Response to Referees

We acknowledge the very thorough and constructive feedback. Implementing the reviewers' comments significantly strengthened our arguments.

In the following we discuss the comments made by each referee (original remarks are in black, our rebuttal/comments in blue).

Response to Referee #1

1 Summary and General Comments
McCormack et al. present a very interesting data-set from a sediment profile (namely, Ahlat Ridge-AR) drilled in Lake Van. There already exist many published papers from the same sediment profile. Other than the previous publications, this manuscript presents abundance data of ostracod species, their temporal morphological distributions, stable isotope data from their valves and C-13 data of bulk carbonate. Accordingly, they offer that abundance of different ostracod species and changes in the morphology of limnocytherinae species reflect the changes in salinity and/or alkalinity of the lake. This suggestion mainly depends on salinity (Tomonaga et al., 2017) and Archaeol and Caldarchaeol Ecometric (ACE) index (Randlett et al., 2017) from previous studies they also support these results with stable isotope data. My impression about the manuscript is positive. Organization of the manuscript is tidy and easy to follow. I think, the data presented in the manuscript and the efforts in interpretation are invaluable and I thank and congratulate the authors for their effort. I think the McCormack et al. ignore some of the previously published studies which should be cited and discussed according to their results. Furthermore, if possible, they should present and/or discuss morphological features of contemporary recent species as done for the fossil data. Overall, I think the manuscript should definitely be published in BG journal.
On the other hand, I have major to moderate critics which you can find below.

Thank you for your compliments and the approval of our work.

2 Major/Moderate Critics

1. There is one major debate about the lake level and accordingly precipitation regime of Lake Van region, which recently Ön and Özeren (2018) made us remember. There are different lake terraces which have been dated to between 26 and 20 kyr BP (Landmann et al., 1996; Kuzucuoglu et al., 2010). These terraces have been interpreted as high stand lake level during 30-20 kyr BP and some authors claimed that the region was not arid (Kuzucuoglu et al., 2010; Ön and Özeren, 2018) as claimed by many Paleovan studies (for example, Kwiecien et al., 2014; Stockhecke et al., 2016). It is clear that McCormack et al. do not focus on LGM, however they ignore this debate and present the paleoenvironmental conditions one sided. Furthermore, faunal distribution data and their interpretations presented in this manuscript seem to me, the authors can take part in this discussion, which can be a major contribution to the precipitation regime of the region during LGM (c.f. Tzedakis, 2007).

As the reviewer noted, the LGM and a discussion on the regional precipitation regime during that period are not the focus of our study. Salinity of closed lakes is inherently related to the volume of water in the lake (which can be expressed as lake level). The relation between precipitation and the volume of water in the lake is not that straightforward. The lake volume is a function of input *versus* output, and precipitation is only one of the input components. Aware of this fact, and having only salinity data at hand, we deliberately decide not to take part in the ongoing discussion on the precipitation regime in the region.
Still, in the following we will briefly discuss some problems with the lake-level reconstruction of Ön and Özeren (2018) and why we assume a generally lower lake volume and higher salinity during the Last Glacial period (including the LGM) in comparison to Interglacial conditions as indicated by Lake Van salinity proxies (Tomonaga et al., 2017; Randlett et al., 2017) and regional humidity proxies (e.g., Pickarski et al., 2015a,b; Pickarski & Litt, 2017). We do not exclude the possibility of short-term lake-level highstands during the Last Glacial period.

Ön and Özeren's (2018) reinterpretation of already published Lake Van proxy data by applying an independent component analysis (ICA) is an interesting approach. However, several issues limit the precipitation reconstruction (Van-IC7) presented by Ön and Özeren (2018) in terms of lake-level reconstructions. The main argument for using Van-IC7 as a proxy for precipitation variability is based on its similarity with normalised B* reflectance data from Stockhecke et al. (2016), assuming that sediment colour in laminated sediments mainly reflects precipitation variability. Based on the discussion presented by Ön and Özeren (2018), the authors seem to assume, that Lake Van Ahlat Ridge sediments are laminated throughout the studied interval (250 kyr), which is not the case. It appears, as if in their interpretation the authors took no account of the sedimentary facies (besides falsely stating laminated sediments throughout the studied interval) and causes of lithological changes (as described in Stockhecke et al., 2014a), which greatly affect the original data used as an input for ICA (XRF-element intensities, $CaCO_3$ content, B* and TOC). Further arguments provided by these authors in support of the Van-IC7 as a precipitation proxy is the comparison of Van-IC7 with Lake Van bulk $\delta^{18}O$ data. The claim that bulk $\delta^{18}O$ profiles follow Van-IC7 trends during marine isotope stages is questionable when comparing the records. More importantly, the interpretation of Lake Van bulk $\delta^{18}O$ data remains ambiguous given its mineralogical complexity (discussed briefly in this manuscript and in detail in an additional now published paper: McCormack et al., 2019), and the presence of dolomite distorting the bulk isotopic signals (McCormack et al., 2018). The presence of terraces is a valid argument in regard to lake volume changes, but it must be handled with caution, due to the poorly constrained ages (some of which were recently questioned by Sumita & Schmincke, 2013) and the possibility of tectonic uplift and subsidence in this tectonically active region.

Ön and Özeren (2018) do not discuss other published Lake Van records highly relevant to regional precipitation and lake-level reconstructions. These include: Seismic reflection data (Cukur et al., 2014), porewater salinity/alkalinity data (Tomonaga et al., 2017), diatom preservation-based alkalinity changes (North et al., 2017), and mineralogical documentation highlighting early diagenesis compromising bulk $\delta^{18}O$ data (McCormack et al., 2018). Some of these data directly contradict Ön and Özeren's (2018) interpretation for the LGM (particularly seismic reflection and porewater data, Cukur et al., 2014; Tomonaga et al., 2017). Although, short-term highstands were likely during the Last Glacial period (especially during interstadials), cumulative Lake Van proxy data generally indicates a lower lake volume for most of the Last Glacial period (and particularly the LGM). Our ostracod taxonomic, morphological and isotopic data support a lower Last Glacial lake volume for Lake Van but provide no direct information on precipitation patterns.

According to the data presented, can the authors discuss why there is almost no noded species between 30 and 20 kyr BP?

There are noded valves between 30 to 20 ka BP, however, most samples do not have a sufficient number of limnocytherinae species (*Limnocythere* sp. A excluded as it never shows nodes) to count the number of nodes (i.e. < 20 valves per sample). This does not mean that nodose limnocytherinae valves are absent during this interval, only that we cannot obtain statistically significant results regarding the number of noded valves (see original manuscript page 5 lines 2-4). We added a reminder of our counting method to the discussion to avoid a similar misunderstanding in the future (page 8 line 11). The reasoning for the lower number of node countable limnocytherinae valves, though speculative, is likely linked to the dominance of *Limnocythere* sp. A and the perhaps very unfavourable (high salinity and alkalinity) conditions.

Why did maximum number of noded individuals and the number of nodes per valve were attained during MIS 4 and 3 (Page 8, line 7), but nor during MIS 2?

See also our answer above.
Interpreting noding during MIS 2 should be done with caution, given the lack of samples with a high enough number of limnocytherinae valves for node counting. Still, the samples with a high enough number of limnocytherinae valves for node counting show a significant amount of noded valves, even though the total percentage of noded valves is slightly lower than during MIS 3. There are several reasons that could explain the apparent lower percentage of noded valves during MIS 2 compared to MIS 3, all of which are highly speculative given the low MIS 2 resolution and the uncertainties regarding

node formation, especially in limnocytherinae species. This study is, to our knowledge, the first to link the occurrence of noded limnocytherinae species within a geological record to proxies of past water hydrochemistry including parameters such as salinity and alkalinity. Furthermore, no study investigated the physiological process of node formation on limnocytherinae species. Therefore, we consider a discussion regarding subtle differences in the percentage of noded valves (particularly for MIS 2) as too speculative. Instead, we focus on larger variations of the relative concentration of noded valves over longer time periods.

At page 4, line 2 they cite Lake Xinias and Lake Urmia. That is right, Xinias seem to have low level during MIS 2, but previous conditions do not reflect the same conditions of Lake Van. Furthermore, in and around Anatolia there are other high lake levels or evidences of high precipitation rates (see Ön and Özeren, 2018, and references therein). I don't find it fair to cite Urmia and Xinias, while there is a lake level reconstruction presented in Ca̧gatay et al. (2014) and a precipitation reconstruction presented in Ön and Özeren (2018). What if the authors correlate their data with these reconstructions? I can understand, they use curves of Tomonaga et al. (2017) and Randlett et al. (2017), because they are proxies of salinity. However, ACE index has very low resolution and salinity curve reflects fluctuations "over tens of thousands of years" (Tomonaga et al., 2017).

Please refer to our response above detailing why we do not plot our data against Van-IC7 by Ön and Özeren (2018). The lake-level reconstructions of, Ça̧gatay et al. (2014) rely on proxies that have been shown to be less reliable for Lake Van palaeohydrological reconstructions by more recent subsequent studies (e.g. Tomonaga et al., 2017; McCormack et al., 2018, 2019). The presence of the terraces is a clear evidence of fluctuating lake levels in the past, but their dating is still controversial (Tomonaga et al., 2017). McCormack et al. (2018, 2019) identified flaws in the traditional interpretation of bulk inorganic carbonate-based proxies (δ^{18}O and δ^{13}C the occurrence of dolomite and relative calcite to aragonite concentrations). Therefore, we choose to compare our data with direct proxies of salinity and original time series, rather than with fallible interpretations. Still, we find the comment justified and have implemented a sentence on the complexity of hydroclimate reconstruction in the Eastern Mediterranean region during the last glacial/interglacial cycle (page 4 lines 2-4).

Can the authors elaborate, why they couldn't find no ostracod species between 133 and 125 kyr? Also, if this is due to environmental conditions, they should express the ages according to Stockhecke et al. (2016) (see below comment #5)

Although ostracod-based palaeosalinity proxies (combined taxonomy, morphology and geochemistry) have the potential of being the highest-resolution Lake Van salinity proxies to date, the presence of ostracods depends on bottom water oxygen content and their record is not necessarily continuous. Particularly, ostracods might be absent during short lake-level highstands (during e.g. Greenland Interstadial), due to the establishment of bottom water suboxia/anoxia. Accordingly, in this proxy-development paper, we do not discuss in detail possible short-term lake level variations within the Last Glacial period. Similarly, the termination II and the transition into the Last Interglacial likely led to an oxygen depleted bottom water body preventing or hindering a colonisation of the profundal zone by ostracods (see original manuscript page 11, lines 13-17).
Regarding the age model please see our response to comment #5 below.

2. Why don't the authors inform us with the modern ostracod assemblage, and also, if possible, with the distribution of number of the nodes of modern Limnocythere inopinata? They still exist within the lake (Altinsaçli and Griffiths, 2002).

Yes, *Limnocythere inopinata* does still exist in Lake Van (see also Külköylüoğlu et al., 2012), however, studies on the modern Lake Van ostracod assemblage (Altinsaçli and Griffiths, 2002; Külköylüoğlu et al., 2012) do not focus exclusively on Lake Van and include records from different regions in Turkey (Anatolia). There is no detailed study describing the modern fauna of Lake Van that would include node counting or even a mentioning whether *L. inopinata* are nodose or not. Our study focusses on ICDP

sedimentary material and we have no access to the modern faunal assemblage here. However, we are currently working on a manuscript describing the limnocytherinae fauna of Lake Van in more detail.

3. The AR record is mentioned neither in the abstract nor in the introduction. Readers are unaware of which sediment record is being analyzed till section 3. Please name the sediment record, at least, in the introduction with proper references.

Done for both abstract and introduction.

4. I know there are too many figures in the manuscript, however readers would want to see the geographical location with a map. This is an optional request since I don't know the restrictions on figure numbers of the journal. Maybe map or some other figures can be presented as supplementary.

Because the location of Lake Van is shown in so many of the cited papers dealing with Lake Van records, we decided not to show it here again.

5. The chronology is only mentioned as: Composite profile depth (**and age; Stockhecke et al., 2014b**) was assigned to off-section samples by visual correlation based on high resolution core images. in page 4, line 24. As far as I know, there are two different age models of AR (Stockhecke et al., 2014, 2016). And these models differ a couple of thousand years during MIS-5 and 6. I know, it won't change the results substantially, however, why do authors use the old age model? Do all the data given to correlate (such as ACE index, Ca/K, salinity curve) use the same old age model? And maybe, the age model should be a little bit highlighted within the text.

The minor differences between these age models have no impact on our results nor our interpretations which are based on the comparison with other Lake Van proxies and therefore age independent. All data presented herein is plotted on the same age model, but also plotted against depth (in mcblf, Figs. 2, 3, 4, 8), and all data will also be made available with given sediment depth, upon manuscript acceptance. In any case, the Stockhecke et al. (2014) age model remains the most commonly used age model for Lake Van ICDP Ahlat Ridge records, not only used in all publications prior to 2016 but also in most thereafter (e.g., Pickarski & Litt, 2017; Randlett et al., 2017; Tomonaga et al., 2017; Damcı & Çağatay, 2018; McCormack et al., 2018, 2019; Schmincke et al., 2018; Kappenberg et al., 2019). To our knowledge, the slightly altered Stockhecke et al. (2016) age model is only used in two other publications (North et al., 2017, Ön & Özeren, 2018), while some of the data presented by the latter example are also plotted on the Stockhecke et al. (2014) age model.

6. In the material and methods section: What is the sampling interval? How much dry weight has been used per sample for counting ostracod valves and are these samples normalized to equal weights? I strongly suggest the authors to publish the data. Let the efforts given to this study open new doors to other researchers.

The sampling interval is described in the material and methods section. Sampling range covers the uppermost 68 m (56 m without event deposits) of the composite profile (page 4, lines 25-30). In this section we also detail our sampling strategy (lines 24-30). We report here the concentration of each dominant species relative to the total number of valves per sample (i.e. the relative taxonomic abundance). We have added the information that our data is presented as relative taxonomic abundance to the methods section to clarify (page 5 line 5).
Naturally, all data presented here will be published alongside the article, once the manuscript is accepted.

7. Why didn't the authors use the "continuous" Limnocythere inopinata species for isotope measurements, please explicitly state that.

For our isotopic measurements we require at least 25 to 60 µg of ostracod carbonate (clean, fully translucent, well preserved valves). Variations in *L. inopinata* valve abundance, size and thickness do not allow the "continuous" measurement of this species throughout the studied interval. *L. inopinata* valves were measured where our sample material allowed it.

We have made this information clearer in the methods section (page 5 line 13).

3 Minor suggestions
Below you can find my suggestions. I am not a native English speaker therefore language suggestions do not have to be correct.

• Page 1, line 10. Replace "while" with "and"

Done.

• Page 1, line 22. Is the "The" at the start of the line necessary?

"The" is used here to avoid starting a sentence with a delta notation.

• Page 2, lines 23-28. Why did the authors describe trace elements of valves with extensive references, is it really necessary? Maybe I am missing something.

Ostracod valve trace element composition is often used for salinity reconstructions. In the introduction we provide a general overview of ostracod based salinity reconstructions which include trace element compositions. Unfortunately, due to the sampling size and number of valves per sample we were not able to perform trace element measurements in this study.

• Page 3, line 4. "well-constrained palaeoenvironmental conditions", please expand this or rewrite the sentence.

We have added a citation (Litt and Anselmetti, 2014 and references therein) summarising some of the earlier results of the ICDP PALEOVAN project and the environmental interpretations.

• Page 3, line 17. No need to cite Litt and Anselmetti (2014) or any other study for this basic piece of information.

Done.

• Page 3, line 19. Not "lakes", I think it should be "lake's"

Done.

• Page 3, line 23. Delete alkaline.

Done.

• Page 4, line 27. Is the resolution 540 years? Otherwise, check the given numbers.

No, it is ca. 54 years as written in the manuscript. The mean resolution of a single 2 cm thick sample is, for the studied interval in accordance with the age model from Stockhecke et al., 2014a, ca. 54 years.

• Page 5, line 2. Maybe it is a good idea to name the dominant species in this sentence.

Done.

• Page 5, line 19. What is Van12-08? Any references and/or location? Why did you specifically use it? Frankly, I don't understand the depths given in this sentence.

Van12-08 is a short gravity core retrieved at the Ahlat Ridge site in May 2012. We have used its material (four samples, prepared in the same way as the ICDP samples) to complement our relatively scarce late

Holocene ostracod profile. We have now added the missing information in the main text (page 5 lines 23-25).

• Page 6, line 2. Delete "from"

Done.

• Page6 line 6-7. "The highest number of noded valves appears between ca. 73-35, 30-12 and 11-3ka BP with mean percentages of noded valves of 64, 43 and 57% respectively (Fig. 3)." Is this true for 30-12 ka BP. I see many zeros in this interval, or do the authors neglect zeros?

Unfortunately, not all samples had a high enough number of limnocytherinae valves (≥ 20) and these samples were thus not used for node counting (page 5, lines 2-4; now page 5 lines 5-7). We repeat this information now also in the discussion (page 8 lines 11-12). This does not mean that there were no limnocytherinae valves, or that all limnocytherinae valves were unnoded. Particularly the 30-12 ka BP interval is dominated by valves of *Limnocythere* sp. A, which was not included in the node counting, and therefore samples from this interval often lacked enough limnocytherinae valves for node counting.

• Page 6, line 10. A comma after Holocene maybe, or rewrite the sentence.

Done.

• Page 7, line 23. "At the same time, Lake Van's lake level was at its lowest and the salinity concentrations at its highest (ca. 50 to 80 g kg$_{-1}$; Tomonaga et al., 2017)". While Tomonaga et al. (2017) express temporal resolution of the fluctuations is over tens of thousands of years, is it true to use salinity to support ideas this way?

Yes, it is. We discuss here the general relative taxonomic abundance of *Limnocythere* sp. A for a longer time period between 26 to 18 ka BP. Short-term lake level fluctuations, i.e. rising lake levels or highstands, are likely during this period (coinciding with Greenland Interstadials, Stockhecke et al., 2014a; 2016). However, such short highstands are not necessarily recorded by faunal changes here (also due to changes in bottom water oxygen content), or observable at our sample resolution. Generally the lake volume was lower during this period, supported by salinity proxies (Tomonaga et al., 2017, Randlett et al., 2017), seismic interpretations (Cukur et al., 2014), and by indicators of a generally more arid Lake Van environment including arboreal pollen data (Litt et al., 2014; Pickarski et al., 2015b), Ca/K ratios (Kwiecien et al., 2014), sediment facies and TOC content (Stockhecke et al., 2014a). Our ostracod valve data (taxonomic diversity, valve morphology and $\delta^{18}O$ values) further support generally lower lake levels, higher salinity and more arid conditions during this interval. We cannot, however, exclude short-term highstands.

