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Potential impact of the 74 ka Toba eruption on the Balkan region, SE Europe

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Abstract

The 74 ka Toba eruption in Sumatra, Indonesia, is considered to be one of the largest volcanic events during the Quaternary. Tephra from the Toba eruption has been found in many terrestrial and marine sedimentary deposits, and acidity peaks related to the eruption have been used to synchronize ice core records from Greenland and Antarctica. Seismic profiles from Lake Prespa on the Balkan Peninsula, SE Europe, indicate a lake level lowstand, which is confirmed by the occurrence of an exceptional bivalve shell layer of *Dreissena* sp. in the sediment record, the isotope composition of the shells, as well as pollen data. ESR dating and extrapolation of the tephra and radiocarbon chronologies indicate that this lowstand occurred at 73.6 ± 7.7 ka. Our data, showing a short term shift to aridity superimposed on the general cooling trend at the end of MIS 5 and coupled with the chronological correspondence to the Toba eruption imply a distinct impact of the Toba eruption on environmental conditions in the northern Mediterranean region. The recovery from this dramatic environmental condition, in turn, may have triggered spatial expansion events in one of the lake's most abundant benthic species, the carino mussel *Dreissena presbensis*.

1 Introduction

The Toba Caldera Complex in Northern Sumatra, Indonesia, formed due to number of volcanic eruptions, of which the most recent one at 74 ka is considered to be one of the largest volcanic eruptions on Earth during the Quaternary (Chesner, 2012). The tephra products from this eruption can be found in many records from the Arabian Sea in the west to the South China Sea in the east (e.g. Williams, 2012a and references therein). Though 73 and 74 ka can be found in the literature, the most precise dating of the Toba eruption is using Ar/Ar of the tephra found in Malaysia and indicates an age of 73.88 ± 0.3 (Storey et al., 2012). The impact of the Toba eruption on regional climatic and hydrologic conditions, and on regional human dispersal and activity are relatively well known (e.g. Blinkhorn et al., 2012; Jones, 2012; Petraglia et al., 2012). Some authors suggest that the Toba eruption was followed by a volcanic winter, i.e. a decade or two of drastic cooling (compiled in Williams, 2012a, b). On a regional scale, this could have affected plant and animal as well as human populations (e.g. Jones, 2012; Louys, 2012). The global impact of the Toba eruption is more under debate (Williams, 2012b). Acidity peaks occurring at the transition from Greenland Interstadial 20 (GI-20) into Greenland Stadial 20 (GS-20) in the NGRIP ice core record from Greenland and during a prominent isotope minima between Antarctic Isotope Maxima (AIM) 20 and 19 in the EDML and EDC ice core records from Antarctica are correlated with the Toba eruption (Svensson et al., 2013). However, Svensson et al. (2013) point out that it is difficult to explain sustained cold temperatures over more than a millennium as a result of the Toba event. Climate models suggest both a strong and long lasting cooling and devastating impacts on both ecosystems and humans (e.g. Ambrose, 1998; Robock et al., 2009), while others suggest the contrary, with only moderate changes in temperature in S and E Africa and in the Indian subcontinent, but with significant precipitation anomalies (Timmreck et al., 2012). The potential global climate impact of the Toba eruption could have also affected the dispersal of modern humans from Africa to Europe (Oppenheimer, 2012; Petraglia et al., 2012).

More records from distal sites would help to better understand the environmental impact of the Toba eruption on a global scale. Here, we provide seismic and sedimentological data from Lake Prespa, which is situated in SE Europe between Albania, Macedonia and Greece and located on the pathway of human dispersal from Africa to Europe (Oppenheimer, 2012). Data for the last 92 ka indicate that the sedimentary record is very sensitive to environmental change, which is partly due to a relatively low volume (3.6 km^3), a large surface area (254 km^2), and a mean water depth of only ca. 14 m (Wilke et al., 2010; Damaschke et al., 2012; Wagner et al., 2012; Leng et al., 2013). However, none of the published studies have considered the possible impact of the 74 ka Toba eruption.

