic anomalies associated with shallow gas using multi-channel seismic reflection and chirp profiles from Lake Van (Fig. 2). We discuss the origin of gases and their relationship with tectonic, sedimentary processes and possible past lake level fluctuations. The study area consists of three basins, namely the Northern, Tatvan, and Deveboynu basins. These basins contain up to 400 m thick of sediments, composed mainly of lacustrine deposits interbedded with volcaniclastic and mass-transport deposits.

2. Regional settings

Lake Van (43.0°E and 38.5°N) is located in the eastern Anatolia (Fig. 1), Turkey, at an altitude of 1648 m a.s.l. (meters above the sea level). With a maximum water depth of about 450 m, Lake Van is the deepest and largest lake in Turkey and is the fourth largest terminal lake in the world (576 km^3). The lake measures 130 km WSW-ENE and has a surface area of 3522 km^2.

The drainage basin covers about 16,000 km^2 (Kempe et al., 1978) and encompasses the eastern part of the Mus basin, while the southern shore is formed by the Bitlis massif towering more than 3500 m a.s.l. (Fig. 1). The Bitlis massif consists of metamorphic rocks of Paleozoic age. The northern and western regions of the lake are almost completely covered by volcanics of Pliocene to Quaternary age erupted from the stratovolcanoes Nemrut (3050 m a.s.l.) and Süphan (4434 m a.s.l.).

The cause and timing of the formation of Lake Van is still source of scientific debate. Previously, it was suggested that a lava flow from Nemrut volcano built a dam across the Mus basin, cutting off the drainage to the ancient Murat river (Degens et al., 1984). Also the hypothesis that the circular shape of the deep Tatvan basin might reflect a caldera-like structure has been formulated (Litt et al., 2009; Tomonaga et al., 2011). More recently, Sumita et al. (2012), instead, speculated that thick ignimbrites underlying the high plateau south of Tatvan and the Mus basin and a debris avalanche from Kirkor dome cut off the outlet of an ancient river. Kuzucuoğlu et al. (2010) suggested a former outlet of Lake Van was dammed by an ignimbrite ca. 100–130 ka ago. However, preliminary evidence from recent drill core records clearly shows that lake alkalinity and thus isolation of the lake must have developed long more than 550 ka ago (Litt et al., 2011, 2012). Following the formation of Lake Van as an endorheic water body, subsidence and extension further helped to form a large internal drainage basin (Cukur et al., 2013; Degens et al., 1984).

Lake Van is known to accumulate mantle fluids (Kipfer et al., 1994; Kaden et al., 2010). Tomonaga et al. (2011) mapped the spatial distribution of the emission of terrigenic He from the sediment column into the water body of Lake Van. The study showed that the highest He fluxes ("hot spots") are located at the steep borders of the Tatvan subbasin, which is an area of possible release of other fluids as well. The typical He isotope composition found in the pore water indicates that the terrigenic He in Lake Van is a mixture of two components: He of mantle origin (i.e., from the deep lithosphere) and radiogenic He (most likely produced in the sediment column or in the underlying basement). Hence, the accumulation of biogenic gases in Lake Van is likely to be accompanied

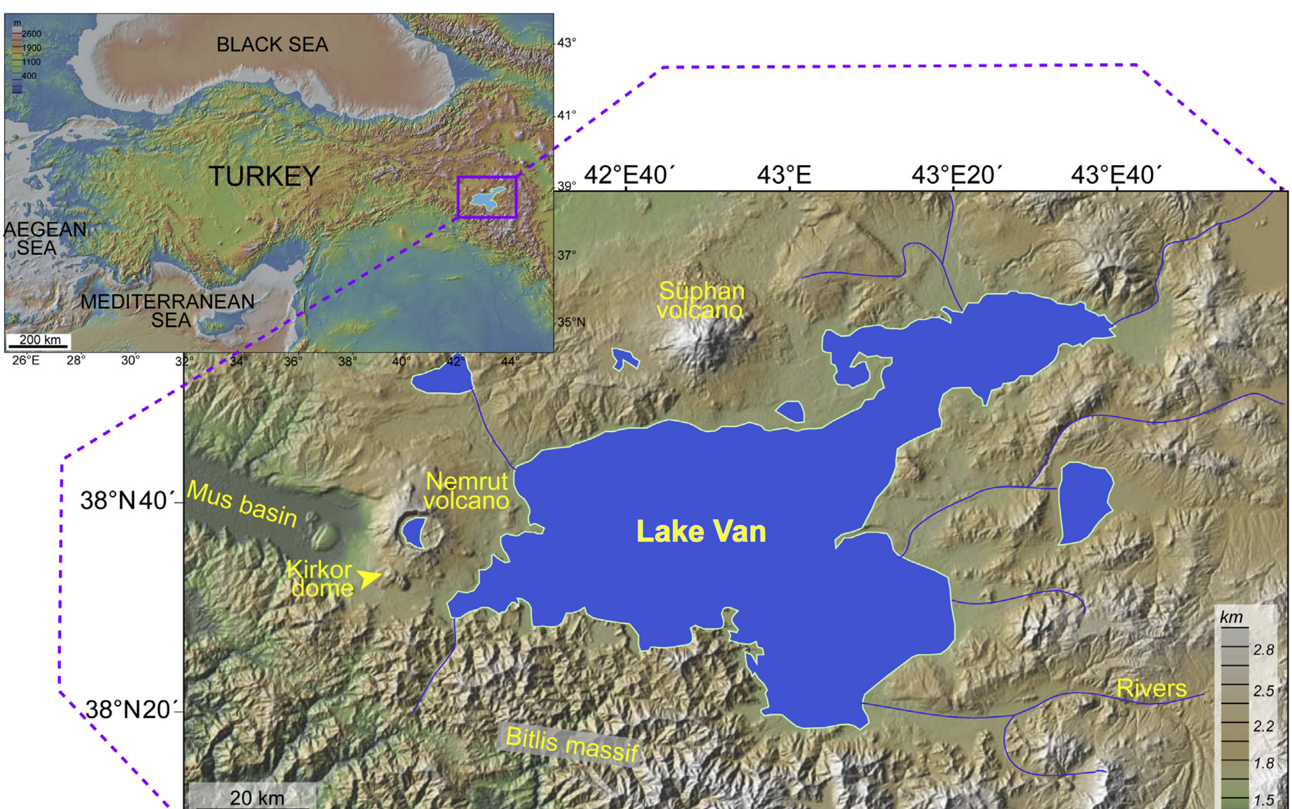

Figure 1. Map showing Lake Van and vicinity including major tectonic and structural elements.