• Page 9, line 4. "the absolute size and number of nodes is smaller " it should be "are".

Done.

• Page 9, line 17. Delete "In the literature".

Done.

• Page 11, line 4 delete "also effect" to "affects", or rewrite the sentence which may be a better idea.

Done.

C Neil Roberts (Referee #2)

This is really nice study which combines some detailed and critical evaluation of their data sets (e.g. sampling sizes, potential biases due to vital effects, etc) with evaluation in terms of wider issues of Quaternary climate reconstruction.

I am not an ostracod specialist so cannot comment in any detail on this aspect of the paper, and instead will focus my comments on the stable isotopes, carbonate mineralogy and climate stratigraphy.

The stable isotope record of the PALEOVAN core record has been a bit of a puzzle. The pre-PALEOVAN core record from Lake Van, covering the last ~15 ka and based on bulk carbonates, showed good overall correspondence to other lake isotope records from SW Asis (Roberts et al., Quat Sci Rev, 2008). However, the bulk carbonate isotope data for the PALEOVAN cores, older than ~15 ka BP, made no real sense, either in comparison with other proxies from the same cores (e.g. XRF Ca/K ratio) or with other sequences from the same climate region. Potential explanations for this discrepancy included isotopically-light glacial meltwater or inwash of detrital carbonate. The authors here focus on an alternative explanation, namely fractionation effect due to changes in carbonate mineralogy. They show, 1) that ïA¸d'18O and ïA¸d'13C measurements on ostracod shells do not correlate with equivalent stable isotope measurements on bulk carbonate, 2) that instead they correlate well with other proxies from the same core, 3) that there have been important shifts in carbonate mineralogy through the core sequence. The resulting hydro-climate reconstruction makes a lot more sense, with more positive isotope values (and low lake levels) during the last glacial stage (70-15 ka BP).

Thank you for your approval of our work!

The effect of carbonate mineralogy on isotope values is most marked for dolomite, whose fractionation factor is substantially different from either calcite or aragonite. The authors might want to cite other studies where this has also been demonstrated (e.g. Nar lake, also in Turkey – Dean et al., Quat Sci Rev 2015). In contrast, the difference in the mineral-water fractionation factors of calcite and aragonite is small (ïA¸d'18O of aragonite is 0.7‰ more positive than ïA¸d'18O of calcite formed in the same ïA¸d'18Olakewater and temperatures; Grossman and Ku, 1986; Kim et al., 2007), so seems unlikely to explain the much bigger offset between ïA¸d'18Oostr and ïA¸d'18Obulk in Lake Van.

Differences in the fractionation factors alone are not enough to explain the isotopic differences between these inorganic carbonate phases (calcite, aragonite, dolomite). In another manuscript dealing with the bulk isotope record (McCormack et al., 2019) we demonstrate, that all three inorganic phases precipitate in isotopically variable parent waters. Dolomite precipitates during early diagenesis in cold bottom/porewater (resulting in variable $\delta^{13}C$ and high $\delta^{18}O$ values; see also McCormack et al., 2018). Both, calcite and aragonite precipitate in surface water, for which the isotopic composition is changing throughout the year. Calcite precipitates in spring, under close-to-freshwater-conditions within river plumes (resulting, in respect to aragonite, in lower $\delta^{13}C$ and $\delta^{18}O$ values), while aragonite precipitates in summer under evapoconcentrated conditions (resulting, in respect to calcite, in higher $\delta^{13}C$ and $\delta^{18}O$ values). The bulk $\delta^{18}O$ values represent isotopically mixed signals shifted towards the volumetrically dominant inorganic carbonate mineral within a given sample (see page 11, lines 27-33, now page 12 lines 5-10). We suggest that the isotopic composition of ostracod valves document hydrological changes more faithfully than bulk samples integrating spring, $\delta^{18}O$-lower calcite and summer $\delta^{18}O$-higher aragonite values.

Although, in general, the new isotope, carbonate mineralogy and ostracod data match other data sets well, I think it would be worth highlighting those time periods when they do not match so well. For example, the end of MIS6 in L Van shows high % Candona and a low ACE index, both suggesting relatively high lake levels, in contrast to previous interpretations, and also in contrast to the last glacial period (MIS 2 and 4). MIS 5a also seems a bit mixed, with some indicators showing high lake levels (e.g. ïA¸d'18O and ïA¸d'13C) but others indicating low water levels (e.g. ACE index).

This comment touches on an interesting question. The end of MIS 6 is characterised by very low ACE values, and the highest abundance of *Candona*, throughout the record, pointing to low salinity. However, the lithology implies a falling or low lake level. Based on diatom assemblage analyses North et al. (2017) suggested that during MIS 7e Lake Van has been hydrologically opened, though for a shorter time than during the MIS 5e. Here the difficulty lies in the data gaps – while North et al. (2017) present only discrete interval during MIS 7 our record starts only in MIS 6. None of our data is quantitative but we can imagine that MIS 6, following the MIS 7 period of hydrological opening was less dry /more humid than MIS 4 or 2. Consequently, although the lake level was relatively lower, and salinity relatively higher, it neither surpasses the ecological threshold of *Candona,* nor reached the one for halophilic euryarchaeota (ACE index) or *Limnocythere* sp. A. Following this scenario, the short-lived salinity increase during MIS 5d likely resulted in unfavourable conditions for *Candona*. This tentative explanation is supported by a near constant porewater salinity of approximately 20 g/kg found below a sediment depth of 100 m. Tomonaga et al. (2017) suggested a long-term balance between the salt input from rivers and the salt export resulting from burial in the sediments. Meaning, that for most of Lake Van's history salinity changes were probably less severe compared to the Last Glacial Period (which is accompanied by the disappearance of *Candona* and the emergence of *Limnocythere* sp A and heavily noded limnocytherinae). In this regard, it would be very interesting to investigate the taxonomy, morphology and geochemistry (isotopy and trace element content) of ostracod valves in the older sediments. Particularly interesting would be to see whether *Candona* is a frequent component of the ostracod assemblage in the older sediments as suggested from the porewater salinity profile.

As for the ACE index and MIA 5a, it was suggested by Randlett et al. (2017), that this proxy responded non-quantitatively in a binary way with low values (i.e. no archaeol from halophiles) indicating fresh(er) water conditions *versus* high values indicating the presence of halophiles at higher salinity. From combined salinity proxies (ostracod valves, ACE index and porewater salinity) we can tentatively estimate a general slow rise in salinity throughout MIS 5c to a, interrupted by lake level highstands, and followed by a stronger salinity increase throughout MIS 4-2. Further studies are required to estimate the sensitivity of each record to short time lake-level fluctuations and the duration of highstands.

Overall, though, I don't see much here that needs changing before full publication.

Thank you very much. We appreciate your positive feedback.

Anonymous Referee #3

General comments:

The presented new dataset provides a useful addition of previous investigations of the lake Van (Turkey). Previous studies of the two cores, containing in total 600.000 years lake history, mainly focused on pollen and geochemical data provides a very excellent geo-bio-climate archive and is unique over the world. Ostracod investigations are a very important tool to figure out lake history and at least climate record of these huge archive. Authors used not only the species diversity (poorly in this case) but also valve morphology and shell geochemistry. These are powerful tools, especially if the ostracod diversity is very poor like in this case. If the authors could show that noding of the limnocytherids is (also) environmental controlled that's really important. It's a pity that the authors only investigated the upper 150 ky. It would be exciting to see what happened in the older sections.

We thank the referee for his/her approval of our manuscript and for the most enthusiastic encouragement for further work! We limited our first investigation of ostracod valves in sedimentary profiles of Lake Van to the last 150 kyr of the record, due to the chosen resolution and the very time-consuming processes of sample sieving (256 samples) and valve picking and counting (23,168 valves).

We ourselves are curious to see what happens in the older sediments and we are determined to find it out in future studies!

Specific comments:

The authors should distinguish between noded Limnocythere sp. and Limnocythere inopinata to exclude species depending noding.

This is a valid comment. The as of yet not described *Limnocythere* sp. A was excluded from the node counting, as it never shows nodes and is easily distinguishable from other limnocytherinae species. Because *Limnocythere inopinata* is a polymorphic species and valve morphology is variable throughout the studied interval, the differentiation between *Limnocythere inopinata* and other limnocytherinae species is in Lake Van very complex, and we currently prepare a separate manuscript on the topic.

The authors should present a cross plot of oxygen isotopes and nodding to present this very important context.

While the idea is very intriguing, at the present we are technically not able to put it into practice. We were not able to measure noded *versus* unnoded valves within a given sample, due to the often low amount of *Limnocythere inopinata* valves and their low thickness in many samples. Additionally, in many cases it was not possible to remove foreign sedimentary matter accumulated within the hollow nodes, without breaking the valves. *Limnocythere inopinata* valves showed no consistent differences in $\delta^{18}O$ and $\delta^{13}C$ that could be related to reticulation and given that the node formation process is likely related to the difficulty of achieving an osmotic balance, we assume the formation of nodes does not impact the valve isotopy. Still, as soon as we have ample material for independent measurements, we will test this hypothesis.

The authors only mentioned the three dominant taxa and refer to a subsequent paper treating the limnocytherid fauna. However, it is important to have information about the ostracod diversity in the current contribution.

The ostracod diversity is very low and, throughout the studied interval comprises three dominant taxa *Candona* sp., *Limnocythere inopinata* and *Limnocythere* sp. A (Figure 1). Already from the relative abundance of these three taxa we were able to demonstrate an environmental control on ostracod diversity. The present manuscript is the first documentation of, until now largely overlooked, Lake Van ostracods and their application as multi-proxy salinity archives. Working on this data set we have only realised the intricate complexity of limnocytherid species present in Lake Van sediments and we feel that a detailed investigation of subtle differences in limnocytherinae species and morphotypes would be too wide a scope for this paper and a too specific topic for Biogeosciences. The paper in preparation is aimed for a microfossil/micropalaeontology-oriented journal.

However, congratulation to this very nice study!

Thank you for your positive comments. They are very much appreciated.

Author Response References:

Altınsaçlı, S., and Griffiths, H. I.: A review of the occurrence and distribution of the recent non-marine Ostracoda (Crustacea) of Turkey, Zool. Middle East., 27(1), 61-76, https://doi.org/10.1080/09397140.2002.10637941, 2002.

Çağatay, M. N., Öğretmen, N., Damcı, E., Stockhecke, M., Sancar, Ü., Eriş, K. K., and Özeren, S.: Lake level and climate records of the last 90ka from the Northern Basin of Lake Van, eastern Turkey, Quat. Sci. Rev., 104, 97-116, https://doi.org/10.1016/j.quascirev.2014.09.027, 2014.

Cukur, D., Krastel, S., Schmincke, H. U., Sumita, M., Çağatay, M. N., Meydan, A. F., Damci, E., and Stockhecke, M.: Seismic stratigraphy of Lake Van, eastern Turkey, Quat. Sci. Rev., 104, 63-84, https://doi.org/10.1016/j.quascirev.2014.07.016, 2014a.

Cukur, D., Krastel, S., Schmincke, H. U., Sumita, M., Tomonaga, Y., and Çağatay, M. N.: Water level changes in Lake Van, Turkey, during the past ca. 600 ka: climatic, volcanic and tectonic controls J. Paleolimnol., 52(3), 201-214, https://doi.org/10.1007/s10933-014-9788-0, 2014b.

Damcı, E., and Çağatay, M. N.: Chronological evolution of some morphological, tectonic and volcanic features in Lake Van, based on correlation of seismic and core data, Quat. Int., 486, 29-43, https://doi.org/10.1016/j.quaint.2017.12.047, 2018.

Külköylüoğlu, O., N. Sari and D. Akdemir,: Distribution and ecological requirements of ostracods (Crustacea) at high altitudinal ranges in Northeastern Van (Turkey), Ann. Limnol.-Int. J. Lim., 48(1), 39-51, https://doi.org/10.1051/limn/2011060, 2012.

Kwiecien, O., Stockhecke, M., Pickarski, N., Heumann, G., Litt, T., Sturm, M., Anselmetti, F., Kipfer, R., and Haug, G. H.: Dynamics of the last four glacial terminations recorded in Lake Van, Turkey, Quat. Sci. Rev., 104, 42-52, https://doi.org/10.1016/j.quascirev.2014.07.001, 2014.

Litt, T., and Anselmetti, F. S.: Lake Van deep drilling project PALEOVAN, Quat. Sci. Rev., 104, 1-7, https://doi.org/10.5194/sd-14-18-2012, 2014.

Litt, T., Pickarski, N., Heumann, G., Stockhecke, M., and Tzedakis, P. C.: A 600,000 year long continental pollen record from Lake Van, eastern Anatolia (Turkey), Quat. Sci. Rev., 104, 30-41, https://doi.org/10.1016/j.quascirev.2014.03.017, 2014.

McCormack, J., Bontognali, T. R. R., Immenhauser, A., and Kwiecien, O.: Controls on Cyclic Formation of Quaternary Early Diagenetic Dolomite, Geophys. Res. Lett., 45(8), 3625-3634, https://doi.org/10.1002/2018GL077344, 2018.

McCormack, J., Nehrke, G., Jöns, N., Immenhauser, A., and Kwiecien, O.: Refining the interpretation of lacustrine carbonate isotope records: Implications of a mineralogy-specific Lake Van case study, Chem. Geol., https://doi.org/10.1016/j.chemgeo.2019.03.014, 2019.

North, S. M., Stockhecke, M., Tomonaga, Y., and Mackay, A. W.: Analysis of a fragmentary diatom record from Lake Van (Turkey) reveals substantial lake-level variability during previous interglacials MIS7 and MIS5e, J. Paleolimnol., 59(1), 119–133, https://doi.org/10.1007/s10933-017-9973-z, 2017.

Ön, Z. B., and Özeren, M. S.: Temperature and precipitation variability in eastern Anatolia: Results from independent component analysis of Lake Van sediment data spanning the last 250 kyr BP. Quat. Int. https://doi.org/10.1016/j.quaint.2018.11.037, 2018.

Pickarski, N., and Litt, T.: A new high-resolution pollen sequence at Lake Van, Turkey: insights into penultimate interglacial–glacial climate change on vegetation history, Clim. Past, 13(6), 689, https://doi.org/10.5194/cp-13-689-2017, 2017.

Pickarski, N., Kwiecien, O., Djamali, M., and Litt, T.: Vegetation and environmental changes during the last interglacial in eastern Anatolia (Turkey): a new high-resolution pollen record from Lake Van, Palaeogeogr. Palaeoclimatol. Palaeoecol., 435, 145-158, https://doi.org/10.1016/j.palaeo.2015.06.015, 2015a.

Pickarski, N., Kwiecien, O., Langgut, D., and Litt, T.: Abrupt climate and vegetation variability of eastern Anatolia during the last glacial, Clim. Past, 11(11), 1491-1505, https://doi.org/10.5194/cp-11-1491-2015, 2015b.

Randlett, M. E., Bechtel, A., van der Meer, M. T., Peterse, F., Litt, T., Pickarski, N., Kwiecien, O., Stockhecke, M., Wehrli, B., and Schubert, C. J.: Biomarkers in Lake Van sediments reveal dry conditions in eastern Anatolia during 110.000–10.000 years BP, Geochem. Geophys., 18(2), 571-583, https://doi.org/10.1002/2016GC006621, 2017.

Stockhecke, M., Kwiecien, O., Vigliotti, L., Anselmetti, F. S., Beer, J., Çağatay, M. N., Channell, J. E. T., Kipfer, R., Lachner, J., Litt, T., Pickarski, N., and Sturm, M.: Chronostratigraphy of the 600,000 year

old continental record of Lake Van (Turkey), Quat. Sci. Rev., 104, 8-17, https://doi.org/10.1016/j.quascirev.2014.04.008, 2014b.

Stockhecke, M., Sturm, M., Brunner, I., Schmincke, H. U., Sumita, M., Kipfer, R., Cukur, D., Kwiecien, O., and Anselmetti, F. S.: Sedimentary evolution and environmental history of Lake Van (Turkey) over the past 600 000 years, Sedimentology, 61(6), 1830-1861, https://doi.org/10.1111/sed.12118, 2014a.

Stockhecke, M., Timmermann, A., Kipfer, R., Haug, G. H., Kwiecien, O., Friedrich, T., Menviel, L., Litt, T., Pickarski, N., and Anselmetti, F. S.: Millennial to orbital-scale variations of drought intensity in the Eastern Mediterranean, Quat. Sci. Rev., 133, 77-95, https://doi.org/10.1016/j.quascirev.2015.12.016, 2016.

Sumita, M., and Schmincke, H. U.: Impact of volcanism on the evolution of Lake Van II: temporal evolution of explosive volcanism of Nemrut Volcano (eastern Anatolia) during the past ca. 0.4 Ma. J. Volcanol. Geotherm. Res., 253, 15-34, https://doi.org/10.1016/j.jvolgeores.2012.12.009, 2013.

Tomonaga, Y., Brennwald, M. S., Livingstone, D. M., Kwiecien, O., Randlett, M. È., Stockhecke, M., Unwin, K., Anselmetti, F. S., Beer, J., Haug, G. H., Schubert, C. J., Sturm, M., and Kipfer, R.: Porewater salinity reveals past lake-level changes in Lake Van, the Earth's largest soda lake, Sci. Rep., 7, 1-10, https://doi.org/10.1038/s41598-017-00371-w, 2017.

Ostracods as ecological and isotopic indicators of lake water salinity changes: The Lake Van example

Jeremy McCormack[1], Finn Viehberg[2,3], Derya Akdemir[2], Adrian Immenhauser[1] and Ola Kwiecien[1]

[1]Sediment and Isotope Geology, Ruhr-University Bochum, Universitätsstraße 150, 44801 Bochum, Germany
[2]Institute for Geology and Mineralogy, University of Cologne, Zülpicher Straße 49A, 50674 Köln, Germany
[3]Institute for Geography und Geology, University of Greifswald, Friedrich-Ludwig-Jahn Str. 16, 17487 Greifswald, Germany

Correspondence to: Jeremy McCormack (jeremy.mccormack@rub.de)

Abstract.

