

Clim. Past Discuss., referee comment RC2  
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## Comment on cp-2021-149

Anonymous Referee #2

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Referee comment on "Expression of the "4.2 ka event" in the southern Rocky Mountains, USA" by David T. Liefert and Bryan N. Shuman, Clim. Past Discuss.,  
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This submission centres on identifying & interpreting evidence (or not) for a climatic anomaly at 4.2 ka in the southern Rocky Mountains of the USA, using new data from a lake sediment core. The authors present a very nice new multi-proxy palaeolimnological record, supported by a radiocarbon-based age-depth model and some modern lake water physical and geochemical observations. The authors conclude that their new record *does* preserve evidence for a climatic anomaly at 4.2 ka (and hence that their work provides support for a wider 4.2 ka event), but are a little hazy on the details of what exactly this climatic anomaly might have been, and (importantly) how/why it manifests as a positive excursion in lake carbonate  $\delta^{18}\text{O}$ .

The record itself is a valuable contribution to the North American Holocene palaeoclimate literature, and much of the paper is well written. However, there are several points that need to be addressed before this manuscript is ready for publication. In particular, some missing methodological details, occasionally confusing phrasing, erroneous direct comparison of lake water and lake carbonate  $\delta^{18}\text{O}$  values, and the lack of a thorough explanation of how various hydroclimate anomalies should result in the observed lake carbonate  $\delta^{18}\text{O}$  variability should all be addressed.

Here I give a few general comments to be addressed, then give the remainder of my review as line edits, with suggestions for figures and captions included based on where they sit in the manuscript. The review is quite long already so I won't compliment your nice lines of reasoning every time they come up! These are just things which will strengthen the readability and scientific integrity of your work.

- Regarding the Abstract/Introduction and general framing: I found the description of the '4.2 ka event' a little confusing. The authors switch between describing an event at 4 vs

4.2 ka (are these the same thing?), and also provide quite vague background about the global nature of the event compared to the greater detail provided for North America (including potential forcings). I'd suggest just a sentence or two about the event in a global context before jumping more immediately into discussing the event in the context of North American climate (which, after all, is the focus of this paper)

- It would be nice to see some discussion of possible anthropogenic influences on this (and other) lakes, even if it's just a referenced statement like 'there was probably not any anthropogenic influence'
- Some of the text in the discussion would be better place in the introduction; reserve the discussion for interpreting your new record and placing those interpretations in the context of existing literature
- You should be more explicit in the links between various possible climatic factors affecting lake carbonate  $\delta^{18}\text{O}$ , and what you see in the  $\delta^{18}\text{O}$  record itself. That is, *why* would some particular process (more or less snowpack, for example) drive a positive/negative change in lake carbonate  $\delta^{18}\text{O}$ ? Changes in lake water  $\delta^{18}\text{O}$  via some associated fractionating mechanism? Changes in the water-carbonate fractionation factor? Changes in when and how the carbonate precipitates? Specific mechanisms are important for the interpretation of your carbonate  $\delta^{18}\text{O}$  in a climatic context
  - On this note, you should also include at least a brief discussion of how your proposed snowpack change fits dynamically with climatic interpretations from the region

Line 26: define 'ka' at the first instance

Line 28: abrupt **global** drying?

Line 35: "...records from Colorado do not record it." – what exactly is 'it'? we've lost the subject that this 'it' should be attached to

Line 40: 'the strong enrichment.....summer months today' I suspect that this sentence may be referencing an erroneous comparison of lake water  $\delta^{18}\text{O}$  and lake carbonate  $\delta^{18}\text{O}$  values that I point out later on. If so, this should be removed.

Line 45: 4 ka and not 4.2 ka? Is this meant to be the same 'event'?

Line 50: list dates (in parentheses) of the YD chronozone as a reminder for us

Line 59-61: This sentence is a bit grammatically ambiguous; I suggest rearranging it along the lines of 'However, some regions show increased precipitation, which is consistent with...'

Line 62: 'Recent' -> 'Recent **model**'

Line 67: Unless I'm mis-remembering, Ault et al 2018 specifically describes drought in western North America (i.e. this isn't globally applicable). In any case, I suggest that by here you have already focused in on the nature of the '4.2 event' in North America (not globally)

Line 75-76: put the 'in the North American midcontinent' modifier earlier in the sentence; this is grammatically ambiguous as written

Line 80: I suggest putting the 'However' at the start of this sentence for clarity

Line 84: what exactly is a 'dune record'? Is this a 'dune-field chronology' as per below? If yes, you should write that out here too

Line 83: 'Rocky Mountains **of North America**'

Line 85: It would be good if here you also listed the proxy record types that *don't* show evidence for a 4.2 ka event

Line 94-97: Two 'prominent's in one sentence (just in case you want to change one)

Line 97 (last word): again, what is 'It'?