2 Dataset and discussion

Most of the seismic and sedimentological data presented here from Lake Prespa have been previously published (Wagner et al., 2010, 2012; Leng et al., 2013). Radiocarbon dates, tephrostratigraphy, ESR dating and cross correlation with the NGRIP ice core indicate that the sediment core Co1215 spans the last ca. 92 ka (Damaschke et al., 2012; Fig. 2). Total inorganic carbon (TIC) and total organic carbon (TOC) from the sediments show both Glacial/Interglacial periods, as well as short-term climate events, including Heinrich and the 8.2 ka events (e.g. Wagner et al., 2010, 2012; Aufgebauer et al., 2012; Fig. 2). The stable isotope data also show both long-term and short-term changes in the lakes hydrology (Leng et al., 2013).

The most exceptional lithological horizon in the core is a horizon between 14.63–14.58 m depth, where shells and shell fragments of the carino mussel (probably *Dreissena presbensis*) occur (Fig. 1). Most likely this horizon represents a distinct lake level lowstand when near-shore habitats of *D. presbensis* became subaerial and eroded, leading to the redistribution of shell fragments into the deeper parts of the lake. A lake level lowstand is also indicated by an undulated reflector in the seismic data (see Wagner et al., 2012, Fig. 1) and by high δ^{18}O from the shell fragments (see Leng et al., 2013, Fig. 2). A concurrent maximum of non-arboreal pollen percentages suggests dry conditions at the catchment. A conspicuous Poaceae peak (Fig. 2), which includes *Phragmites* sp. pollen grains, points to an expansion of the littoral zone and a decrease in the distance from the coring location. This is supported by a peak in the TOC/N ratio indicating higher allochthonous organic input. These data are very different from other abrupt events seen throughout the core (Fig. 2). It is likely that this lowstand also affected the lake level of neighbouring Lake Ohrid, which is partly fed by Lake Prespa via karst aquifers (Matzinger et al., 2006b). There is evidence for significant lake level lowering at the end of Marine Isotope Stage (MIS) 5 as indicated by subaquatic terrace at ca. 30 m water depth (Lindhorst et al., 2010). In core Co1202 from the northern part of Lake Ohrid (Fig. 1), a hiatus was thought to span the period ca. 98–82 ka (Vogel et al., 2010). However, the exact timing of this hiatus is weakly constrained and it could have been generated much later by a significant lake level lowstand due to less water input from Lake Prespa. The lake level lowering could then have led to destabilisation of the slopes and a mass wasting event.

The ESR dates of the *Dreissena* shells and shell fragments in the Lake Prespa core provide a mean age for the deposition of the shell horizon and the reconstructed lake level lowstand of 73.6 ± 7.7 ka (Damaschke et al., 2012). Despite a relatively large uncertainty on this age, the mean age is supported by tephrostratigraphic markers above the shell horizon and by chronological tie points below and above the shell horizon (Damaschke et al., 2012). The chronological tie points were obtained by cross correlation of mainly TOC, which is known to be a very sensitive proxy of climatic changes in the Lake Prespa sediments (Wagner et al., 2010), with the NGRIP ice core record. Moreover, extrapolation of tephrostratigraphic ages and radiocarbon ages as well as the lithology of the core imply that there is no significant change in sedimentation conditions above and below the shell horizon. We can exclude that the lake level lowstand is related to a long-term change from interglacial to glacial conditions at the MIS 5 to MIS 4 boundary. We can also exclude that the lowstand is triggered by a short-term change correlated with a Heinrich event (cf. Wagner et al., 2010), as potential Heinrich events around 74 ka are not reported. Moreover, the more pronounced Heinrich events, which occurred later between MIS 4 and 2 and which are characterized by distinct peaks in TIC (siderite), have unusual δ^{13}C values related to their mode of formation (Fig. 2) and are not seen in the seismic data. Other short-lived aridity events, such as the 8.2 ka event, are also not known to have occurred around 74 ka from the region.