Ostracods are common lacustrine calcitic microfossils. Their faunal assemblage and morphological characteristics are important ecological proxies, ~~while~~ and their valves are archives of geochemical information related to palaeoclimatic and palaeohydrological changes. In an attempt to assess ostracod ecology (taxonomic diversity and valve morphology) combined with valve geochemistry ($\delta^{18}O$ and $\delta^{13}C$) as palaeosalinity indicators, we analysed sedimentary material from the ICDP Ahlat Ridge site from terminal and alkaline Lake Van (Turkey) covering the last 150 kyr. Despite a low species diversity, the ostracod faunal assemblage reacted sensitive to changes in the concentration of total dissolved salts in their aquatic environment. *Limnocythere inopinata* is present throughout the studied interval, while *Limnocythere* sp. A is restricted to the Last Glacial period and related to increased lake water salinity and alkalinity. The presence of species belonging to the genus *Candona* is limited to periods of lower salinity. Valves of limnocytherinae species (incl. *L. inopinata*) display nodes (hollow protrusions) during intervals of increased salinity. Both the amount of noded valves and the number of nodes per valve appear to increase with rising salinity, suggesting that node formation is related to hydrological changes (salinity and/or alkalinity). In contrast to Lake Van's inorganic $\delta^{18}O$ record, the $\delta^{18}O$ values of ostracod valves do record relative changes of the lake volume, with lower values during high lake level periods. The $\delta^{13}C$ values of different species reflect ostracod habitat preferences (i.e., infaunal *versus* epifaunal) but are less sensitive to hydrological changes. However, combined with other proxies, decreasing Holocene $\delta^{13}C$ values may indicate a freshening of the lake water compared to the low lake level during the Last Glacial period. The Lake Van example underscores the significance and value of coupling ostracod ecology and valve geochemistry in palaeoenvironmental studies of endorheic lake~~s~~ basins.

1. Introduction

The water volume of closed lakes (endorheic basins) in arid and semi-arid regions reacts particularly sensitive to climatically induced changes in the ratio of meteoric precipitation to evaporation (P/E). When the lake volume decreases, the concentration of solutes increases (e.g., Dana and Lenz, 1986; Aladin and Potts, 1992) and consequently (pore-) water salinity is a conservative tracer of past climate fluctuations (Tomonaga et al., 2017). Yet, pore water salinity profiles have a relatively low

resolution and record only major changes at millennial time scales. Palaeoecological (e.g., faunal assemblage, phenology/morphologic variation) and geochemical (e.g., biomarker, carbonate trace elemental and isotope geochemistry) salinity proxies offer higher temporal resolution but are, per definition, indirect indicators. In non-marine environments, calcitic valves of ostracods (benthic, bivalve Crustacea) are established biological proxies to infer past environmental conditions from species ecological tolerance, morphometry, and/or valve geochemistry. Numerous previous studies exemplified the application of ostracod valves in tracking past hydrological changes (e.g., Van der Meeren et al., 2010, 2011; Decrouy, 2012; Smith and Palmer, 2012; Horne et al., 2012; Viehberg et al., 2012; Meyer et al., 2016).

The composition of an ostracod assemblage is influenced by several factors such as the type of surface sediment, ambient water temperature, dissolved oxygen concentration, and salinity (Holmes et al., 2010; Mesquita et al., 2012; Ruiz et al., 2013). Concerning salinity, not only the concentration of total dissolved ions (De Deckker 1981; Aladin and Potts, 1996) but also the ionic composition of the water control the diversity of ostracod assemblages (Forester and Brouwers, 1985; Smith, 1993). Based on species-specific tolerances and optima towards salinity and water chemistry, ostracod assemblages are valuable palaeosalinity indicators (e.g., Boomer et al., 2003; Keatings et al., 2010).

Several authors related a variety of morphological changes of the hard parts (single valves or complete carapaces) of the same ostracod species to changing salinity. Rosenfeld and Vesper (1977) observed an inverse relationship between the roundness of sieve-pores of the species *Cyprideis torosa* (Jones, 1850) and salinity. The valve length or length-height ratio of some species e.g., *Mytilocypris henricae* (Chapman, 1966), *C. torosa* and *Limnocythere inopinata* (Baird, 1843) seem to be salinity dependent (Martens, 1985; Neale, 1988; Van de Meeren et al., 2010). The most easily recognisable morphological change related to salinity is the development of a distinct type of ornamentation on the valves lateral surface expressed as hollow, typically round protrusions termed `nodes´ (Kilenyi, 1972; van Harten, 2000; Keyser, 2005). Among the species developing these nodes, most research focussed on the brackish species *C. torosa* (e.g., Kilenyi, 1972; Vesper, 1975; van Harten, 2000), which is presumed to produce more and prominent nodes with decreasing salinity (Keyser, 2005; Frenzel et al., 2012).

In addition, by means of their calcite valves, ostracods have the potential to reinforce palaeoecological and -environmental implications by using a geochemical approach (Smith and Palmer, 2012). The ratios of trace-elements to calcium, primarily Sr/Ca and Mg/Ca often covary positively with salinity (Holmes, 1996; Holmes and De Deckker, 2012). However, other factors, not necessarily salinity-related, such as increased inorganic carbonate precipitation and mineralogy, water temperature, Mg concentration and/or alkalinity of the ambient water may also affect Sr/Ca and Mg/Ca ratios of ostracod valves (e.g., Engstrom and Nelson, 1991; De Deckker et al., 1999; Bahr et al., 2009; Zhang et al., 2009; Gouramanis and De Deckker, 2010). The oxygen isotope composition ($\delta^{18}O$) of ostracod valves is a function of the temperature and the isotopic composition of the lake water in which the biominerals were secreted, modified by a vital offset, a systematic, species-specific deviation from the $\delta^{18}O$ value of a theoretical calcite precipitated under equilibrium conditions (von Grafenstein et al., 1999, Decrouy, 2012). The carbon isotopic composition ($\delta^{13}C$) of an ostracod valve reflects the $\delta^{13}C$ of the dissolved inorganic carbon ($\delta^{13}C_{DIC}$) at the time of moulting (von Grafenstein et al., 1999; Keatings et al., 2002). Three processes control the lake water $\delta^{13}C_{DIC}$: (i) biological activity in the lake, (ii) atmosphere-water CO_2 exchange, and (iii) the $\delta^{13}C_{DIC}$ of inflowing water (Kelts and Talbot,

1990; Leng and Marshall, 2004). Often and in combination with other proxies, increasing $\delta^{13}C_{ostracod}$ values have been interpreted in terms of a decreasing lake volume, associated with lower freshwater input and enhanced productivity (e.g., von Grafenstein et al., 2000; Frogley et al., 2001; Edwards et al., 2006).

Here we take advantage of Lake Van's well-constrained palaeoenvironmental conditions (Litt and Anselmetti, 2014 and
5 references therein) and test the versatility of ostracods as salinity indicators in an endorheic lake basin. We juxtapose changes in ostracod taxonomy, valve morphology (noding) and oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotopic composition for the last 150 kyr (ICDP Ahlat Ridge site) with independent low-resolution salinity proxies including biomarker indicators (Randlett et al., 2017) and directly measured pore water salinity (Tomonaga et al., 2017). Further, we document the variability in the valve isotopic composition of three concurrent ostracod taxa and identify its ecology-related controlling mechanisms. Finally, we
10 compare the isotopic data of ostracod valves and of inorganic carbonates (calcite and aragonite; McCormack et al., 2018 9b) with proxy records for relative changes in the P/E ratio including arboreal pollen percentage (Litt et al., 2014; Pickarski et al., 2015 a, b), XRF-Ca/K ratio (Kwiecien et al., 2014), lithology and total organic carbon content (TOC; Stockhecke et al., 2014a). We expect that, while the mixed nature of the inorganic carbonates (McCormack et al., in review 2019) masks the response of their isotopic composition to salinity changes, the biogenic carbonate mirrors these changes with a higher fidelity.

15 **2. Limnological setting/state of the art of Lake Van**

Lake Van is a terminal, alkaline lake in Eastern Anatolia, Turkey, situated on a high plateau with a lake level today at an altitude of 1648 m above sea level (Litt and Anselmetti, 2014). Its alkaline nature, characterised by near equal shares of sodium carbonate and sodium chloride, is a result of the volcanic hinterland and high evaporation rates (Kempe et al., 1991; Reimer et al., 2009). The lake's total alkalinity reaches ca. 151 mmol l^{-1}, salinity ca. 22 g kg^{-1} and pH 9.7 – 9.8 (Kempe et al., 1991;
20 Reimer et al., 2009; Litt et al., 2012). The Mg^{2+} concentration in the water is low, whereas Ca^{2+} is strongly depleted (Kempe et al., 1991; Reimer et al., 2009) and its concentration decreases further below the epilimnion due to the precipitation of carbonate minerals in the surface water (Landmann et al., 1996; Reimer et al., 2009; Stockhecke et al., 2012).

The recovery of a continuous 220 m long sedimentary succession in alkaline Lake Van in 2010 supported by the International Continental Scientific Drilling Program (ICDP) greatly expanded our knowledge about the evolution of the lake itself and the
25 environmental changes in the Near East over the last ~ 600.000 years (Litt and Anselmetti, 2014). Several independent proxy records including palynological, XRF-Ca/K ratios, total organic carbon content (TOC) and lithology show a mostly coherent palaeoclimate signal, involving wetter interglacials with a higher lake level, and more arid glacial periods with a generally lower lake level (Kwiecien et al., 2014; Litt et al., 2014; Stockhecke et al., 2014; Pickarski et al., 2015 a, b). A generally lower lake level between ca. 80 to 30 ka BP is also implied from biomarker salinity proxies and direct pore water measurements
30 (Randlett et al., 2017; Tomonaga et al., 2017) with the maximum salinity (ca. 50 to 80 g kg^{-1}) reached during a lowstand between 30 to 14 ka BP and a lake level ca. 200 m lower than present (Stockhecke et al., 2014a; Tomonaga et al., 2017). Seismic profiles reveal palaeo-shorelines/geomorphological features supporting this lowstand (Cukur et al., 2014 a, b). Similar

lower lake levels and more arid late glacial conditions are also documented from other lakes in the vicinity such as Lake Xinias (Digerfeldt et al., 2000) and Lake Urmia (Stevens et al., 2012). On the contrary, the glacial Dead Sea lake level is assumed high (Dor et al., 2018) highlighting the complex spatial pattern of hydrological variability during the last glacial/interglacial cycle in the Eastern Mediterranean, which is a matter of a long-lasting debate (see reviews Tzedakis, 2007; Jones et al., 2019)

5   An array of independent proxy records (e.g, Kwiecien et al., 2014; Stockhecke et al., 2014a; Pickarski et al., 2015b; McCormack et al., 2018a) have demonstrated a high sensitivity of Lake Van and its catchment to Northern Hemisphere temperature oscillations in particular to Greenland Stadials and Interstadials dubbed Dansgaard-Oeschger cycles. Interstadials contrast typical glacial/stadial conditions, and are characterised by higher moisture availability in the Lake Van area (Pickarski et al., 2015b) resulting in a rising lake level and the deposition of finely laminated sediments (Stockhecke et al., 2014a).

10 The bulk carbonate $\delta^{18}O$ record ($\delta^{18}O_{bulk}$) is at odds with the other proxy records recovered from the 2010 ICDP coring with higher values appearing in both, cold arid periods such as the Younger Dryas and in warm wet periods such as the Last Interglacial (MIS 5e; Kwiecien et al., 2014). McCormack et al. (2018, 2019 a, b) have shown that the bulk carbonate fraction consists of variable amounts of different carbonate mineral phases; primary low-Mg calcite and aragonite and early diagenetic calcian dolomite. Further, these authors argue, that surface water carbonates (calcite and aragonite) differ isotopically from each other due to their precipitation in close-to-freshwater and evaporative concentrated lake water, respectively. Consequently

15 the isotopic composition of the bulk carbonate is biased towards the composition of the most abundant inorganic carbonate fraction. Ostracod valves, relatively easy to separate from the inorganic fraction, provide an independent and in the case of Lake Van hitherto unexplored palaeoenvironmental archive/proxy. Although the episodic presence of turbidite layers in the sediment cores implies periodical transport of allochthonous material to the site (Stockhecke et al., 2014a), the presence of

20 ostracod valves in finely laminated undisturbed (varved) sediments and their generally excellent preservation suggest an autochthonous deposition or if any, then a very short transport.

3. Material and Methods

This study was carried out on material recovered in 2010 in the frame of the International Continental Drilling Program

25 PALEOVAN. We resampled 2-cm-thick intervals from the Ahlat Ridge composite profile and off-sections avoiding the sampling of event-deposits. Composite profile depth (and age; Stockhecke et al., 2014b) was assigned to off-section samples by visual correlation based on high resolution core images. The data presented here comprises 256 samples. Sampling range covers the uppermost 68 m (56 m without event deposits) of the composite profile corresponding to 147.8 ka BP with a mean temporal resolution of 54 years per sample. Sediment samples were wet-sieved into three fractions (> 250 µm, 250 – 125 µm,

30 125 – 63 µm), rinsed with distilled water and air dried. Ostracod valves were picked and counted from the > 250 µm and 250 – 125 µm fractions under a stereomicroscope and stored in microfossil slides. The identification of ostracod valves was based on morphological characteristics and verified with regional and standard identification keys and taxonomic reports (Suzin

1956; Bubikjan 1966; Bubikjan 1984; Meisch 2000; Wilkinson et al. 2005; Karanovic 2012; Külköylüoğlu et al. 2012; Danielopol et al., 2018), using a high magnification of the stereomicroscope and scanning electron microscope. The diverse limnocytherid fauna will be subject of an additional paper (McCormack et al. in prep), however, the geochemical studies focus on the dominant species of the fossil record (*Limnocythere inopinata, Limnocythere* sp. A and *Candona* sp.; Fig. 1). For

5 statistical assemblage analyses (relative taxonomic abundance), only samples with more than 20 ostracod valves were taken into account, similarly cumulative statistics regarding noding are based on samples with at least 20 limnocytherid valves (excluding *Limnocythere* sp. A, which never features nodes). Only well-preserved valves, i.e. translucent, well calcified and mostly intact were counted. SEM images were taken from gold-sputtered samples using a LEO/Zeiss Gemini 1530 as well as a Gemini 2 – Merlin, both operating with an acceleration voltage of 20 kV.

10 After careful visual inspection with the stereomicroscope, only clean (fully translucent, without any foreign matter) valves were used for isotopic analyses. If necessary valves were manually cleaned using a fine brush and distilled water to remove artefacts. Isotopic analyses were carried out on adult and juvenile *Limnocythere inopinata, Limnocythere* sp. A and *Candona* sp. valves for samples with a sufficient number of valves in a pristine state. Size range and sex of the valves were noted for each sample to estimate potential influences of ontogeny and sex on valve isotopy. Ostracod valve length was determined

15 using the image software ZEN 2.3 lite based on digital stereomicroscope photographs, taken with a Zeiss Axiocam 105 color camera attached to a Stemi 508 stereomicroscope. Length measurement errors were determined by repeated length measurements (10 times) for five different valves, yielding a maximum standard deviation of 3.2 µm. For isotope measurements of the genus *Candona* sp., large clearly identified fragments, as well as valves from samples with less than 20 valves were also analysed.

20 Oxygen and carbon isotope ratios (δ^{18}O and δ^{13}C) were determined on a ThermoScientific Kiel IV carbonate device coupled to a MAT253Plus mass spectrometer at the Ruhr-University Bochum. A total of 140 measurements, including replicate analyses, were performed on samples from the Ahlat Ridge ICDP site, as well as four measurements on samples from a ~~shallow short gravity~~ core (Van12-08, 53 ~~and~~to 31 cm below ~~the~~ lake floor) ~~at depths between 53 and 31 cm below the lake floor~~. The gravity core was retrieved at the Ahlat Ridge site in May 2012 and its material complemented the late Holocene sedimentary

25 record of the Ahlat Ridge composite profile. Between 15 and 60 µg of ostracod carbonate were weighed into Kiel reaction vials and reacted at 70 °C in orthophosphoric acid (105 % H_3PO_4). Depending on valve size and thickness between 2 and 68 valves were measured. Results are reported in ‰ in the common delta notation. Raw data were corrected using the standard ISO-A (Bernasconi et al., 2018) and the international standards NBS-19, IAEA-603, and CO-8. Final isotope ratios are normalised against the Vienna PeeDee Belemnite (V-PDB) standard. The external standard deviation of repeated analyses is

30 <0.05 ‰ for both, δ^{13}C and δ^{18}O.

4. Results

4.1 Ostracod taxonomy and morphology

The three dominant taxa, *Limnocythere inopinata*, *Limnocythere* sp. A and *Candona* sp. were identified (Fig. 1). *L. inopinata*, is present throughout the studied sediment sequence with both valves of females and males, implying the presence of a sexual population (Fig. 1, 2). *Limnocythere* sp. A, also occurs as a sexual population, but clearly differs from *L. inopinata* and other limnocytherinae species from its general outline and morphologic texture (Fig. 1). *Limnocythere* sp. A generally dominates the faunal assemblage contributing up to 98 % to the relative ostracod composition (mean = 63 %) between 36.2 and 5.2 metre composite below lake floor (mcblf) corresponding to 81.0 to 12.2 ka BP. Valves of the genus *Candona* were not further differentiated herein. *Candona* sp. contributes ~~from~~ up to 43 % to the relative ostracod composition (mean = 5 %), occurring only at depths between 67.6 and 50.9 mcblf, corresponding to an age between 147.9 and 108.9 ka BP.

The valves of polymorphic limnocytherinae species show varying reticulation and valve morphometrics. Here we focus on the most noticeable morphological variation, the appearance of hollow protrusions (nodes) with different intensity (number of nodes and size) and shape (round, spinous). The highest number of noded valves appears between ca. 73-35, 30-12 and 11-3 ka BP with mean percentages of noded valves of 64, 43 and 57 %, respectively (Fig. 3). Intervals with very low amounts of noded valves at ca. 148-137, 137-105 and 3-0 ka BP have mean percentages of noded valves of 4, 1 and 3 % respectively. One sample dated at ca. 137 ka BP has 31 % noded valves and the interval between 105-75 ka BP is characterised by valves with highly varying amounts of noding between 0 and 47 % (Fig. 3). Among the noded valves from the Holocene, most valves only have one node (Fig. 3). Three noded valves dominate the period of ca. 73-35 ka BP with a mean of 45 % of valves with three or more nodes. Nodes from the Holocene are typically smaller and round and are documented on *Limnocythere inopinata* valves, whereas those from the Last Glacial period are commonly larger and often spinous (Fig. 4).