Line 100: 'By contrast, the 4.2 ka...' -> 'By contrast, **a** 4.2 ka...'

Line 117: measurements of what? Something like 'Measurements of modern lake water physical and geochemical characteristics can help...' might be clearer

Line 177: controls on what? Lake carbonate  $\delta^{18}\text{O}$ ? Lake water  $\delta^{18}\text{O}$ ? Other?

Line 121: You could reference Figure 1 here

Line 127: spell out 'water isotopes' at the first instance i.e. 'water stable isotopic compositions ('water isotopes' hereafter)'

Line 132: 'interpretations of **the stable isotopic composition of lacustrine carbonate interpreted in terms of past hydroclimate variability**' or similar

Line 142: 'but high elevations' -> 'but high-**elevation sites**'

Line 145: could you just say 'average annual temperature range'?

Line 146: add reference

Line 163: were these precipitation/groundwater samples collected at the same time/over the same time interval as the lake water samples? Either way, you should state the collection dates.

Figure 1: Add a spatial scale of some sort to inset a (eg lat/lon). It would also be good to highlight Bison & Yellow lakes in some way, given you do a lot of explicit comparison of your new observations with similar observations from these lakes. Additionally, could you not slightly extend box b so that it includes Little Molas Lake? It would be good to be able to see it, given you show data from this lake in Figure 7 and it's a bit odd that it's the only lake cut out.

Line 164: 'Isotopic ratios **of all water samples** were measured...'

Line 166: Here (or at least somewhere) you should state that water stable isotopic ratios are reported relative to VSMOW (this is an important distinction from your carbonate values, for which you *do* state the standard)

Line 182: 'At the same time' at the same time as what, exactly? Better just to state the time again (I am guessing January 2017, in which case something like 'In January 2017, we also collected...')

Line 186-line 189: Your methodology here is a bit unclear. Do you mean to say that you

roasted the samples at 550 degrees, then performed stable isotopic analysis on the carbonate from that roasted sediment? What are the oxidizing agents mentioned in line 188? Did you oxidise the roasted/raw sediment, or just the roasted sediment? It would also be good to show the results of this comparison (mentioned in line 188) as a supplementary figure

Line 189-190: grammatically ambiguous; I think you mean to say that you sieved out the fine fraction, and then measured the stable isotopic composition of that fine fraction using the mass spec?

Line 192: if the calcite isn't ostracod tests, then what is it? Amorphous fine-grained? Unidentified but probably autochthonous? Do you have any SEM (or other microscope) images of this carbonate? It would help the reader a LOT throughout the rest of the paper to have at least some idea of the nature of this lake carbonate

Line 195-198: I don't really understand what you are trying to say in this sentence; consider re-writing into several shorter sentences each describing one thing. Also you state here that you isolated conifer needles, but I don't see them on Table 1(?)

Line 204 and all later instances where you report stable isotopic compositions of lake **water**: I assume that these values are relative to VSMOW, which is an important distinction from your lake carbonate  $\delta^{18}\text{O}$  values which are reported relative to VPDB. These two things are **not directly comparable in terms of their absolute values**

Line 205: unless I am mistaken, the 'thick black line' on Figure 2 is the LEL defined by your samples, but also shows the range in values (comparable to the arrows for the other lakes)? I found this a bit confusing so probably other readers will as well. Maybe re-think how you show the various data on this figure.

Line 207: 'Several consecutive years'?? Where are these data from? In the methods, you mention only that you collected lake water samples in 2017.

Line 208: '**water** isotope values at HL'

Line 214-215: Are the water isotope values from these lakes truly comparable in terms of absolute range of variability? Do the measurements represent approximately the same seasonal range/duration of collection?

Line 218: Actually, just eyeballing the inset plot in Figure 2, it looks like the snow/rain ratios at the two lakes were quite different in 2017 when your data were collected

Line 222: Provide a reference for the lake-water temperature range at HL

Line 231: Add a citation at the end of this sentence

Figure 2: from what data were the dotted LELs calculated? You should put the references explicitly in the figure caption. Also for ease of reading, at the filled black dots and thick black line to the figure legend

Line 239: Remove both instances of 'in' after the percentages

Line 244: Here is another instance where I'd really like to know already how the carbonate is being produced in this particular lake!

Figure 4 (and also Figure 5): It would be better if you combined these two figures, by simply plotting all the timeseries from Figure 4 on a **time axis**, and then showing the age-depth model as a supplementary figure (along with the core image, which doesn't add a huge amount given how narrowly it is shown). That would make later comparisons of these timeseries *much* easier. You could also then highlight time windows of interest.

It would also be much better (and would aid in some later interpretation) to follow modern best practice & incorporate the chronological uncertainty into your plotted timeseries (which are currently shown on only one realisation of the age-depth model) – there are many examples of this in recent palaeoclimate literature, as well as guides as how to do such things (e.g. the recently-published geoChronR package from McKay et al).