3 Interpretation and conclusions

Overall, we conclude that the lake level lowstand in Lake Prespa (and potentially Lake Ohrid) was probably triggered by an extraordinary event, which was too short lived to be clearly visible in the pollen data, particularly given the relatively low resolution of this dataset. Though tectonic activity in the Balkan region is common (e.g. Reicherter et al., 2011) and could have affected the karst aquifer system connecting lakes Prespa and Ohrid, a significant tectonic event at the end of MIS 5 has not been described thus far. Lake Prespa is mainly fed today by river runoff from numerous small streams (56 %) and by direct precipitation (35 %; Matzinger et al., 2006a), which peaks in winter when snowfalls are frequent (Hollis and Stevenson, 1997). We cannot completely exclude that the lake level lowstand in Lake Prespa was due to a period of higher aridity related to the cooling at the transition from GI-20 to GS-20 or to a Heinrich event. However, there is a remarkable correlation between the age of a lake level lowstand (73.6±7.7 ka based on ESR dating) and the Toba eruption (73.9 ± 0.3 ka). This leads us to the assumption that the severity of the lake level lowstand and its short-lived character at Lake Prespa may be an expression of a volcanically triggered aridity event superimposed on the overall cooling trend between GI-20 and GS-20. Tephra particles from the Toba eruption have not so far been found in Lake Prespa (or Ohrid). Hence, the lake level lowstand can only be correlated to the Toba eruption by a significant change in climate conditions with reduced precipitation in SE Europe. A potential recovery from the 74 ka old Prespa lake level lowstand and/or with the end of a potential volcanic winter is probably correlated with an important spatial expansion event of *D. presbensis* from Lake Prespa to neighbouring water bodies. According to independent mitochondrial DNA data, this event took place about 72 ka ago, however, the confidence interval for this estimate is very high (95 % CI: 0–153 ka; Wilke et al., 2010).

As water loss from Lake Prespa is mainly through evaporation (52 %) and outflow through karst aquifers (46 %) into the larger Lake Ohrid located 150 m below and ca. 10 km to the west (Fig. 1), the hydrologic changes at Lake Prespa likely led to a significantly reduced water input in Lake Ohrid. This could have triggered mass movement events in Lake Ohrid, which are supported by the steep slopes in this lake. A lake level lowstand around 74 ka in Lake Prespa could have led to the formation of the terrace at ca. 30 m water depth as it is described by Lindhorst et al. (2010) and it could also have led to the hiatus between ca. 98–82 ka in core Co1202 (Vogel et al., 2010) as described before assuming slightly different sedimentation rates.

As the lake level lowstand in Lake Prespa (and Ohrid?) apparently is close in age to the 74 ka Toba eruption, there is a potential correlation between the eruption and the regional climate on the Balkans. If there was a so-called volcanic winter, it could have been correlated with drier conditions in the lake catchment. We did not find independent evidence for a correlation of the lake level lowstand with the Toba eruption, i.e. glass shards of calc-alkaline composition, but the eruption of the Tambora volcano in Indonesia in 1815 AD has demonstrated the impact of volcanic eruptions from the equator belt to the climate of the Northern Hemisphere (i.e. being responsible of the world-famous "year without summer"; e.g., Oppenheimer, 2003).

Several records from the northern Mediterranean region show cold and dry conditions, which are probably related to the GS-20 (e.g., Tzedakis et al., 2004; Brauer et al., 2007), but chronological uncertainties hamper the correlation between the individual records and a potential link to the Toba eruption. Moreover, these records do not indicate the exceptionality as it is expressed in the Prespa record for the period discussed. Our evidence from Lake Prespa is therefore key to contributing to the ongoing discussion related to the possible global impact of the Toba eruption (Williams, 2012b).

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References

Ambrose, S. H.: Late Pleistocene human population bottlenecks, volcanic winter, and differentiation of modern humans, J. Human Evol., 34, 623–651, 1998.

Aufgebauer, A., Panagiotopoulos, K., Wagner, B., Schäbitz, F., Viehberg, F. A., Vogel, H., Zanchetta, G., Sulpizio, R., Leng, M., and Damaschke, M.: Climate and environmental change in the Balkans over the last 17 ka recorded in sediments from Lake Prespa (Albania/ F. Y. R. of Macedonia/Greece), Quaternary Int., 274, 122–135, 2012.