4.2 Ostracod valve oxygen and carbon isotopy

The isotopic composition of valves varies for both $\delta^{18}O$ and $\delta^{13}C$ between different species (Tab. 1). Geochemical data from valves belonging to the same species, sex, reticulation intensity and size range, within one sample, generally show a mean isotopic variability in the order of up to 0.6 ‰ only (Fig. 5 a; Tab. 1). Geochemical data from *L. inopinata* valves of different reticulation intensity, size range and sex showed no consistent differences in $\delta^{18}O$ and $\delta^{13}C$ that could be related to either of these factors (Fig. 5 a, b, c). Co-occurring smooth and reticulated valves of *L. inopinata* dated between 137 to 117 ka BP have a $\delta^{18}O$ difference of up to 0.4 ‰, while only one sample shows smooth valves with 1.9 ‰ higher values compared to the more reticulated valves (Tab. 1). The valves of *Limnocythere* sp. A are with one exception continuously higher in both $\delta^{18}O$ and $\delta^{13}C$ compared to *L. inopinata*, from the same stratigraphic horizon, by 0.4 to 2.9 ‰ and 0.4 to 1.3 ‰ respectively (Fig. 5 d, e). *Candona* sp. valves from the same sample have constantly 0.4 to 0.9 ‰ higher $\delta^{18}O$ values and 2 to 6 ‰ lower $\delta^{13}C$ values than those of *L. inopinata* (Fig. 5 d, e).

5. Discussion

5.1 Ostracod taxonomy and morphology as palaeosalinity proxies

5.1.1 Variations in relative species abundance

5 In the sample material studied, the taxonomic diversity is relatively low, as expected from a saline lake with low Ca^{2+} concentrations (De Deckker and Forester, 1988; McCormack et al., in prep.). Only *L. inopinata* is found throughout the profile. *L. inopinata* tolerates high alkalinity (Meisch, 2000) and a high salinity range (ca. 0 - 50 g kg^{-1}), favouring a Na^+-HCO_3^--CO_3^{2-}-rich and Ca^{2+}-depleted water composition (Forester, 1983; 1986, Neale et al., 1988; Smith, 1993; Holmes et al., 1999; Li et al., 2010). The presence of *L. inopinata* throughout the profile suggests a close-to-constant Na^+-HCO_3^--CO_3^{2-}-rich water

10 composition and is in agreement with a close to steady-state relative proportion of most ions indicated by pore water analyses (Tomonaga et al., 2017).

Species belonging to the genus *Candona* sp. are typically associated with lower salinities (ca. 0 - 15 g kg^{-1}; e.g., De Deckker, 1981; Anadón et al., 1986; Neale, 1988; Forester, 1991; Li et al., 2010). *Candona* (*Fabaeformiscandona*) *rawsoni* (Tressler, 1957), for example, is mainly documented in alkaline lakes with low water salinity, but can also be found in lakes with higher

15 salinity and less alkaline conditions (Forester, 1986). In Lake Van, *Candona* sp. valves occur in sediments for which pore water and biomarkers indicate deposition under lower salinity conditions (Fig. 2; Randlett et al., 2017; Tomonaga et al., 2017) and lithology and TOC suggest well ventilated water column (Stockhecke et al., 2014a). The presence of *Candona* sp., an infaunal genus (Decrouy et al., 2012), appears to be controlled here by a lower concentration of total dissolved salts, alkalinity and higher dissolved oxygen concentrations in the bottom water, rather than changes in the ionic composition of the lake water.

20 *Limnocythere* sp. A is near-constantly present between ca. 81 and 12 ka BP and generally dominates the assemblage. Based on its occurrence restricted to the Last Glacial period (Fig. 2), coinciding with high pore water salinity and alkalinity (Tomonaga et al., 2017) and generally higher values for biomarker salinity proxies (Randlett et al., 2017), *Limnocythere* sp. A had likely a high salinity and/or high alkalinity preference. Between 26 and 18 ka BP, *Limnocythere* sp. A reached its highest relative taxonomic abundance of 86 to 98 % (Fig. 2). At the same time, Lake Van's lake level was at its lowest and the salinity

25 concentrations at its highest (ca. 50 to 80 g kg^{-1}; Tomonaga et al., 2017). At the Pleistocene/Holocene transition, characterised by more humid conditions, an increasing lake level and lower salinity (Litt et al., 2014; Tomonaga et al., 2017), *Limnocythere* sp. A disappeared from the sedimentary record.

5.1.2 Noding in limnocytherinae species (morphological variation)

For some species (e.g., *Cyprideis* species and *Leucocytherella sinensis,* Huang 1982) noding is a phenotypic reaction to a decrease in salinity (Keyser and Aladin, 2004; Keyser, 2005; Frenzel et al., 2012; Fürstenberg et al., 2015; Meyer et al., 2016). However, whether nodes in limnocytherinae species, especially *L. inopinata*, are morphological traits that are genetically controlled (genotypic; Yin et al., 1999; Fuhrmann, 2012) or environmentally influenced (phenotypic; Benson, 1969) is at present open to debate. As far as we know, the occurrence of noded *L. inopinata* within a geological record has not been directly compared in detail to other proxies of past water hydrochemistry including parameters such as salinity and alkalinity. While the physiological process of noding has been studied for *C. torosa* (Keyser, 2005), there are no such studies for limnocytherinae species. In Lake Van, the highest concentration of noded *L. inopinata* and other limnocytherinae species, in terms of the highest number of nodes per valve, and most pronounced nodes occurred during the Last Glacial period (Fig. 3, 4) strongly suggesting a relation with salinity (note that only samples with ≥ 20 limnocytherinae valves, excluding *Limnocythere* sp. A, were counted).

The number of noded individuals and the number of nodes per valve starts to increase at the end of MIS 5 and reaches maximum values during MIS 4 and 3. Concurrently, Lake Van data indicate generally increased lake water salinity, due to increased aridity and a decreasing lake level (Fig. 3; Litt et al., 2014; Stockhecke et al., 2014a; Pickarski et al., 2015; Tomonaga et al., 2017; Randlett et al., 2017). This observation is in disagreement with the interpretation of node formation as a genotypic trade suggested by Yin et al. (1999) referring to culture experiments exposing ostracods to variable aquaria water salinities. Based on the increase of noded individuals and the number of nodes under intensified aridity and increasing Lake Van salinity and alkalinity (Fig. 3), we propose that the node formation on limnocytherinae species (incl. *L. inopinata*) is primarily a phenotypic phenomenon.

Further we suggest that nodes on *L. inopinata* represent a malfunction during or shortly after moulting, before the newly formed valves calcified, analogue to studies on *C. torosa* (Keyser and Aladin, 2004). During the hormone-induced moulting process, the ostracod increases the volume of its bodily fluid by an intake of ambient water (Aladin and Potts, 1996; Keyser and Aladin, 2004). This leads to an inflation of the valve producing tissue, which under too high pressure may rupture during this process, leading to the formation of nodes during the subsequent biomineralisation (Keyser and Aladin, 2004; Keyser, 2005). According to Keyser (2005), the formation of nodes in *C. torosa* results from the lower osmotic pressure of the ambient water (low salinity) and the inability of the ostracod to regulate its internal osmotic pressure accordingly. A higher-than-normal pressure takes effect in the caverns between the inner and outer epidermal layers, when the ostracod presses its bodily fluid (haemolymph) into the valve. This is caused by the higher osmotic concentration within the haemolymph relative to the external aquatic medium. The higher pressure causes cell-to-cell connections between the inner and outer epidermal layer to tear allowing the flexible valves to bulge out in these areas and form protrusions that are stabilised as nodes during the subsequent calcification. However, limnocytherinae species (i.e., *L. inopinata*) are hyperosmotic regulators at salinities below 8 g kg^{-1} and isosmotic regulators between salinities of 8 and 14 to 20 g kg^{-1} (Aladin and Potts, 1996). Hence, we presume that

the haemolymph of limnocytherinae species will be hypo-osmotic relative to the lake water, and the mechanism of node formation is also related to the difficulty of achieving an osmotic balance during moulting.

Similar to the observation of van Harten (2000) for *C. torosa*, noded and unnoded valves of *L. inopinata* and other limnocytherinae species typically co-occur and while some stratigraphic horizons are free of noded valves, unnoded valves can be found throughout the profile. Keyser (2005) explains this by the ability of some individuals to better adjust to the environment. Not all individuals will have the same specific genetic predisposition (i.e., vulnerable cell-to-cell connections between the inner and outer epidermal layer) triggered by less favourable environmental conditions (i.e., salinity or alkalinity). This may explain why there is no linear relationship in relative abundance of noded valves and salinity (Fig. 3). However, it is evident that the occurrence of noded individuals and the number of nodes per valve is higher at periods of inferred high salinity from MIS 4 to 2. Moreover, it is also noteworthy, that the relative number of noded individuals increased again in the Holocene, but contrary to the Last Glacial period, the absolute size and number of nodes is are smaller (Fig. 3 f; Fig. 4). Keyser (2005) associated the size, shape, and extent of the protrusion (largest extent as spine) in *C. torosa* to the amount of pressure applied to the caverns between the epidermal layers, with larger nodes at higher pressure. In analogy, we interpret the higher number of nodes and the larger size of nodes for *L. inopinata*, as an expression of enhanced environmental stress reflected in increased and more excessive malfunctions during moulting.

The Ca^{2+} deficiency in the water was suggested, next to salinity changes, as another driver of node formation in *C. torosa* (Keyser, 2005). Low Ca^{2+} concentrations within the bodily fluid during the moulting increase the risk of disrupting stabilising structural elements within the epidermal cavities by causing spasm-like reactions (Keyser, 2005; Frenzel et al., 2012). Modern Lake Van water is strongly Ca-depleted (0.105 to 0.087 mmol L^{-1}, Reimer et al., 2009). We assume that lake water Ca^{2+}-concentrations have not varied significantly within the last 150 kyr, as Ca^{2+} transported into the lake is quantitatively precipitated in the epilimnion as inorganic calcite and aragonite (McCormack et al., in review2019). The Ca^{2+} limitation in Lake Van may increase the likelihood of node formation in limnocytherinae species but is apparently not the ultimate controlling mechanism.

In the literature tThe relation between noding and alkalinity is yet unresolved (Van Harten, 2000; De Deckker and Lord, 2017). In Lake Van salinity and alkalinity of the pore water correlate exceptionally well and both increased during the documented generally lower lake level of the Last Glacial (Tomonaga et al., 2017). Due to this correlation, we cannot evaluate the effect of either of these parameters on node formation independent of the other. Still, our results suggest that noding of *L. inopinata* and other limnocytherinae species is controlled by the ambient water salinity and perhaps alkalinity. Noding of limnocytherinae species is therefore a valid indicator for relative palaeohydrological changes.

5.2 Ostracod valve oxygen and carbon isotopy

5.2.1 Isotopic composition of ostracod valves and the "vital effect"

Similar to other studies (e.g., Heaton et al., 1995; Li et al., 2007; Marco-Barba et al., 2012), we observe no systematic variation between sex, valve size, reticulation and the isotopic composition of ostracod valves of the same species in Lake Van (Fig. 5
a, b, c; Tab. 1). The isotopic composition, however, varies systematically between different species from the same stratigraphic horizons (Fig. 5 d, e). This observation may be related to different microhabitats, or different vital effects. Ostracod calcite is typically enriched in ^{18}O (Xia et al., 1997; von Grafenstein et al., 1999) relative to inorganic calcite precipitated in isotopic equilibrium with the lake water (Kim and O´Neil, 1997) under the same geochemical conditions. While the exact controls of this vital offset remain ambiguous, its amplitude is species-specific (von Grafenstein et al., 1999) and perhaps related to the
salinity and/or the ionic composition of the bottom water (Decrouy, 2011; Decrouy and Vennemann, 2013), water temperature, lake water pH conditions (Chivas et al., 2002) or the ambient water $[CO_3^{2-}]/[DIC]$ molar ratios (Devriendt et al., 2017).
In the same stratigraphic horizon, *Limnocythere* sp. A has, with one exception, constantly higher $\delta^{18}O$ values relative to *L. inopinata* by a mean of 1.4 ‰ (n = 13; Fig. 5 d). The positive correlation between the $\delta^{18}O$ values of both species (r = 0.57, Fig. 6 a) and the persistent ^{18}O enrichment in *Limnocythere* sp. A suggests a different vital offset from *L. inopinata*. Similarly,
generally higher $\delta^{18}O$ values of *Candona* sp., relative to *L. inopinata* (mean 0.6 ‰ for n=9), indicates a different vital offset (Fig. 5 d). The mean offset between Candoninae species and *L. inopinata* is lower than expected from studies in freshwater environments, where the vital offset of Candoninae is ca. 2 to 3 ‰ and for *L. inopinata* ca. 0.8 ‰ (von Grafenstein 1999; Keatings et al 2002, Decrouy et al 2011; Decrouy and Vennemann, 2013). The positive correlation between $\delta^{18}O$ of *L. inopinata* and *Candona* sp. from the same stratigraphic horizon (r = 0.93, Fig. 5 d; Fig. 6 b), however, not only supports a
relatively constant vital offset between both taxa, but also suggests that both respond to changes in the $\delta^{18}O$ of the lake water. Determining the vital offset for ostracod valve $\delta^{13}C$ is more complex due to the species-specific microhabitat preferences of ostracods (von Grafenstein et al., 1999). Within the ostracods microhabitat, the carbon isotope composition of the dissolved inorganic carbon ($\delta^{13}C_{DIC}$) may vary significantly from that of the open water column (Decrouy et al., 2011). For most ostracod taxa (including Candoninae) the carbon isotopic composition presumably represents a value expected for equilibrium calcite
formation (von Grafenstein et al., 1999; Keatings et al., 2002). The carbon isotope values of *L. inopinata*, however, are suggested to be 1 to 3 ‰ lower than what is expected for equilibrium precipitation, a feature that may be attributed to the biomineralisation pathway of the species (von Grafenstein et al., 1999; Decrouy et al., 2011). The $\delta^{13}C$ values of *Limnocythere* sp. A are generally higher by ca. 0.6 ‰ relative to *L. inopinata*. The statistically relevant correlation between $\delta^{13}C$ values of *Limnocythere* sp. A and *L. inopinata* (r = 0.72; Fig. 5 e; 6 a) suggests a constant vital offset. Alternatively, both species may
moult within different microhabitats. The second scenario explains the large offset between *Candona* sp. and *L. inopinata* $\delta^{13}C$ values (Fig. 5 e). While *L. inopinata* is a preferentially epifaunal species, the genus *Candona* sp. is considered to be infaunal (Decrouy et al., 2012b). The $\delta^{13}C$ values of *Candona* sp. will in contrast to *L. inopinata* reflect not the $\delta^{13}C_{DIC}$ of the bottom water, but that of the pore water. The oxidation of ^{13}C-depleted organic matter shifts the $\delta^{13}C_{DIC}$ of the pore water towards

lower values (von Grafenstein et al., 1999). The pronounced carbon isotope difference between both species implies a strong gradient between pore water and lake water $\delta^{13}C_{DIC}$ (Fig. 5 e, 6 b).

We cannot exclude that larger variations in the past water chemistry affected the magnitude of the biologically-induced disequilibrium. However, the relatively constant offsets among the isotopic compositions of different species (Fig. 5 d, e),
5 implies only minor variations in the magnitude of the vital offsets. The offset between *Candona* sp. and *L. inopinata* $\delta^{13}C$ values is an exception, and is primarily a function of varying microhabitats. Variations in the isotopic composition of species-specific ostracod valves over glacial/interglacial timescales are larger than the potential amplitude of disequilibrium effects related to the biomineral secretion. Moreover, these patterns are synchronous with variations in other proxy records (Fig. 7, 8), indicating a sensitivity of the ostracod valve $\delta^{18}O$ and $\delta^{13}C$ records towards relative changes in Lake Van's palaeohydrology.

10 **5.2.2 Ostracod $\delta^{18}O$: Palaeoenvironmental implications and comparison to inorganic carbonate isotope signatures**

The $\delta^{18}O$ value of ostracod valves is not directly affected by salinity, but rather by the isotopic composition and the temperature of the ambient water. In some cases ostracod valve $\delta^{18}O$ is used to estimate relative changes in the lake volume (e.g., Lister, 1988; Gouramanis et al., 2010; Wrozyna et al., 2012; Marco-Barba et al., 2013), which also ~~effect~~ affect lake water salinity. Changes in the $\delta^{18}O$ of the lake water ($\delta^{18}O_{Lake}$) in large closed lakes are predominantly controlled by the
15 precipitation/evaporation (P/E) ratio, with higher $\delta^{18}O_{Lake}$ values indicating lower P/E ratios (decreasing lake level) due to the preferential loss of ^{16}O during evaporation (Leng and Marshall, 2004). A comparison of the isotopy of *L. inopinata* valves with the depositional lithostratigraphy indicates generally lower $\delta^{18}O$ values for valves deposited in finely laminated compared to such sedimented in banded or mottled deposits (Fig. 7). The generally lower $\delta^{18}O$ values within laminated sediments deposited during high lake levels (Fig. 7) emphasises the sensitivity of ostracod valve chemistry in Lake Van to environmentally-driven
20 lake level fluctuations.

Despite its low resolution, *L. inopinata* $\delta^{18}O$ data seem to reach lower values at the transition from the penultimate glacial period (MIS 6) to the Last Interglacial (MIS 5e; Fig. 8 h). Ostracod valves are almost absent in the Ahlat Ridge sediments deposited during the early MIS 5e (124 – 133 ka BP; Fig. 2 j), a period in which the lake level probably rose sufficiently to establish a short-lived outflow (Stockhecke et al., 2014a; Tomonaga et al., 2017; North et al., 2017). Apparently, this has led
25 to a larger and/or more oxygen-depleted suboxic/anoxic water body compared to other highstand periods, preventing or hindering a colonisation of the profundal zone by ostracods. Subsequent periods representing lake level highstands (ca. 86-77 ka BP and 106-99 ka BP; Stockhecke et al., 2014; Tomonaga et al., 2017) document decreasing *L. inopinata* $\delta^{18}O$ values (Fig. 8 h) and thereby increasing P/E ratios and decreasing salinity.