Line 259-260: might as well just say 'there is no significant trend'

Line 262: are these 'isotope excursions' statistically significant? That is, did you define them quantitatively in some way? Or are you just eyeballing peaks? If the former, you should describe the method that you use to identify anomalous intervals. If the latter, then you should either attempt some quantitative analysis, or say explicitly that the 'excursions' are qualitative.

Line 282: You need to define how exactly a change in the ratio of snowfall to rain manifests as a change in lake carbonate  $\delta^{18}\text{O}$ .

Figure 6: Consider plotting these three records on their own y-axes. This would make the plot a lot clearer, and also the absolute values are not really of value here, but rather the variability

Line 292-293: are 'the records' mentioned here all in the Medicine Bow Mountains? Throughout the discussion I lose track of which records do versus do not have evidence for a climatic anomaly at 4.2 ka, and also where they are (Medicine Bow Mountains, other parts of the Rockies etc). This could be quite easily clarified via a **table** (probably near Figure 1), listing the names of each site that you mention in the text, the proxy type, the region name, and whether or not there is evidence for some sort of event around 4.2 ka (and what that event was – drying, warmth other etc).

Line 304: 'high-elevation lakes' – there are only a few that you are referring to, so it would be clearer for the reader if you listed them by name

Line 307: 'the sediment stratigraphies **in these three lakes**'

Line 320: is there reason to suspect that this age is out of sequence? If so, this should be mentioned in the results. This potential bias from the age-depth model could also be addressed by showing age uncertainty on your plots as I suggest above

Line 330: From what you have plotted here, in most cases the sedimentological changes at 4.2 ka do indeed look unique, but I wouldn't say that that is the case for the isotopic values

Line 333: 'associated with the widespread climatic anomaly'- this is the hypothesis you're testing here, so you can't really cite it as being associated with the widespread North American drought (which is also something that you are assessing!)

Line 347: 'when **precipitation at** high-elevation sites...'

Line 348: How, exactly would these changes result in high lake carbonate  $\delta^{18}\text{O}$ ? Some known influence on precipitation  $\delta^{18}\text{O}$ , which is then passed on to the lake carbonate  $\delta^{18}\text{O}$ ?

Line 361: 'Given the potential prominence of the 4.2 ka drought at HL': I'm still not exactly convinced of a mechanism linking the high lake carbonate  $\delta^{18}\text{O}$  values and local drought conditions

Line 376: This section might be better off at the start of the discussion – that way the reader has been introduced to the possible drivers of carbonate  $\delta^{18}\text{O}$  values in the various lakes, the climatic implications of which can *then* be placed into the wider context

Line 390: I am not convinced that there is much worth in comparing the *absolute* magnitude of carbonate  $\delta^{18}\text{O}$  values from different lakes, especially given how far they are apart. There are WAY too many processes (climatic and otherwise) that can affect absolute values, even if there are common drivers of *variability*

Line 398: So increased lake carbonate  $\delta^{18}\text{O}$  at HL indicates less snowpack? Why, exactly? I think that you allude to various possible reasons but you should clearly outline the connection in terms of water isotope systematics.

Lines 403-406 and 411-416: Unless I am mistaken, here you seem to be directly comparing the absolute values of lake water  $\delta^{18}\text{O}$  (relative to VSMOW) and lake carbonate  $\delta^{18}\text{O}$  (relative to VPBD). This is not valid. Even when autochthonous lake carbonate precipitates using lake water as its source water, the fractionation depends on various things including the temperature at the point of carbonate precipitation (this is an unknown, in your case). Any conclusions that you have drawn based on comparison of absolute lake water and lake carbonate  $\delta^{18}\text{O}$  values should either be removed, or re-thought in the context of anomalies.

Line 417-421: this information would have been nice to know much earlier on – you could possibly sneak it into the results when you outline the specific conductance (or at least when you first discuss result from HL).

Line 463: 'approximately 1% lower at HL' what exactly is lower than what?

Paragraph starting line 460: The premise of this paragraph seems a little flawed to me. Again, discussing difference in absolute magnitudes of lake carbonate  $\delta^{18}\text{O}$  between these three lakes is not particularly valuable, given the huge range of things (carbonate phase, seasonality, precipitation regime, seasonal cycle of precipitation  $\delta^{18}\text{O}$ , groundwater input, groundwater  $\delta^{18}\text{O}$ , local geology.....) which could affect these absolute values, and which you don't have enough information to tease out. It's a comparison of *variability* (trends and other features of the timeseries) which is interesting (and relevant)



Line 476: what are they 'surprisingly' negative?

Line 491: I am not convinced that the evidence or lines of reasoning presented here provide any new support for a North American megadrought at 4.2 ka. Maybe more so if you could more clearly & convincingly tie a positive lake carbonate  $\delta^{18}\text{O}$  excursion to decreased effective moisture.