Blinkhorn, J., Parker, A. G., Ditchfield, P., Haslam, M., and Petraglia, M.: Uncovering a landscape buried by the super-eruption of Toba, 74 000 years ago: a multi-proxy environmental reconstruction of landscape heterogeneity in the Jurreru Valley, south India, Quaternary Int., 258, 135–147, 2012.

Brauer, A., Allen, J. R. M., Mingram, J., Dulski, P., Wulf, S., and Huntley, B.: Evidence for last interglacial chronology and environmental change from Southern Europe, P. Natl. Acad. Sci. USA, 104, 450–455, 2007.

Chesner, C. A.: The Toba Caldera complex, Quaternary Int., 258, 5–18, 2012.

Damaschke, M., Sulpizio, R., Zanchetta, G., Wagner, B., Böhm, A., Nowaczyk, N., Rethemeyer, J., and Hilgers, A.: Tephrostratigraphic studies on a sediment core from Lake Prespa in the Balkans, Clim. Past, 9, 267–287, doi:10.5194/cp-9-267-2013, 2013.

Dumurdzanov, N., Serafimovski, T., and Burchfiel, B. C.: Cenozoic tectonics of Macedonia and its relation to the South Balkan extensional regime, Geosphere, 1, 1–22, 2005.

Flückiger, J., Blunier, T., Stauffer, B., Chappellaz, J., Spahni, R., Kawamura, K., Schwander, J., Stocker, T. F., and Dahl-Jensen, D.: N_2O and CH_4 variations during the last glacial epoch: insight into global processes, Global Biogeochem. Process., 18, 1–14, 2004.

Hollis, G. E. and Stevenson, A. C.: The physical basis of the Lake Mikri Prespa systems: geology, climate, hydrology and water quality, Hydrobiologia, 351, 1–19, 1997.

Jones, S. C.: Local- and regional-scale impacts of the ~ 74 ka Toba supervolcanic eruption on hominin populations and habitats in India, Quaternary Int., 258, 100–118, 2012.

Leng, M. J., Wagner, B., Böhm, A., Panagiotopoulos, K., Vane, C. H., Snelling, A., Haidon, C., Woodley, E., Vogel, H., Zanchetta, G., and Baneschi, I.: Understanding past climatic and hydrological variability in the Mediterranean from Lake Prespa sediment isotope and geochemical record over the Last Glacial cycle, Quaternary Sci. Rev., 66, 123–136, 2013.

Lindhorst, K., Vogel, H., Krastel, S., Wagner, B., Hilgers, A., Zander, A., Schwenk, T., Wessels, M., and Daut, G.: Stratigraphic analysis of lake level fluctuations in Lake Ohrid: an integration of high resolution hydro-acoustic data and sediment cores, Biogeosciences, 7, 3531–3548, doi:10.5194/bg-7-3531-2010, 2010.

Louys, J.: Mammal community structure of Sundanese fossil assemblages from the Late Pleistocene, and a discussion on the ecological effects of the Toba eruption, Quaternary Int., 258, 80–87, 2012.

Matzinger, A., Jordanoski, M., Veljanoska-Sarafiloska, E., Sturm, M., Müller, B., and Wüest, A.: Is Lake Prespa jeopardizing the ecosystem of ancient Lake Ohrid?, Hydrobiologica, 553, 89–109, 2006a.

Matzinger, A., Spirkovski, Z., Patceva, S., and Wüest, A.: Sensitivity of ancient Lake Ohrid to local anthropogenic impacts and global warming, J. Great Lakes Res., 32, 158–179, 2006b.

Oppenheimer, C.: Climatic, environmental and human consequences of the largest known eruption: Tambora volcano (Indonesia) 1815, Prog. Phys. Geogr., 27, 230–259, 2003.

Oppenheimer, S.: A single southern exit of modern humans from Africa: Before or after Toba?, Quaternary Int., 258, 88–99, 2012.

Panagiotopoulos, K., Aufgebauer, A., Schäbitz, F., and Wagner, B.: Vegetation and climate history of the Lake Prespa region since the Lateglacial, Quaternary Int., 293, 157–169, 2013.

Petraglia, M. D., Ditchfield, P., Jones, S., Korisettar, R., and Pal, J. N.: The Toba volcanic super-eruption, environmental change, and hominin occupation history in India over the last 140 000 years, Quaternary Int., 258, 119–134, 2012.