Within the sediments of MIS 3 and 4, high amplitude fluctuations (> 3 ‰) in the *Limnocythere* sp. A and *L. inopinata* $\delta^{18}O$
30 values likely indicate frequently changing P/E ratios and a subsequent rising (interstadials) and falling (stadials) lake level. *Limnocythere* sp. A shows less variable, ^{18}O-enriched values (4 – 5 ‰) between ca. 33-17 ka BP (Fig. 8 h, j). This supports relatively stable but arid conditions (Pickarski et al., 2015b; Kwiecien et al., 2014; Stockhecke et al., 2014a) and a low lake level (Cukur et al., 2014a, b; Tomonaga et al., 2014). Following the uniformly high values during MIS 2, *Limnocythere* sp. A

$\delta^{18}O$ values show a slight decrease (to ca. 2.8 ‰) at ca. 15 ka BP, while higher values (ca. 4.4 ‰) are reached during the arid Younger Dryas. A significant rise in lake level at the onset of the Holocene (Landmann et al., 1996; Stockhecke et al., 2014a; Cukur et al., 2014a, b; Çağatay et al., 2014; Tomonaga et al., 2017), led to lower Holocene *L. inopinata* $\delta^{18}O$ values (Fig. 8 h). The Lake Van bulk carbonate is composed of varying concentrations of the inorganic carbonate minerals aragonite, low-Mg
5 calcite, and calcian dolomite and, volumetrically less important, biogenic carbonates (ostracods). The significantly different isotopic composition of each component results from their precipitation in isotopically distinct ~~host~~ parent waters (McCormack et al., 2018a, ~~in review~~2019). McCormack et al. (~~in review~~2019) has shown that both calcite and aragonite precipitate within isotopically contrasting surface water: Calcite under close-to-freshwater-conditions within river plumes and aragonite within evapoconcentrated lake water. Therefore, the bulk $\delta^{18}O$ values, but also the isotopic composition of surface water precipitates
10 calcite and aragonite ($\delta^{18}O_{Ar+Cc}$, $\delta^{13}C_{Ar+Cc}$), represent isotopically mixed signals shifted towards the dominant polymorph. An estimation of the aragonite $\delta^{18}O$ value ($\delta^{18}O_{Ar}$) (assuming a range for the $\delta^{18}O$ of calcite between -4 and -10 ‰, and a constant surface water temperature at the time of calcite precipitation at 10 °C) represents the closest approximation for changes in Lake Van's surface water isotopic composition over glacial/interglacial time scales (McCormack et al., ~~in review~~2019; Fig. 8 i). The estimates of $\delta^{18}O_{Ar}$ values may be compromised by the uncertainty in the relative concentrations of aragonite and calcite
15 and the adequacy of our assumptions. Nevertheless, the estimated $\delta^{18}O_{Ar}$ record shares more similarities with the $\delta^{18}O$ pattern of ostracod valves than with the bulk $\delta^{18}O$ record (Fig. 8). While the bulk $\delta^{18}O$ record shows no systematic variations, both the estimated $\delta^{18}O_{Ar}$ and the $\delta^{18}O_{Ar+Cc}$ records document decreasing values coinciding with the lake level highstands at ca. 106 – 99 ka BP and 86 – 77 ka BP synchronous with the ostracod $\delta^{18}O$ data. The shift towards lower $\delta^{18}O_{Lake}$ values from the late glacial into the Holocene, however, is evidenced by the estimated $\delta^{18}O_{Ar}$ and ostracod $\delta^{18}O$ records but not in the $\delta^{18}O_{Ar+Cc}$ or
20 bulk record (Fig. 8 f, g, h, i). The ostracod $\delta^{18}O$ record shows a higher sensitivity to relative lake level changes than the inorganic isotope records in Lake Van. Concluding, in lakes with a mixed inorganic carbonate composition, ostracod $\delta^{18}O$ signatures may be a more accurate recorder of palaeohydrological changes than the $\delta^{18}O$ values of inorganic carbonate.

5.2.3 Ostracod $\delta^{13}C$: Palaeoenvironmental implications and comparison to inorganic carbonate isotope signatures

25 The species-specific $\delta^{13}C$ variability is much lower than the respective $\delta^{18}O$ variability (Fig. 8 e, h). This pattern is particularly well pronounced within the Last Glacial period, when the amplitude of $\delta^{13}C$ change is low for both *L. inopinata* and *Limnocythere* sp. A, while the amplitude of $\delta^{18}O$ change is large. The lower variability in ostracod $\delta^{13}C$ is probably related to the large dissolved inorganic carbon (DIC) pool of Lake Van (ca. 100 mmol kg^{-1}, Reimer et al., 2009). In general, the $\delta^{13}C$ of large DIC pools is less variable with changes in the lakes hydrology compared to that of $\delta^{18}O_{Lake}$ (Li and Ku, 1997).
30 Importantly, the $\delta^{13}C$ of the infaunal *Candona* sp. valves do not reflect bottom water $\delta^{13}C_{DIC}$ but the $\delta^{13}C_{DIC}$ of the pore water of the uppermost sediment column.

In contrast to the ostracod taxonomy, morphological variability, and valve $\delta^{18}O$, the ostracod $\delta^{13}C$ appears to be a less sensitive recorder of lake volume (salinity) or other hydrological changes in Lake Van. Still, markedly lower $\delta^{13}C$ values of the epifaunal

L. inopinata during two periods, the Holocene and the late MIS 5e (ca. 120 to 115 ka BP) document lower $\delta^{13}C_{DIC}$ of the bottom water. Interestingly, for both periods, other proxy records (TOC, lithology and ostracod $\delta^{18}O$; Fig. 8 b, h, j) show contrasting signals. One interpretation of this feature is that the shift towards lower $\delta^{13}C$ values was possibly triggered by different processes for each period. The decrease in *L. inopinata* $\delta^{13}C$ values at the Pleistocene/Holocene transition is here tentatively explained by the significant rise in the lake level (ca. 200 m) and more humid conditions. This may have resulted in a dilution of the lake water by the influx of ^{13}C-depleted freshwater. However, two previous lake level highstands at ca. 106 – 99 ka BP and 86 – 77 ka BP documenting decreasing *L. inopinata* $\delta^{18}O$ values similar to the Holocene are not associated with decreasing $\delta^{13}C$ values (Fig. 8 e, h, j). Further, the low $\delta^{13}C$ values in *L. inopinata* valves that calcified within the well-ventilated bottom water during the late MIS 5e (Stockhecke et al., 2014a) cannot be interpreted by increasing ^{13}C-depleted runoff due to the very different depositional setting. Another potential explanation for lower ostracod valve $\delta^{13}C$ values may be varying degrees of bottom water DIC exchange with upward diffusing ^{13}C-depleted pore water at the lake floor. The lack of correlation between ostracod $\delta^{13}C$ values and other proxy records and the differences in the depositional setting between both periods with lower *L. inopinata* $\delta^{13}C$ values does not allow for a conclusive interpretation of our data.

While any palaeoenvironmental interpretation based on changes in ostracod $\delta^{13}C$ remains at this point speculative, the shift towards lower values within Holocene sediments likely documents changes in the lakes bottom water DIC composition. An opposite trend towards higher values is clearly visible in the inorganic $\delta^{13}C_{Ar+Cc}$ record (Fig. 8 d, e). The complementary evolution in Holocene inorganic *versus* ostracod $\delta^{13}C$ values may be related to a highly stratified water column. Given that $\delta^{13}C_{Ar+Cc}$ is a mixture of ^{13}C-enriched aragonite and comparably ^{13}C-depleted calcite, the Holocene increase in aragonite content (Fig. 8 c, McCormack et al., ~~in review~~2019) may have masked a trend towards lower water column $\delta^{13}C_{DIC}$.

6. Conclusions

Taking advantage of the legacy of the ICDP PALEOVAN project – the well-documented hydrological evolution of Lake Van – this study examined the applicability of ostracods as multi-proxy archives for relative changes of the past lake water chemistry, with ~~the~~ an emphasis ~~is~~ on salinity reconstructions. We focussed on the ostracod faunal assemblage, valve morphology (noding) of limnocytherinae species (incl. *Limnocythere inopinata*) and the valve geochemistry ($\delta^{18}O$ and $\delta^{13}C$) of three different ostracod taxa from ICDP cores covering the last 150 kyr. We conclude:

1) The composition of the ostracod assemblage of Lake Van is primarily controlled by the salinity and/or alkalinity of the lake water. While *Limnocythere* sp. A is present only during high salinity and alkalinity intervals, *Candona* sp. valves are limited to periods of less saline lake water. *Limnocythere inopinata* a cosmopolitan species with high tolerance to changing water chemistry is present throughout the record.

2) The presence and amount of nodes (hollow protrusions) is compared here to independent palaeohydrological proxies. Our results indicate, that node formation on valves of limnocytherinae species is primarily a phenotypic response to higher salinity and/or alkalinity and as such represents a novel promising proxy in semiquantitative lacustrine palaeohydrology.

3) The $\delta^{18}O$ records from ostracods in Lake Van are sensitive towards relative changes in the lake volume related to varying precipitation/evaporation ratios. Ostracod valves have generally lower $\delta^{18}O$ values when embedded in sediments deposited during lake level highstands and higher values when embedded in sediments deposited during a low lake level.

4) Ostracod $\delta^{13}C$ values while less sensitive to hydrological changes due to the large dissolved inorganic carbon pool of Lake Van, still reflect the microhabitat of the respective species.

5) The isotopic composition of ostracod valves, particularly their $\delta^{18}O$ values, document hydrological changes that are not recorded by the inorganic (bulk) isotope records due to their mineralogically-mixed composition. The isotopic analyses of ostracod valves is therefore particularly useful for estimating changes in the isotopic composition of the water in lakes in which more than one inorganic carbonate phase accumulates in the bulk sediment.

Acknowledgements

We acknowledge funding from the Deutsche Forschungsgemeinschaft (DFG) grant KW90/2-1. We are grateful to Sebastian Breitenbach, Matthias Born, and Rolf Neuser for instrumental assistance, and appreciate the assistance of Julian Stromann and Annabel Wolf with the sample sieving. The manuscript benefited from the thorough, positive and constructive feedback from Neil Roberts and two anonymous referees and the professional handling by the associate editor Wajih Naqvi.

References

Aladin, N. V., and Potts, W. T. W.: Changes in the Aral Sea ecosystems during the period 1960-1990, Hydrobiologia, 237(2), 67-79, https://doi.org/10.1007/BF00016032, 1992.

Aladin, N. V., and Potts, W. T. W.: The osmoregulatory capacity of the Ostracoda, J. Comp. Physiol. B, 166(3), 215-222, https://doi.org/10.1007/BF00263985, 1996.

Anadón, P., De Deckker, P., and Julia, R.: The Pleistocene lake deposits of the NE Baza Basin (Spain): salinity variations and ostracod succession, Hydrobiologia, 143(1), 199-208, https://doi.org/10.1007/BF00026662, 1986.

Bahr, A., Lamy, F., Arz, H. W., Major, C., Kwiecien, O., and Wefer, G.: Abrupt changes of temperature and water chemistry in the late Pleistocene and early Holocene Black Sea, Geochem. Geophys. Geosyst., 9(1), 1-16, https://doi.org/10.1029/2007GC001683, 2008.

Baird, W.: Notes on British Entomostraca, The Zoologist—A Popular Miscellany of Natural History, 1, 193–197, 1843.

5   Barker, S., Knorr, G., Edwards, R. L., Parrenin, F., Putnam, A. E., Skinner, L. C., Wolff, E., and Ziegler, M.: 800,000 years of abrupt climate variability, Science, 334(6054), 347-351, https://doi.org/10.1126/science.1203580, 2011.

Benson, R. H.: Ostracodes of the Rita Blanca lake deposits. Geological Society of America, Memoir, 113, 107-115, 1969.

Bernasconi, S. M., Müller, I. A., Bergmann, K. D., Breitenbach, S. F. M., Fernandez, A., Hodell, D. A., Meckler, A. N., Millan, I., and Ziegler, M.: Reducing uncertainties in carbonate clumped isotope analysis through consistent carbonate-based

10   standardization, Geochem. Geophys. Geosyst., 19(9), 2895-2914, https://doi.org/10.1029/2017GC007385, 2018.

Boomer, I., Horne, D. J., and Slipper, I. J.: The use of ostracods in palaeoenvironmental studies, or what can you do with an ostracod shell?, The Paleontological Society Papers, 9, 153-180, https://doi.org/10.1017/S1089332600002199, 2003.

Bubikjan, S. A.: Ostracoda from Pliocene deposits of Armenia. Ostrakody iz Pliotsenovykh otlozheniy Armenii. Izvestiia Akademii Nauk Armyanskoy SSR, Seriya nauki o zemle 19(3), 3-11, 1966.

15   Bubikjan, S. A.: Recent Ostracoda from the bottom beds of the south-western part of Lake Sevan. Izvestia Akademii nauk Armanskoj SSR. Naukii o Zemlye 37(2), 10-24, 1984.

Çağatay, M. N., Öğretmen, N., Damcı, E., Stockhecke, M., Sancar, Ü., Eriş, K. K., and Özeren, S.: Lake level and climate records of the last 90ka from the Northern Basin of Lake Van, eastern Turkey, Quat. Sci. Rev., 104, 97-116, https://doi.org/10.1016/j.quascirev.2014.09.027, 2014.

20   Carbonel, P., Colin, J. P., Danielopol, D. L., Löffler, H., and Neustrueva, I.: Paleoecology of limnic ostracodes: a review of some major topics, Palaeogeogr. Palaeoclimatol. Palaeoecol., 62(1-4), 413-461, https://doi.org/10.1016/0031-0182(88)90066-1, 1988.

Chapman, M. A.: On *Eucypris mytiloides* (Brady), and three new species of *Eucypris* Vavra (Cypridae, Ostracoda) from Australia. Hydrobiologia, 27, 368-378, https://doi.org/10.1007/BF00042699, 1966.

25   Chivas, A. R., De Deckker, P., Wang, S. X., and Cali, J. A.: Oxygen-isotope systematics of the nektic ostracod *Australocypris robusta*, in: The Ostracoda: Applications in Quaternary Research, edited by: Holmes, J. A., and Chivas, A. R., American Geophysical Union, Washington, DC, 301-313, https://doi.org/10.1029/GM131, 2002.

Cukur, D., Krastel, S., Schmincke, H. U., Sumita, M., Çağatay, M. N., Meydan, A. F., Damci, E., and Stockhecke, M.: Seismic stratigraphy of Lake Van, eastern Turkey, Quat. Sci. Rev., 104, 63-84, https://doi.org/10.1016/j.quascirev.2014.07.016, 2014a.

30   Cukur, D., Krastel, S., Schmincke, H. U., Sumita, M., Tomonaga, Y., and Çağatay, M. N.: Water level changes in Lake Van, Turkey, during the past ca. 600 ka: climatic, volcanic and tectonic controls J. Paleolimnol., 52(3), 201-214, https://doi.org/10.1007/s10933-014-9788-0, 2014b.

Dana, G. L., and Lenz, P. H.: Effects of increasing salinity on an Artemia population from Mono Lake, California, Oecologia, 68(3), 428-436, https://doi.org/10.1007/BF01036751, 1986.

Danielopol D.L., Cabral M.C., Lord A., Carbonel P., Gross M., Stoica M., Humphreys W.F., Namiotko T., Tóth E., Külköylüoğlu O., Piller W.E., and Nunes T.: Sieve-type pore canals in the Timiriaseviinae - A contribution to the comparative morphology and the systematics of the Limnocytheridae (Ostracoda, Crustacea), Zootaxa, 4495(1), 1-64, https://doi.org/10.11646/zootaxa.4495.1.1., 2018.

5   De Deckker, P. and Forester, R. M.: The Use of Ostracods to Reconstruct Palaeoenvironmental Records, in: Ostracoda in the Earth Sciences, edited by: De Deckker, P., Colin, J.P., Peypouquet, J.P., Elsevier, Amsterdam, 175-199, 1988.

De Deckker, P.: Ostracods of athalassic saline lakes, Hydrobiologica, 81, 131-144, https://doi.org/10.1007/978-94-009-8665-7_10, 1981.

De Deckker, P., and Lord, A.: *Cyprideis torosa*: a model organism for the Ostracoda?, J. Micropalaeontol., 36(1), 3-6,
10   https://doi.org/10.1144/jmpaleo2016-100, 2017.

De Deckker, P., Chivas, A. R., and Shelley, J. M. G.: Uptake of Mg and Sr in the euryhaline ostracod *Cyprideis* determined from in vitro experiments, Palaeogeogr. Palaeoclimatol. Palaeoecol., 148(1-3), 105-116, https://doi.org/10.1016/S0031-0182(98)00178-3, 1999.

Decrouy, L.: Biological and environmental controls on isotopes in ostracod shells, in: Ostracoda as proxies for quaternary
15   climate change, edited by: Horne, D., Holmes, J., Rodriguez-Lazaro, J., Viehberg, F., Elsevier, Oxford, 165-181, https://doi.org/10.1016/B978-0-444-53636-5.00010-X, 2012.

Decrouy, L., and Vennemann, T. W.: Potential influence of the chemical composition of water on the stable oxygen isotope composition of continental ostracods, J. Paleolimnol., 50(4), 577-582, https://doi.org/10.1007/s10933-013-9719-5, 2013.

Decrouy, L., Vennemann, T. W., and Ariztegui, D.: Controls on ostracod valve geochemistry: Part 2. Carbon and oxygen
20   isotope compositions., Geochim. Cosmochim. Acta, 75(22), 7380-7399, https://doi.org/10.1016/j.gca.2011.09.008, 2011.

Decrouy, L., Vennemann, T. W., and Ariztegui, D.: Sediment penetration depths of epi-and infaunal ostracods from Lake Geneva (Switzerland), Hydrobiologia, 688(1), 5-23, https://doi.org/10.1007/s10750-010-0561-8, 2012.

Devriendt, L. S., McGregor, H. V., and Chivas, A. R.: Ostracod calcite records the $^{18}O/^{16}O$ ratio of the bicarbonate and carbonate ions in water, Geochim. Cosmochim. Acta, 214, 30-50, https://doi.org/10.1016/j.gca.2017.06.044. 2017.

25   Digerfeldt, G., Olsson, S., and Sandgren, P.: Reconstruction of lake-level changes in lake Xinias, central Greece, during the last 40 000 years, Palaeogeogr. Palaeoclimatol. Palaeoecol., 158(1-2), 65-82, https://doi.org/10.1016/S0031-0182(00)00029-8. 2000.

Dor, Y. B., Armon, M., Ahlborn, M., Morin, E., Erel, Y., Brauer, A., Schwab, M. J., Tjallingii, R., & Enzel, Y.: Changing flood frequencies under opposing late Pleistocene eastern Mediterranean climates, Sci. Rep., 8(1), 1-10,
30   https://doi.org/10.1038/s41598-018-25969-6, 2018.

Edwards, S., McKirdy, D. M., Bone, Y., Gell, P. A., and Gostin, V. A.: Diatoms and ostracods as mid-Holocene palaeoenvironmental indicators, North Stromatolite Lake, Coorong National Park, South Australia, Aust. J. Earth Sci., 53(4), 651-663, https://doi.org/10.1080/08120090600686801. 2006.

Engstrom, D. R., and Nelson, S. R.: Paleosalinity from trace metals in fossil ostracodes compared with observational records at Devils Lake, North Dakota, USA, Palaeogeogr. Palaeoclimatol. Palaeoecol., 83(4), 295-312, https://doi.org/10.1016/0031-0182(91)90057-X, 1991.

Forester, R. M.: Relationship of two lacustrine ostracode species to solute composition and salinity: implications for
5   paleohydrochemistry, Geology, 11(8), 435-438, https://doi.org/10.1130/0091-7613(1983)11<435:ROTLOS>2.0.CO;2, 1983.

Forester, R. M.: Determination of the dissolved anion composition of ancient lakes from fossil ostracodes, Geology, 14(9), 796-799, https://doi.org/10.1130/0091-7613(1986)14<796:DOTDAC>2.0.CO;2, 1986.

Forester, R. M.: Pliocene-climate history of the western United States derived from lacustrine ostracodes, Quat. Sci. Rev., 10(2-3), 133-146, https://doi.org/10.1016/0277-3791(91)90014-L. 1991.

10 Forester, R. M., and Brouwers, E. M.: Hydrochemical parameters governing the occurrence of estuarine and marginal estuarine ostracodes: an example from south-central Alaska, Journal of Paleontology, 59(2), 344-369, 1985.

Frenzel, P., Schulze, I., and Pint, A.: Noding of *Cyprideis torosa* valves (Ostracoda) – a proxy for salinity? New data from field observations and a long-term microcosm experiment, Int. Rev. Hydrobiol., 97(4), 314-329, https://doi.org/10.1002/iroh.201211494, 2012.

15 Frogley, M. R., Griffiths, H. I., and Heaton, T. H.: Historical biogeography and Late Quaternary environmental change of Lake Pamvotis, Ioannina (north-western Greece): evidence from ostracods, J. Biogeogr., 28(6), 745-756, https://doi.org/10.1046/j.1365-2699.2001.00582.x. 2001.

Fuhrmann R.: Atlas quartärer und rezenter Ostrakoden Mitteldeutschlands. Naturkundliches Museum Mauritianum, Altenburg, 2012.

20 Fürstenberg, S., Frenzel, P., Peng, P., Henkel, K., and Wrozyna, C.: Phenotypical variation in *Leucocytherella sinensis* Huang, 1982 (Ostracoda): a new proxy for palaeosalinity in Tibetan lakes, Hydrobiologia, 751(1), 55-72, 2015.

Gouramanis, C., and De Deckker, P.: Alkalinity control on the partition coefficients in lacustrine ostracodes from Australia, Geology, 38(4), 359-362, https://doi.org/10.1130/G30235.1, 2010.

Gouramanis, C., Wilkins, D., and De Deckker, P.: 6000 years of environmental changes recorded in Blue Lake, South
25 Australia, based on ostracod ecology and valve chemistry. Palaeogeogr. Palaeoclimatol. Palaeoecol., 297(1), 223-237, https://doi.org/10.1016/j.palaeo.2010.08.005, 2010.

Hammarlund, D., Aravena, R., Barnekow, L., Buchardt, B., and Possnert, G.: Multi-component carbon isotope evidence of early Holocene environmental change and carbon-flow pathways from a hard-water lake in northern Sweden, J. Paleolimnol., 18(3), 219-233, https://doi.org/10.1023/A:1007953614927, 1997.

30 Heaton, T. H. E., Holmes, J. A., and Bridgwater, N. D.: Carbon and oxygen isotope variations among lacustrine ostracods: implications for palaeoclimatic studies, The Holocene, 5(4), 428-434, https://doi.org/10.1177/095968369500500405, 1995.

Holmes, J. A.: Trace-element and stable-isotope geochemistry of non-marine ostracod shells in Quaternary palaeoenvironmental reconstruction, J. Paleolimnol., 15(3), 223-235, https://doi.org/10.1007/BF00213042, 1996.

Holmes, J. A., and De Deckker, P.: The chemical composition of ostracod shells: applications in Quaternary palaeoclimatology, in: Ostracoda as proxies for quaternary climate change, edited by: Horne, D., Holmes, J., Rodriguez-Lazaro, J., Viehberg, F., Elsevier, Oxford, 131-143, https://doi.org/10.1016/B978-0-444-53636-5.00008-1, 2012.

Holmes, J. A., Allen, M. J., Street-Perrott, F. A., Ivanovich, M., Perrott, R. A., and Waller, M. P.: Late Holocene
5 palaeolimnology of Bal Lake, northern Nigeria, a multidisciplinary study, Palaeogeogr. Palaeoclimatol. Palaeoecol., 148(1-3), 169-185, https://doi.org/10.1016/S0031-0182(98)00182-5, 1999.

Holmes, J., Sayer, C. D., Liptrot, E., and Hoare, D. J.: Complex controls on ostracod palaeoecology in a shallow coastal brackish-water lake: implications for palaeosalinity reconstruction, Freshwater Biology, 55(12), 2484-2498, https://doi.org/10.1111/j.1365-2427.2010.02478.x, 2010.

10 Horne, D. J., Holmes, J. A., Rodriguez-Lazaro, J., and Viehberg, F. A.: Ostracoda as proxies for Quaternary climate change: overview and future prospects, in: Ostracoda as proxies for quaternary climate change, edited by: Horne, D., Holmes, J., Rodriguez-Lazaro, J., Viehberg, F., Elsevier, Oxford, 305-315, https://doi.org/10.1016/B978-0-444-53636-5.00018-4, 2012.

Huang, B., Yang H., and You, K.,: Pliocene and Quaternary Ostracoda from southern and southwestern Xizang, in: Integrated Survey of Tibetan Plateau of Chinese Academy of Sciences, Palaeobiology of Xizang 4, 326-348, in Chinese with English
15 abstract, 1982.

Jones, M. D., Abu-Jaber, N., AlShdaifat, A., Baird, D., Cook, B. I., Cuthbert, M. O., Dean, J. R., Djamali, M., Eastwood, W., Fleitmann, D., Haywood, A., Kwiecien, O., Larsen, J., Maher, L. A., Metcalfe, S. E., Parker, A., Petrie, C. A., Primmer, N., Richter, T., Roberts, N., Roe, J., Tindall, J. C., Ünal-Imer, E., Weeks, L.: 20,000 years of societal vulnerability and adaptation to climate change in southwest Asia, WIREs Water, 6(2), 1-31, https://doi.org/10.1002/wat2.1330, 2018.

20 Jones, T. R.: Description of the Entomostraca of the Pleistocene Beds of Newbury, Copford, Clacton, and Grays, The Annals and Magazine of Natural History Series, 2(6), 25-28, 1850.

Karanovic, I.: Recent Freshwater Ostracods of the World, Springer-Verlag, Berlin. 2012.

Keatings, K. W., Heaton, T. H. E., and Holmes, J. A.: Carbon and oxygen isotope fractionation in non-marine ostracods: results from a 'natural culture' environment, Geochim. Cosmochim. Acta, 66(10), 1701-1711, https://doi.org/10.1016/S0016-
25 7037(01)00894-8, 2002.

Keatings, K., Holmes, J., Flower, R., Horne, D., Whittaker, J. E., and Abu-Zied, R. H.: Ostracods and the Holocene palaeolimnology of Lake Qarun, with special reference to past human–environment interactions in the Faiyum (Egypt), Hydrobiologia, 654(1), 155-176, https://doi.org/10.1007/s10750-010-0379-4, 2010.

Kelts, K., Talbot, M.: Lacustrine carbonates as geochemical archives of environmental change and biotic/abiotic interactions,
30 in: Large Lakes: Ecological Structure and Function, edited by: Tilzer, M. M., Serruya, C. Science Technical Publications, Madison, 290-317, 1990.

Kempe, S., Kazmierczak, J., Landmann, G., Konuk, T., Reimer, A., and Lipp, A.: Largest known microbialites discovered in Lake Van, Turkey, Nature, 349(6310), 605-608, https://doi.org/10.1038/349605a0, 1991.

Keyser, D.: Histological peculiarities of the noding process in *Cyprideis torosa* (Jones)(Crustacea, Ostracoda), Hydrobiologia, 538(1-3), 95-106, https://doi.org/10.1007/s10750-004-4940-x, 2005.

Keyser, D., and Aladin, N.: Noding in *Cyprideis torosa* and its causes, Studia Quaternaria, 21, 19-24. 2004.

Kilenyi, T. I.: Transient and balanced genetic polymorphism as an explanation of variable noding in the ostracode *Cyprideis*
5 *torosa*, Micropaleontology, 18(1), 47-63, https://doi.org/10.2307/1484978, 1972.

Kim, S. T., and O'Neil, J. R.: Equilibrium and nonequilibrium oxygen isotope effects in synthetic carbonates, Geochim. Cosmochim. Acta, 61(16), 3461-3475, https://doi.org/10.1016/S0016-7037(97)00169-5, 1997.

Külköylüoğlu, O., N. Sari and D. Akdemir,: Distribution and ecological requirements of ostracods (Crustacea) at high altitudinal ranges in Northeastern Van (Turkey), Ann. Limnol.-Int. J. Lim., 48(1), 39-51,
10 https://doi.org/10.1051/limn/2011060, 2012.

Kwiecien, O., Stockhecke, M., Pickarski, N., Heumann, G., Litt, T., Sturm, M., Anselmetti, F., Kipfer, R., and Haug, G. H.: Dynamics of the last four glacial terminations recorded in Lake Van, Turkey, Quat. Sci. Rev., 104, 42-52, https://doi.org/10.1016/j.quascirev.2014.07.001, 2014.

Landmann, G., Reimer, A., and Kempe, S.: Climatically induced lake level changes at Lake Van, Turkey, during the
15 Pleistocene/Holocene transition, Glob. Biogeochem. Cycles, 10(4), 797-808, https://doi.org/10.1029/96GB02347, 1996.

Leng, M. J., and Marshall, J. D.: Palaeoclimate interpretation of stable isotope data from lake sediment archives, Quat. Sci. Rev., 23(7-8), 811-831, https://doi.org/10.1016/j.quascirev.2003.06.012, 2004.

Li, H. C., and Ku, T. L.: $\delta^{13}C$-$\delta^{18}C$ covariance as a paleohydrological indicator for closed-basin lakes, Palaeogeogr. Palaeoclimatol. Palaeoecol., 133(1), 69-80, https://doi.org/10.1016/S0031-0182(96)00153-8, 1997.

20 Li, X., Liu, W., Zhang, L., and Sun, Z.: Distribution of recent ostracod species in the Lake Qinghai area in northwestern China and its ecological significance, Ecol. Indic., 10(4), 880-890, https://doi.org/10.1016/j.ecolind.2010.01.012, 2010.

Li, X., Liu, W., Zhang, P., An, Z., and Zhang, L.: Species, valve size, and pretreatment effects on $\delta^{18}O$ and $\delta^{13}C$ values of ostracod valves from Lake Qinghai, Qinghai–Tibet Plateau, Chem. Geol., 246(1-2), 124-134, https://doi.org/10.1016/j.chemgeo.2007.09.007, 2007.

25 Lister, G. S.: Stable isotopes from lacustrine Ostracoda as tracers for continental palaeoenvironments, in: Ostracoda in the Earth Sciences, edited by: De Deckker, P., Colin, J.P., Peypouquet, J.P. Elsevier, Amsterdam, 201-218. 1988.

Litt, T., and Anselmetti, F. S.: Lake Van deep drilling project PALEOVAN, Quat. Sci. Rev., 104, 1-7, https://doi.org/10.5194/sd-14-18-2012, 2014.

Litt, T., Anselmetti, F. S., Baumgarten, H., Beer, J., Çağatay, N., Cukur, D., Damci, E., Glombitza, C., Haug, G., Heumann,
30 G., Kallmeyer, J., Kipfer, R., Krastel, S., Kwiecien, O., Meydan, A. F., Orcen, S., Pickarski, N., Randlett, M.-E., Schmincke, H.-U., Schubert, C. J., Sturm, M., Sumita, M., Stockhecke, M., Tomonaga, Y., Vigliotti, L., Wonik, T., and the PALEOVAN Scientific Team: 500,000 Years of environmental history in eastern Anatolia: the PALEOVAN drilling project, Scientific Drilling, 14, 18-29, https://doi.org/10.5194/sd-14-18-2012, 2012.

Litt, T., Krastel, S., Sturm, M., Kipfer, R., Örcen, S., Heumann, G., Franz, S. O., Ülgen, U. B., and Niessen, F.: 'PALEOVAN', International Continental Scientific Drilling Program (ICDP): site survey results and perspectives, Quat. Sci. Rev., 28(15), 1555-1567, https://doi.org/10.1016/j.quascirev.2009.03.002, 2009.

Litt, T., Pickarski, N., Heumann, G., Stockhecke, M., and Tzedakis, P. C.: A 600,000 year long continental pollen record from Lake Van, eastern Anatolia (Turkey), Quat. Sci. Rev., 104, 30-41, https://doi.org/10.1016/j.quascirev.2014.03.017, 2014.

Marco-Barba, J., Ito, E., Carbonell, E., and Mesquita-Joanes, F.: Empirical calibration of shell chemistry of *Cyprideis torosa* (Jones, 1850)(Crustacea: Ostracoda), Geochim. Cosmochim. Acta, 93, 143-163, https://doi.org/10.1016/j.gca.2012.06.019, 2012.

Marco-Barba, J., Mesquita-Joanes, F., and Miracle, M. R.: Ostracod palaeolimnological analysis reveals drastic historical changes in salinity, eutrophication and biodiversity loss in a coastal Mediterranean lake, The Holocene, 23(4), 556-567, https://doi.org/10.1177/0959683612466752, 2013.

Martens, K.: Effects of temperature and salinity on postembryonic growth in *Mytilocypris henricae* (Chapman)(Crustacea, Ostracoda), J. Crustac. Biol., 5(2), 258-272. https://doi.org/10.2307/1547873, 1985.

McCormack J., Akdemir, D., Kwiecien, O., and Viehberg, F.: The Quaternary ostracod fauna of the ancient soda lakes of Asia Minor with special emphasis on Lake Van (Turkey). Manuscript in preparation.

McCormack, J., Bontognali, T. R. R., Immenhauser, A., and Kwiecien, O.: Controls on Cyclic Formation of Quaternary Early Diagenetic Dolomite, Geophys. Res. Lett., 45(8), 3625-3634, https://doi.org/10.1002/2018GL077344, 2018.

McCormack, J., Nehrke, G., Jöns, N., Immenhauser, A., and Kwiecien, O.: Refining the interpretation of lacustrine carbonate isotope records: Implications of a mineralogy-specific Lake Van case study, Chem. Geol., https://doi.org/10.1016/j.chemgeo.2019.03.014, 2019.

Meisch, C.: Freshwater Ostracoda of Western and Central Europe, in: Süßwasserfauna von Mitteleuropa, edited by: Schwoerbel, J. and Zwick, P., Akademischer Verlag Spektrum, Heidelberg, 1-522, 2000.

Mesquita-Joanes F., Smith A.J., Viehberg F.A.: The Ecology of Ostracoda Across Levels of Biological Organisation from Individual to Ecosystem: A Review of Recent Developments and Future Potential, in: Developments in Quaternary Sciences, Vol. 17, edited by: Horne D.J., Holmes J.A., Rodriguez-Lazaro J., Viehberg F.A., Elsevier, Amsterdam, 15-35, https://doi.org/10.1016/B978-0-444-53636-5.00002-0, 2012.

Meyer, J., Wrozyna, C., Gross, M., Leis, A., and Piller, W. E.: Morphological and geochemical variations of Cyprideis (Ostracoda) from modern waters of the northern Neotropics, Limnology, 18(3), 251-273, https://doi.org/10.1007/s10201-016-0504-9, 2016.

Neale, J.W.: Ostracods and palaeosalinity reconstruction, in: Ostracoda in the Earth Sciences, edtied by: De Deckker, P., Colin, J.P., Peypouquet, J.P., Elsevier, Amsterdam, 125-157, 1988.

NGRIP members, Andersen, K. K., Azuma, N., Barnola, J. M., Bigler, M., Biscaye, P., Caillon, N., Chappellaz, J., Clausen, H. B., Dahl-Jensen, D., Fischer, H., Flückiger, J., Fritzsche, D., Fujii, Y., Goto-Azuma, K., Grønvold, K., Gundestrup, N. S., Hansson, M., Huber, C., Hvidberg, C. S., Johnsen, S. J., Jonsell, U., Jouzel, J., Kipfstuhl, S., Landais, A., Leuenberger, M.,

Lorrain, R., Masson-Delmotte, V., Miller, H., Motoyama, H., Narita, H., Popp, T., Rasmussen, S. O., Raynaud, D., Rothlisberger, R., Ruth, U., Samyn, D., Schwander, J., Shoji, H., Siggard-Andersen, M.-L., Steffensen, J. P., Stocker, T., Sveinbjörnsdóttir, A. E., Svensson, A., Takata, M., Tison, J.-L., Thorsteinsson, T., Watanabe, O., Wilhelms, F., White, J. W. C.,: High-resolution record of Northern Hemisphere climate extending into the last interglacial period, Nature, 431(7005), 147-151, https://doi.org/10.1038/nature02805, 2004.

North, S. M., Stockhecke, M., Tomonaga, Y., and Mackay, A. W.: Analysis of a fragmentary diatom record from Lake Van (Turkey) reveals substantial lake-level variability during previous interglacials MIS7 and MIS5e, J. Paleolimnol., 59(1), 119-133, https://doi.org/10.1007/s10933-017-9973-z, 2017.

Pickarski, N., and Litt, T.: A new high-resolution pollen sequence at Lake Van, Turkey: insights into penultimate interglacial–glacial climate change on vegetation history, Clim. Past, 13(6), 689, https://doi.org/10.5194/cp-13-689-2017, 2017.

Pickarski, N., Kwiecien, O., Djamali, M., and Litt, T.: Vegetation and environmental changes during the last interglacial in eastern Anatolia (Turkey): a new high-resolution pollen record from Lake Van, Palaeogeogr. Palaeoclimatol. Palaeoecol., 435, 145-158, https://doi.org/10.1016/j.palaeo.2015.06.015, 2015a.

Pickarski, N., Kwiecien, O., Langgut, D., and Litt, T.: Abrupt climate and vegetation variability of eastern Anatolia during the last glacial, Clim. Past, 11(11), 1491-1505, https://doi.org/10.5194/cp-11-1491-2015, 2015b.

Randlett, M. E., Bechtel, A., van der Meer, M. T., Peterse, F., Litt, T., Pickarski, N., Kwiecien, O., Stockhecke, M., Wehrli, B., and Schubert, C. J.: Biomarkers in Lake Van sediments reveal dry conditions in eastern Anatolia during 110.000–10.000 years BP, Geochem. Geophys., 18(2), 571-583, https://doi.org/10.1002/2016GC006621, 2017.