Reicherter, K., Hoffmann, N., Lindhorst, K., Krastel, S., Fernandez-Steeger, T., Grützner, C., and Wiatr, T.: Active Basins and Neotectonics: Morphotectonics of the Lake Ohrid Basin (FYROM and Albania), Z. Dtsch. Ges. Geowiss., 162, 217–234, 2011.

Robock, A., Ammann, C. M., Oman, L., Shindell, D., Levis, S., and Stenchikov, G.: Did the Toba volcanic eruption of ~74 ka B. P. produce widespread glaciation?, J. Geophys. Res. 114, D10107, doi:10.1029/2008JD011652, 2009.

Storey, M., Roberts, R. G., and Saidin, M.: An astronomically calibrated 40 Ar/39 Ar age for the Toba super-eruption and global synchronisation of late Quaternary records, P. Natl. Acad. Sci. USA, 109, 18684–18688, 2012.

Svensson, A., Bigler, M., Blunier, T., Clausen, H. B., Dahl-Jensen, D., Fischer, H., Fujita, S., Goto-Azuma, K., Johnsen, S. J., Kawamura, K., Kipfstuhl, S., Kohno, M., Parrenin, F., Popp, T., Rasmussen, S. O., Schwander, J., Seierstad, I., Severi, M., Steffensen, J. P., Udisti, R., Uemura, R., Vallelonga, P., Vinther, B. M., Wegner, A., Wilhelms, F., and Winstrup, M.: Direct linking of Greenland and Antarctic ice cores at the Toba eruption (74 ka BP), Clim. Past, 9, 749–766, doi:10.5194/cp-9-749-2013, 2013.

Tzedakis, P. C., Frogley, M. R., Lawson, I. T., Preece, R. C., Cacho, I., and de Abreu, L.: Ecological thresholds and patterns of millennial-scale climate variability: the response of vegetation in Greece during the last glacial period, Geology, 32, 109–112, 2004.

Vogel, H., Wagner, B., Zanchetta, G., Sulpizio, R., and Rosén, P.: A paleoclimate record with tephrochronological age control for the last glacial-interglacial cycle from Lake Ohrid, Albania and Macedonia, J. Paleolimnol., 44, 295–310, 2010.

Wagner, B., Vogel, H., Zanchetta, G., and Sulpizio, R.: Environmental change within the Balkan region during the past ca. 50 ka recorded in the sediments from lakes Prespa and Ohrid, Biogeosciences, 7, 3187–3198, doi:10.5194/bg-7-3187-2010, 2010.

Wagner, B., Aufgebauer, A., Vogel, H., Zanchetta, G., Sulpizio, R., and Damaschke, M.: Late Pleistocene and Holocene contourite drift in Lake Prespa (Albania/ F. Y. R. of Macedonia/Greece), Quaternary Int., 274, 112–121, 2012.

Wilke, T., Schultheiß, R., Albrecht, C., Bornmann, N., Trajanovski, S., and Kevrekidis, T.: Native *Dreissena* freshwater mussels in the Balkans: in and out of ancient lakes, Biogeosciences, 7, 3051–3065, doi:10.5194/bg-7-3051-2010, 2010.

Williams, M.: The similar to 73 kyr Toba super-eruption and its impact: history of a debate, Quaternary Int., 258, 19–29, 2012a.

Williams, M.: Did the 73 ka Toba super-eruption have an enduring effect? Insights from genetics, prehistoric archaeology, pollen analysis, stable isotope geochemistry, geomorphology, ice cores, and climate models, Quaternary Int., 269, 87–93, 2012b.