Reimer, A., Landmann, G., and Kempe, S.: Lake Van, eastern Anatolia, hydrochemistry and history. Aquat. Geochem., 15(1-2), 195-222, https://doi.org/10.1007/s10498-008-9049-9, 2009.

Rosenfeld, A., and Vesper, B.: The variability of the sieve-pores in Recent and fossil species of *Cyprideis torosa* (Jones, 1850) as an indicator for salinity and palaeosalinity, in: Aspects of Ecology and Zoogeography of Recent and Fossil Ostracoda, edited by: Löffler, H., Danielopol, D., Junk, The Hague, 55-67, 1977.

Ruiz, F., Abad, M., Bodergat, A. M., Carbonel, P., Rodríguez-Lázaro, J., González-Regalado, M. L., Toscano, A., García, E. X., and Prenda, J.: Freshwater ostracods as environmental tracers, Int. J. Environ. Sci. Technol., 10(5), 1115-1128, https://doi.org/10.1007/s13762-013-0249-5, 2013.

Smith, A. J.: Lacustrine ostracodes as hydrochemical indicators in lakes of the north-central United States. J. Paleolimnol., 8(2), 121-134, https://doi.org/10.1007/BF00119785, 1993.

Smith, A. J., and Palmer, D. F.: The versatility of Quaternary ostracods as palaeoclimate proxies: comparative testing of geochemical, ecological and biogeographical approaches, in: Ostracoda as proxies for quaternary climate change, edited by: Horne, D., Holmes, J., Rodriguez-Lazaro, J., Viehberg, F., Elsevier, Oxford, 183-203, https://doi.org/10.1016/B978-0-444-53636-5.00011-1, 2012.

Steffensen, J. P., Andersen, K. K., Bigler, M., Clausen, H. B., Dahl-Jensen, D., Fischer, H., Goto-Azuma, K., Hansson, M., Johnson, S. J., Jouzel, J., Masson-Delmotte, V., Popp, T., Rasmussen, S. O., Röthlisberger, R., Ruth, U., Stauffer, B., Siggaard-

Andersen M.-L., Sveinbjörnsdóttir, A. E., Svensson, A., and White, J. W. C.: High-resolution Greenland ice core data show abrupt climate change happens in few years, Science, 321(5889), 680-684, https://doi.org/10.1126/science.1157707, 2008.

Stevens, L. R., Djamali, M., Andrieu-Ponel, V., and de Beaulieu, J. L.: Hydroclimatic variations over the last two glacial/interglacial cycles at Lake Urmia, Iran, J. Paleolimnol., 47(4), 645-660, https://doi.org/10.1007/s10933-012-9588-3, 2012.

Stockhecke, M., Anselmetti, F. S., Meydan, A. F., Odermatt, D., and Sturm, M.: The annual particle cycle in Lake Van (Turkey), Palaeogeogr. Palaeoclimatol. Palaeoecol., 333, 148-159, https://doi.org/10.1016/j.palaeo.2012.03.022, 2012.

Stockhecke, M., Kwiecien, O., Vigliotti, L., Anselmetti, F. S., Beer, J., Çağatay, M. N., Channell, J. E. T., Kipfer, R., Lachner, J., Litt, T., Pickarski, N., and Sturm, M.: Chronostratigraphy of the 600,000 year old continental record of Lake Van (Turkey), Quat. Sci. Rev., 104, 8-17, https://doi.org/10.1016/j.quascirev.2014.04.008, 2014b.

Stockhecke, M., Sturm, M., Brunner, I., Schmincke, H. U., Sumita, M., Kipfer, R., Cukur, D., Kwiecien, O., and Anselmetti, F. S.: Sedimentary evolution and environmental history of Lake Van (Turkey) over the past 600 000 years, Sedimentology, 61(6), 1830-1861, https://doi.org/10.1111/sed.12118, 2014a.

Suzin, A. V.: Ostracoda from tertiary deposits of the North Caucasus. Grozninskii Orlena Trudovogo Krasnogo Znameni Nephtrnoi Institut, 11-184, [in Russian], 1956.

Svensson, A., Andersen, K. K., Bigler, M., Clausen, H. B., Dahl-Jensen, D., Davies, S. M., Johnsen, S. J., Muscheler, R., Parrenin, F., Rasmussen, S. O., Röthlisberger, R., Seierstad, I., Steffensen, J. P., and Vinther, B. M.: A 60 000 year Greenland stratigraphic ice core chronology, Clim. Past, 4(1), 47-57, https://doi.org/10.5194/cp-4-47-2008, 2008.

Tomonaga, Y., Brennwald, M. S., Livingstone, D. M., Kwiecien, O., Randlett, M. È., Stockhecke, M., Unwin, K., Anselmetti, F. S., Beer, J., Haug, G. H., Schubert, C. J., Sturm, M., and Kipfer, R.: Porewater salinity reveals past lake-level changes in Lake Van, the Earth's largest soda lake, Sci. Rep., 7, 1-10, https://doi.org/10.1038/s41598-017-00371-w, 2017.

Tressler, W. L.: The Ostracoda of Great Slave Lake, J. Wash. Acad. Sci., 47(12), 415-423, 1957.

Van der Meeren T., Verschuren D., Ito E., Martens K.: Morphometric techniques allow environmental reconstructions from low-diversity continental ostracode assemblages, J. Paleolimnol., 44(4), 903-911, https://doi.org/10.1007/s10933-010-9463-z, 2010.

Tzedakis, P. C., Seven ambiguities in the Mediterranean palaeoenvironmental narrative, Quat. Sci. Rev., 26(17-18), 2042-2066, https://doi.org/10.1016/j.quascirev.2007.03.014, 2007.

Van der Meeren, T., Ito, E., Verschuren, D., Almendinger, J. E., and Martens, K.: Valve chemistry of *Limnocythere inopinata* (Ostracoda) in a cold arid environment – implications for paleolimnological interpretation, Palaeogeogr. Palaeoclimatol. Palaeoecol., 306(3-4), 116-126, https://doi.org/10.1016/j.palaeo.2011.04.006, 2011.

Van Harten, D.: Variable noding in *Cyprideis torosa* (Ostracoda, Crustacea): an overview, experimental results and a model from Catastrophe Theory, Hydrobiologia, 419(1), 131-139, https://doi.org/10.1023/A:1003935419364, 2000.

Vesper, B.: To the problem of noding on *Cyprideis torosa* (Jones, 1850), Bulletin of American Paleontology, 65, 205-216, 1975.

Viehberg F.A., Mesquita-Joanes F. : Quantitative Transfer Function Approaches in Palaeoclimatic Reconstruction Using Quaternary Ostracods, in: Ostracoda as Proxies for Quaternary Climate Change, Vol. 17, edited by: Horne D.J., Holmes J.A., Rodriguez-Lazaro J., Viehberg F.A., Elsevier, Amsterdam, 47-64, https://doi.org/10.1016/B978-0-444-53636-5.00004-4, 2012.

5   von Grafenstein, U., Eicher, U., Erlenkeuser, H., Ruch, P., Schwander, J., and Ammann, B.: Isotope signature of the Younger Dryas and two minor oscillations at Gerzensee (Switzerland): palaeoclimatic and palaeolimnologic interpretation based on bulk and biogenic carbonates, Palaeogeogr. Palaeoclimatol. Palaeoecol., 159(3-4), 215-229, https://doi.org/10.1016/S0031-0182(00)00086-9, 2000.

von Grafenstein, U., Erlernkeuser, H., and Trimborn, P.: Oxygen and carbon isotopes in modern fresh-water ostracod valves:
10   assessing vital offsets and autecological effects of interest for palaeoclimate studies, Palaeogeogr. Palaeoclimatol. Palaeoecol., 148(1-3), 133-152, https://doi.org/10.1016/S0031-0182(98)00180-1, 1999.

Wick, L., Lemcke, G., and Sturm, M.: Evidence of Lateglacial and Holocene climatic change and human impact in eastern Anatolia: high-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey, The Holocene, 13(5), 665-675, https://doi.org/10.1191/0959683603hl653rp, 2003.

15   Wilkinson, I. P., Bubikyan, S. A. and Gulakyan, S. Z.: The impact of late Holocene environmental change on lacustrine Ostracoda in Armenia, Palaeogeogr. Palaeoclimatol. Palaeoecol., 225(1-4), 187-202, https://doi.org/10.1016/j.palaeo.2005.06.010, 2005.

Wolff, E. W., Chappellaz, J., Blunier, T., Rasmussen, S. O., and Svensson, A.: Millennial-scale variability during the last glacial: The ice core record, Quat. Sci. Rev., 29(21), 2828-2838, https://doi.org/10.1016/j.quascirev.2009.10.013, 2010.

20   Wrozyna, C., Frenzel, P., Daut, G., Mäusbacher, R., Zhu, L., and Schwalb, A.: Holocene lake-level changes of Lake Nam Co, Tibetan Plateau, deduced from ostracod assemblages and $\delta^{18}O$ and $\delta^{13}C$ signatures of their valves, in: Ostracoda as Proxies for Quaternary Climate Change, Vol. 17, edited by: Horne, D., Holmes, J., Rodriguez-Lazaro, J., Viehberg, F., Elsevier, Amsterdam, 47-64, https://doi.org/10.1016/B978-0-444-53636-5.00016-0, 2012.

Xia, J., Ito, E., and Engstrom, D. R.: Geochemistry of ostracode calcite: Part 1. An experimental determination of oxygen
25   isotope fractionation, Geochim. Cosmochim. Acta, 61(2), 377-382, https://doi.org/10.1016/S0016-7037(96)00351-1, 1997.

Xu, H., Ai, L., Tan, L., and An, Z.: Stable isotopes in bulk carbonates and organic matter in recent sediments of Lake Qinghai and their climatic implications, Chem. Geol., 235(3-4), 262-275, https://doi.org/10.1016/j.chemgeo.2006.07.005, 2006.

Yin, Y., Geiger, W., and Martens, K.: Effects of genotype and environment on phenotypic variability in *Limnocythere inopinata* (Crustacea: Ostracoda), Hydrobiologia, 400, 85-114, https://doi.org/10.1023/A:1003759125903, 1999.

30   Zhang, J., Holmes, J. A., Chen, F., Qiang, M., Zhou, A., and Chen, S.: An 850-year ostracod-shell trace-element record from Sugan Lake, northern Tibetan Plateau, China: Implications for interpreting the shell chemistry in high-Mg/Ca waters, Quat. Int., 194(1-2), 119-133, https://doi.org/10.1016/j.quaint.2008.05.003, 2009.

Table 1. Isotopic variability (minimum, maximum and mean) between different species, sex, valve size and reticulation intensity from the ICDP Ahlat Ridge cores. For six samples, replicate analyses were performed with valves showing no differentiating characteristics. Calculated variance is represented by the difference of these replicate analyses. Analyses comparing sex, valve size and reticulation intensity were measured from the same stratigraphic horizon. n represents the number of measurements.

Analyses	n	$\delta^{18}O$			$\delta^{13}C$		
		minimum	maximum	mean	minimum	maximum	mean
Replicate analyses variance	12	0.0	0.5	0.2	0.1	0.5	0.2
L. inopinata	90	-1.1	5.1	2.4	-0.3	3.9	2.0
sex							
female	9	2.8	4.4	3.2	1.2	3.0	2.0
male	8	2.7	4.2	3.1	0.9	3.0	2.0
difference$_{male-female}$	17	0.1	0.4	0.2	0.0	1.1	0.4
valve size							
280 - 430 µm	5	2.1	3.5	2.8	1.4	3.0	2.0
460 - 640 µm	7	2.8	3.5	3.1	1.2	3.0	1.9
difference$_{size}$	12	0.0	1.0	0.4	0.0	0.5	0.2
morphotype							
reticulated	5	2.8	3.1	3.0	1.1	3.0	2.0
smooth	4	3.0	5.1	3.6	1.4	3.5	2.4
difference$_{reticulated-smooth}$	11	0.0	1.9	0.50	0.3	0.9	0.6
Limnocythere sp. A	40	0.9	5.1	3.5	1.7	3.5	2.6
sex							
female	1	4.16	4.16	4.16	3.47	3.47	3.47
male	1	4.14	4.14	4.14	3.53	3.53	3.53
difference$_{male-female}$	2	0.02	0.02	0.02	0.06	0.06	0.06
Candona sp.	10	2.2	4.8	3.7	-3.9	-0.6	-1.4

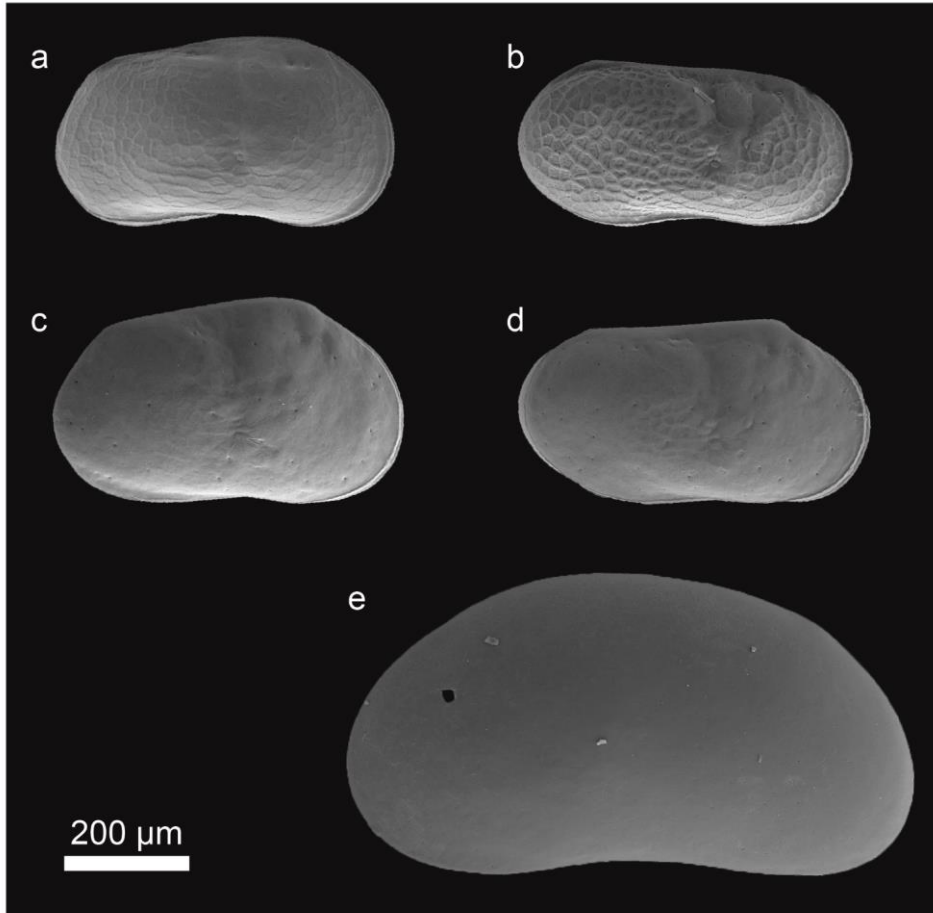



Figure 1: SEM photographs of the external lateral views of key species used in this study. a) female right valve *Limnocythere inopinata*, b) male right valve *Limnocythere inopinata*, c) female right valve *Limnocythere* sp. A, d) male right valve *Limnocythere* sp. A, e) female left valve *Candona* sp..

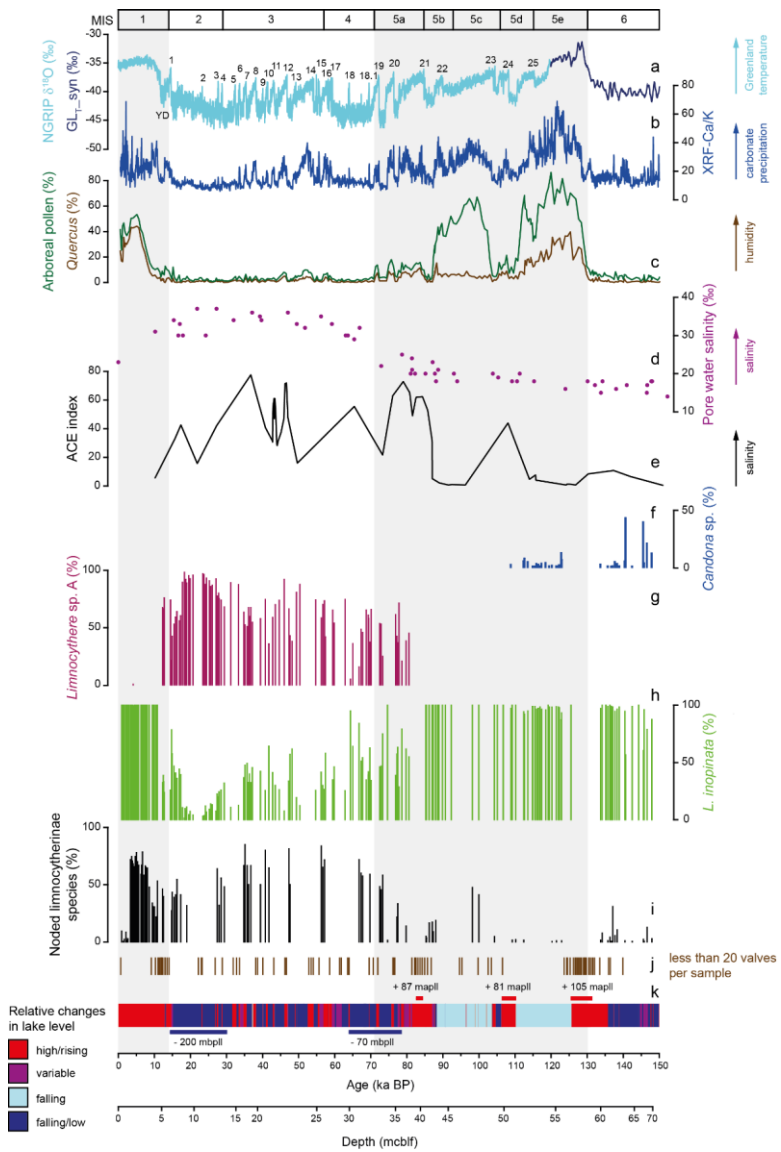



Figure 2. Relative distribution of ostracod taxa in Lake Van in comparison to various palaeoenvironmental proxy records. a) Isotopic composition of the NGRIP ice core (NGRIP, 2004; Steffensen et al., 2008; Svensson et al., 2008; Wolff et al., 2010) and a synthetic Greenland record (GL$_T$_syn) (Barker et al., 2011). Sedimentary proxies from Lake Van include (b) XRF-Ca/K ratio (Kwiecien et al., 2014), (c) arboreal pollen and *Quercus* pollen percentage (Litt et al., 2014; Pickarski et al., 2015a, b; Pickarski and Litt, 2017), d) pore water salinity plotted against depth in metre composite below lake floor (mcblf; Tomonaga et al., 2017), e) biomarker Archaeol and Caldarchaeol Ecometric (ACE) index (Randlett et al., 2017), and k) lithologies with genetic interpretations related to lake-level variability as coloured bar (simplified after Stockhecke et al., 2014a) and major lake-level variations (Stockhecke et al., 2014a; Tomonaga et al., 2017) in metre above/below present lake level (mapll/mbpll). f-h) relative abundance of ostracod taxa. f) *Candona* sp., g) *Limnocythere* sp. A, h) *Limnocythere inopinata*. i) Percentage of noded limnocytherinae species. j) Position of samples containing less than 20 valves, theses samples were not included in the statistical assemblage analyses. The grey shaded areas represent interglacials.