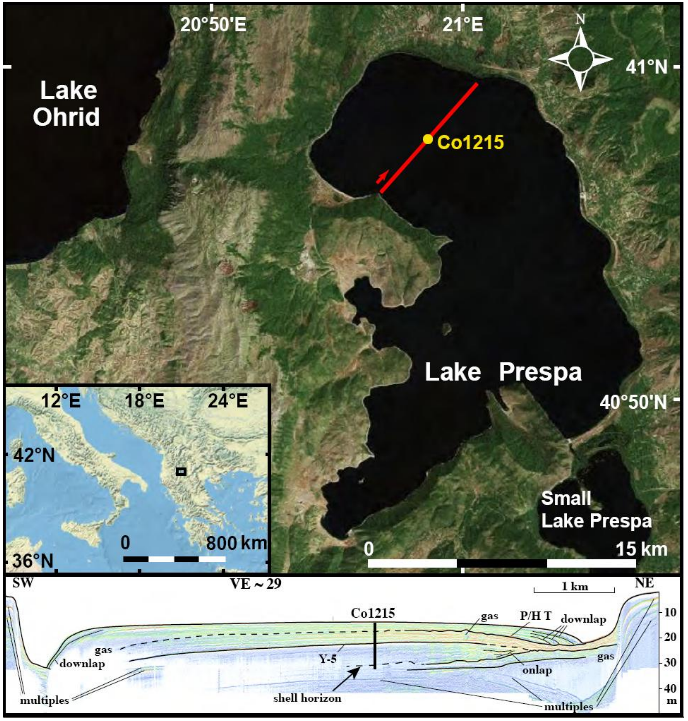

Fig. 1. Map showing the location of Lake Prespa (and Lake Ohrid) in the northeastern Mediterranean region. The red line indicates the hydro-acoustic profile taken in 2007 with an INNOMAR 2000 compact transducer and using the ISE 2.9.2 software. The coring location Co1215 is indicated by a yellow dot. The depth in the seismic profile is indicated below lake surface and based on a P wave velocity of $1450\,\mathrm{m\,s^{-1}}$. The black bar in the seismic profile indicates the location and the recovery depth of sediment core Co1215. The reflectors related to the Y-5 tephra and the Pleistocene/Holocene transition (P/H T) are marked by the black lines (modified from Wagner et al., 2011).

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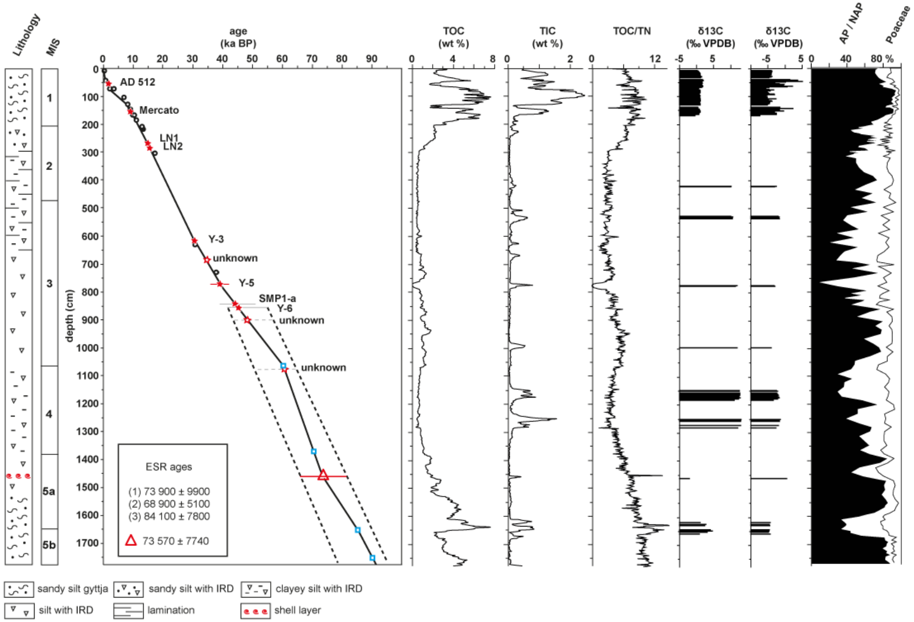

Fig. 2. Age model, lithology and selected datasets from core Co1215 from Lake Prespa (data from Damaschke et al., 2012; Wagner et al., 2012; Leng et al., 2013). Chronological tie points are indicated by black dots (radiocarbon ages), red stars tephras (open stars were not use for age-depth model), and blue squares (cross correlation with NGRIP). Pollen data are obtained according to the methods described in Panagiotopoulos et al. (2013).

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