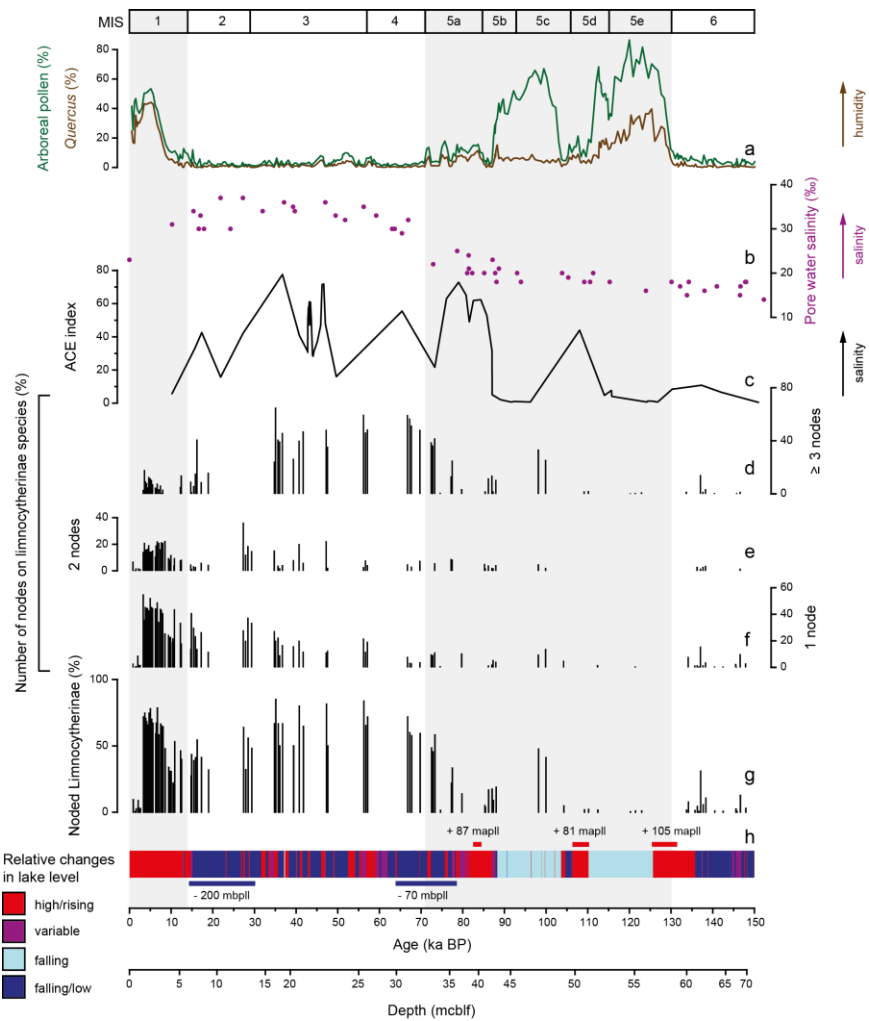



Figure 3. Amount and number of noded limnocytherinae species valves relative to Lake Van palaeoenvironmental proxy records. Sedimentary proxies from Lake Van include a) arboreal pollen and *Quercus* pollen percentage (Litt et al., 2014; Pickarski et al., 2015a, b; Pickarski and Litt, 2017), b) pore water salinity plotted against depth in metre composite below lake floor (mcblf; Tomonaga et al., 2017), c) biomarker Archaeol and Caldarchaeol Ecometric (ACE) index (Randlett et al., 2017) and h) lithologies with genetic interpretations related to lake-level variability as coloured bar (simplified after Stockhecke et al., 2014a) and major

lake-level variations (Stockhecke et al., 2014a; Tomonaga et al., 2017). d-f) Number of nodes in percent. g) Total percentage of noded limnocytherinae species. The grey shaded areas represent interglacials.

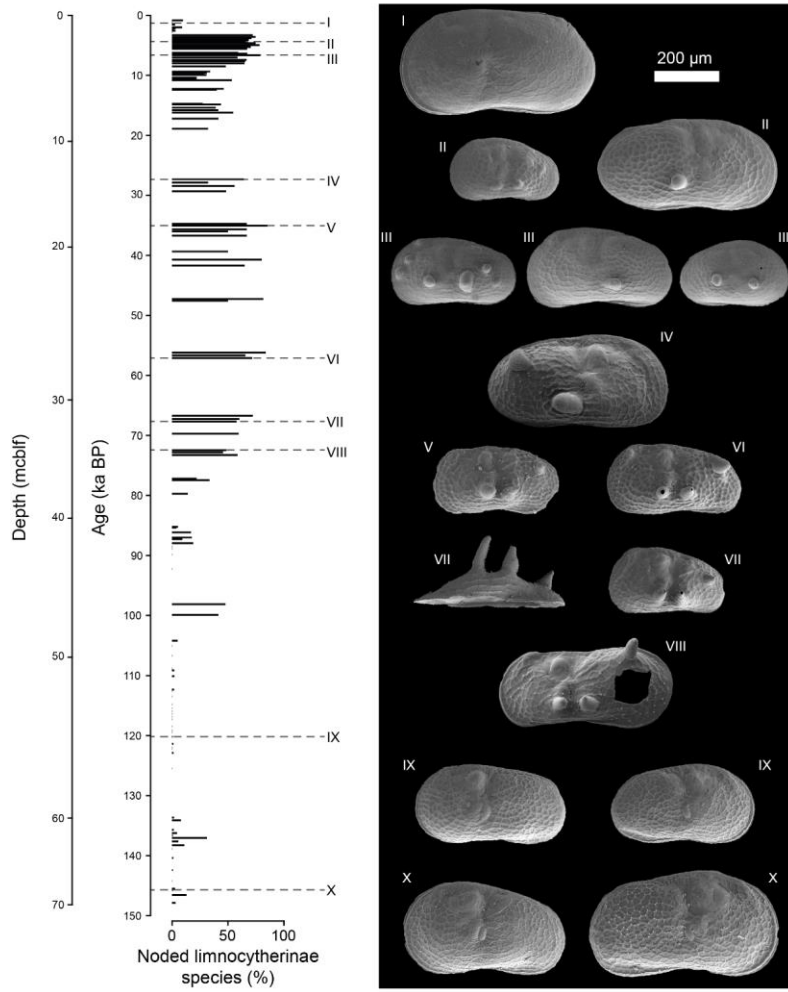
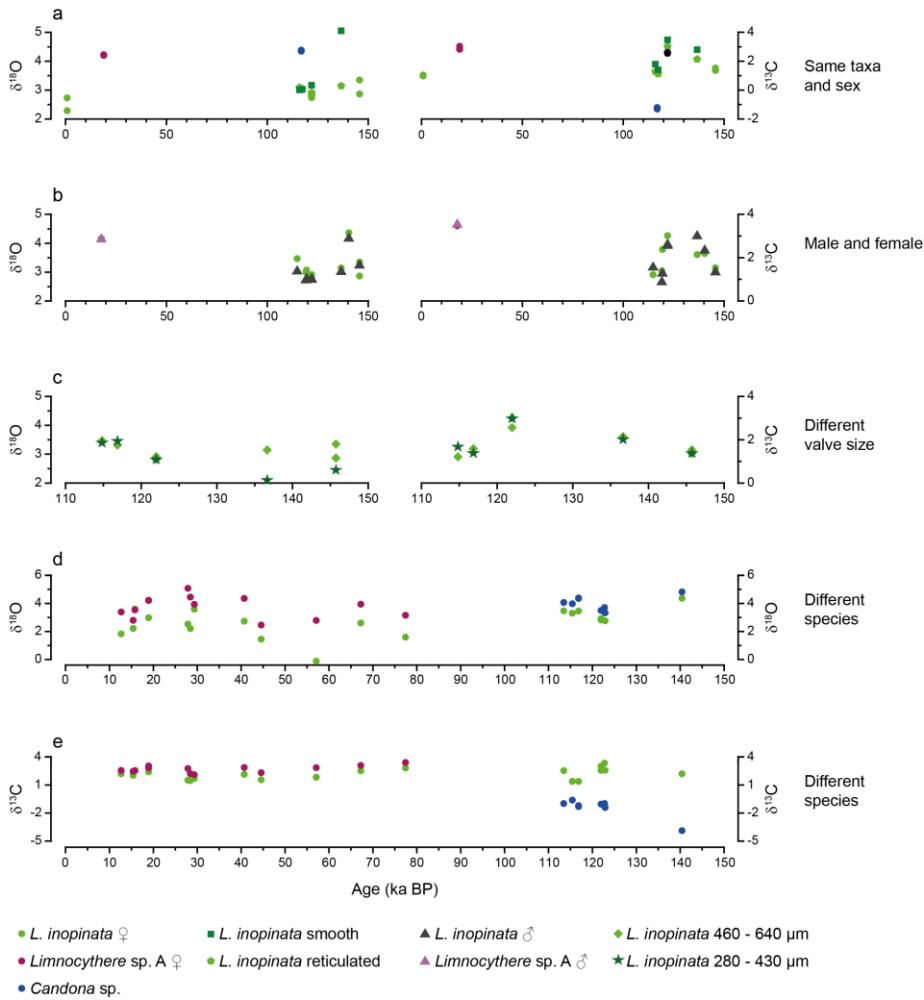
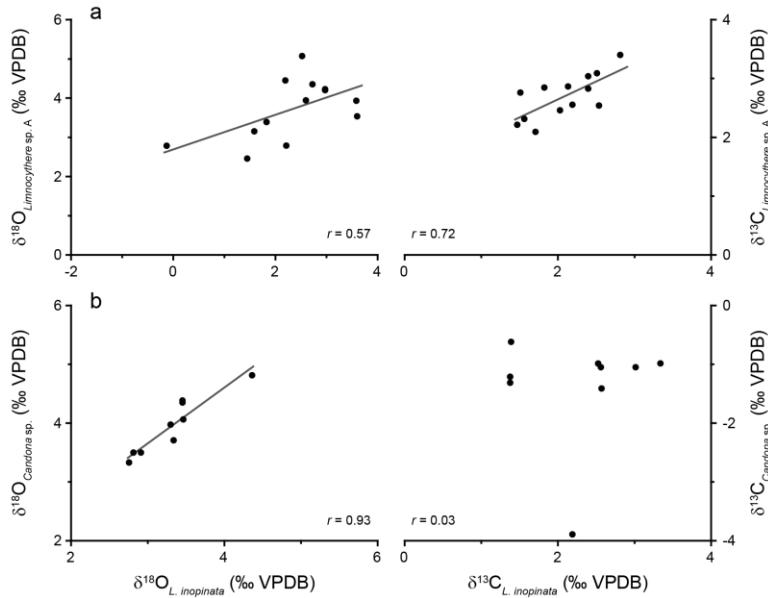



Figure 4. Illustration of amount and intensity of noded limnocytherinae species valves (as SEM images) within the studied interval. Roman numerals indicate the depth and age of individual valves. The valves displayed here are both from adult and juvenile ostracods.

- ● *L. inopinata* ♀
- ■ *L. inopinata* smooth
- ▲ *L. inopinata* ♂
- ◆ *L. inopinata* 460 - 640 µm
- ● *Limnocythere* sp. A ♀
- ● *L. inopinata* reticulated
- ▲ *Limnocythere* sp. A ♂
- ★ *L. inopinata* 280 - 430 µm
- ● *Candona* sp.

5   **Figure 5. Isotopic variability between ostracod measurements from the same stratigraphic horizon against age. a) Variability between valves of the same taxa and sex. b) Variability between *L. inopinata* and *Limnocythere* sp. A female and male valves. c)**

Variability between *L. inopinata* of different valve size. d) δ¹⁸O variability between *L. inopinata* and *Limnocythere* sp. A and *L. inopinata* and *Candona* sp.. e) δ¹³C variability between *L. inopinata* and *Limnocythere* sp. A and *L. inopinata* and *Candona* sp.. *Limnocythere* sp. A and *Candona* sp. could not be compared, as they never occur in the same stratigraphic horizon.

5   **Figure 6. Isotopic composition of *L. inopinata* valves versus *Limnocythere* sp. A (a) and *Candona* sp. (b).**

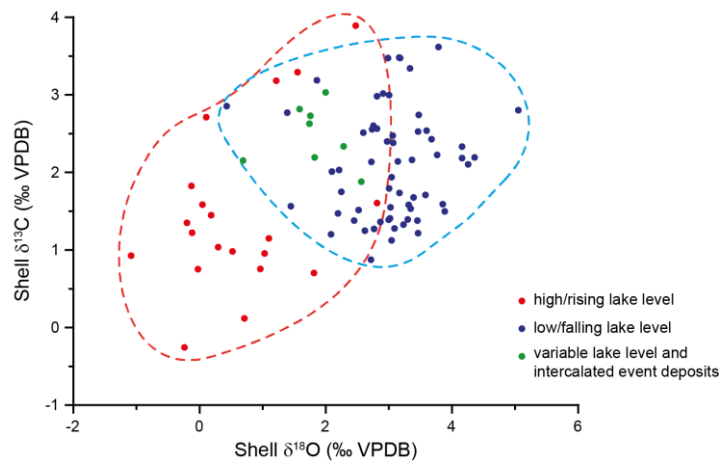



Figure 7. Ahlat Ridge *L. inopinata* δ¹⁸O versus δ¹³C values, colour coded after the lithology of their respective sampling horizon. Lithologies are colour coded after their genetic interpretations related to lake-level variability following Stockhecke et al. (2014a).

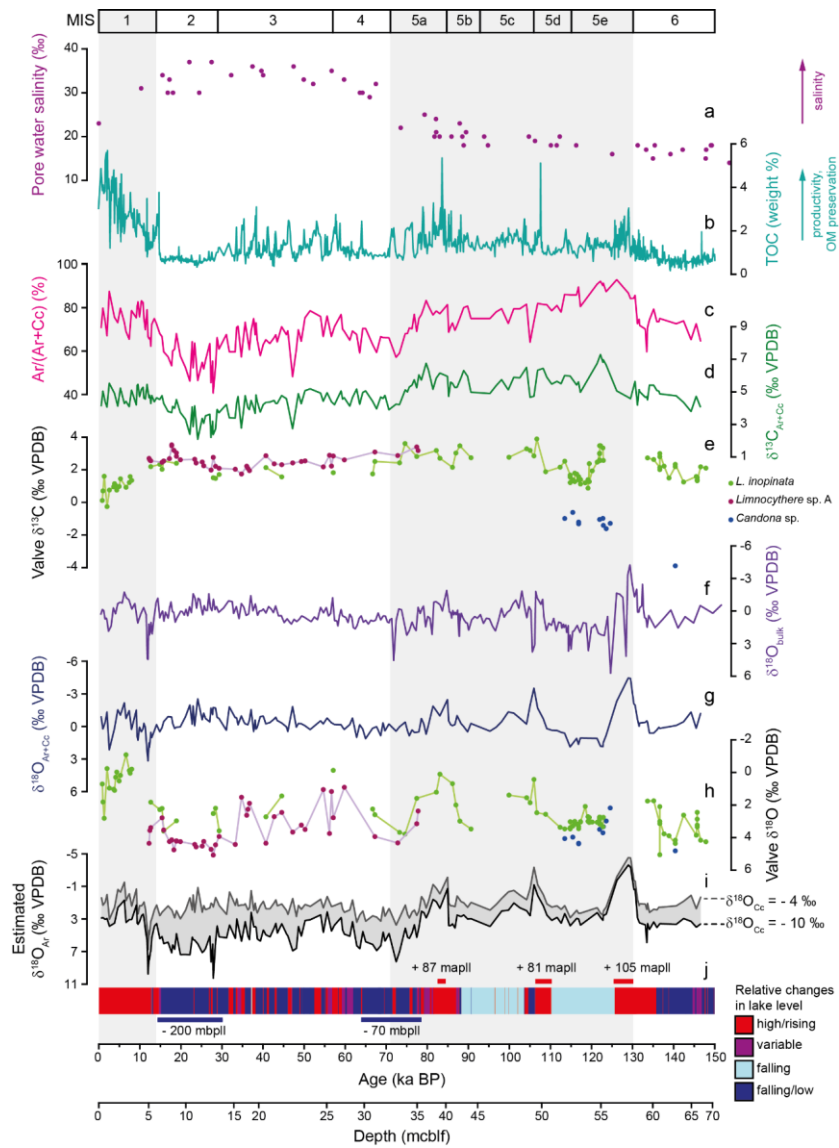



Figure 8. Ostracod isotopy compared with pore water salinity and inorganic carbonate isotopy and mineralogical composition. a) Pore water salinity plotted against depth in metre composite below lake floor (mcblf; Tomonaga et al., 2017). b) Total organic carbon content (Stockhecke et al., 2014a). c, d, g, i) Inorganic mineralogy and isotopy from McCormack at al. (~~in review~~2019). c) Relative aragonite content of dolomite poor samples (< 15 % dolomite) expressed by an aragonite/non-dolomite ratio Ar/(Ar+Cc) in weight % and d, g) isotopic composition of dolomite poor samples ($\delta^{13}C_{Ar+Cc}$ and $\delta^{18}O_{Ar+Cc}$). f) Bulk carbonate oxygen isotope composition from Kwiecien et al. (2014). i) Estimated $\delta^{18}O_{Ar}$ values for $\delta^{18}O_{Cc}$ values between -4 and -10 ‰. j) Lithology-based relative lake-level changes (simplified after Stockhecke et al., 2014a) and major lake-level variations (Stockhecke et al., 2014a; Tomonaga et al., 2017) in metre above/below present lake level (mapll/mbpll). e, h) valve $\delta^{18}O$ values and $\delta^{13}C$ values.