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Climate of the Past Discussions
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Interactive comment

Interactive comment on "Volcanism and climate change as drivers in Holocene depositional dynamic of Laguna del Maule (Andes of central Chile – 36° S)" *by* Matías Frugone-Álvarez et al.

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Response to referee #1

We appreciate the exhaustive work carried out by anonymous referee #1, which have greatly helped to improve manuscript clarity. We believe we have addressed all comments and concerns of reviewer #1 and are mostly in agreement on most issues. Below, we have addressed all the reviewer's comments and explained how we have changed the manuscript accordingly.

General Comments referee #1: Frugone-Álvarez et al. provide a highly detailed, multi-

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proxy study of a volcanic lake in the central Andes, with emphasis on geochemical analysis of downcore lake sediment. The clear organization of scientific methods and assumptions as well as the use and integration of diverse disciplines (e.g., stratigraphy, seismic sur- veys, geochemistry, statistics, tephra, volcanism, climate) to reconstruct a paleoclimate story make this a valuable contribution to Climate of the Past. The well-characterized framework that this paper provides for the complex LdM site sets the stage, for what I imagine, is a lot more interesting work planned by this group. I support acceptance of the manuscript upon some minor revisions outlined below.

R: Thank you very much for your time invested to review our manuscript. The LdM sequence is a complex record, so we really appreciate your help!

1. Specific Comments referee #1:

Specific Comments 1.1 I noticed in the abstract, and at times throughout the text and tables, the nomenclature for describing ages varied. I'd suggest choosing one and sticking with it, such as cal a BP (and cal ka BP), which indicates that the ages discussed are calibrated and provides an appropriate reference point (i.e. BP).

R: We agree and have changed all ages in the ms. to "cal ka BP."

Specific Comments 1.2 Early, Middle and Late Holocene should all be capitalized as they have recently been formalized subdivisions for the Holocene (Walker et al., 2019).

R: These are all now corrected to reflect this new nomenclature.

Specific Comments 1.3 How certain are the authors that the ash layer suggested to be the Quizapú tephra is indeed so? Are there other possible eruptions that could be correlated with this layer as well, especially since major (or trace) elemental analysis was not performed? I know from personal experience that assuming a tephra as a key marker without geochemical data to support it can sometimes be incorrect, and instead, turn out to be another layer all together. This seems especially important considering that one goal of this work is to lay a tephra stratigraphy framework for this

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region.

R: We agree, we do not have evidence geochemistry that it is really the eruption of Quizapú. But, according to historical data and our superficial age model only two eruptions have occurred with a significant explosivity index near LdM during the last 200 years: the eruptions of Quizapú volcano of 1846-47 and of 1932 (Figure 1). The Quizapú eruptions of 1846-47 and 1932 were of nearly identical magma, but the first eruption was effusive and the second plinian with a VEI index = +5 (Fontijn et al., 2014; Hildreth and Drake, 1992). The upper black and grey tephra (Facies T1, $\sim$ 2 cm of thickness in the LEM11-1A core) has been identified throughout the lake basin, with a change in thickness from about 2 cm thick along the northern areas of the basin and 1 cm along the southern areas of the LdM (see Figure S13). Fortunately, the stratigraphic correlation of all short cores was easily performed by comparing TOC profiles and the key ash layer located at a similar depth between all cores, also is consistent with what is described by Hildreth and Drake, (1992) and Sernageomin (Figure 1). Although we only have FESEM-EDX (Figure 2), XRF and DRX data. Sedimentological and compositional (microscope smear slides) description of the Facies T1, the age model based on 137Cs dating supports that this layer is most likely the more recent Quizapú plinian eruption described by the Servicio Nacional de Geología y Minería (Sernageomin) (Figure 1). Therefore, we conclude that T1 has a high probability of being the tefra deposition from the great eruption of 1932.

Fontijn, K., Lachowycz, S. M., Rawson, H., Pyle, D. M., Mather, T. A., Naranjo, J. A., and Moreno-Roa, H. (2014). Late Quaternary tephrostratigraphy of southern Chile and Argentina. Quaternary Science Reviews, 89:70–84. 39 Hildreth, W. and Drake, R. E. (1992). Volcán quizapu, chilean andes. Bulletin of Volcanology, 54(2):93–125. 00134

Specific Comments 1.4 Can the authors place an estimated uncertainty on the reservoir effect that results in offsets of the age model? In other words, the authors assume a constant offset of 4.7 ka, and rightfully acknowledge a level of uncertainty inherent to this, however, to what extent? Could DOC in the lake ever be in equilibrium with the at-

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mosphere during the Holocene such that there is periodically no offset, or somewhere in between? Given that the age model is used to compare against regional climate records, being clearer about this uncertainty is extremely important.

Reply specific comments 1.4: We greatly appreciate the reviewer's comments regarding the geochronologial aspects, as they are critical for understanding the paleoclimate implications of the record. We are very much aware of the variable level of uncertainty in the age model and we have been careful to include this uncertainty in the interpretation of the record and the comparison with other time series. As stated in the paper, the uncertainty of our age estimates was established by the dating errors in the samples from short cores and recent organic matter samples (ca. 60 years, see Table S4). This uncertainty is also clearly present in our figures (as additional shading in our proxy records). Of course we also have to consider the possible variable carbon dynamics in the lake during the Holocene resulting in a variable reservoir effect through time. The epilimnia of most lakes are well mixed tend to be 14C equilibrates between the lake and the atmosphere but in volcanic lakes it does not have to be this way. During the Holocene the DOC could be out of equilibrium at different times, it is true. The correlation with the tephras will be a step forward to understand these processes. Although we are confident that the reservoir effect likely stayed within a similar range during the Late Holocene, as the lake basin and depositional processes did not greatly changed, we could not find enough terrestrial material to date with radiocarbon in the Mid and Early Holocene – or apply other radiometric techniques – so we cannot rule out this possibility. But as a first approach we have considered that the reservoir effect remained within a similar range, as in other volcanic areas with large reservoir effects (Miscanti, Chungará). A detailed and comprehensive tephra chronology will help to produce a more robust chronology in the future.

Specific Comments 1.5 What is the threshold %TOC value for laminated organic-rich silts (L166)?

R: The threshold %TOC values for D6 are $\sim$ 0.5% to 5.5% (see Supplementary Figure

S6). Laminated facies D6 have the highest TOC and TS values, up to 5.5 % and 7.0 %, respectively. Endogenic calcite occurrences are common in D6. Subfacies are identified based on organic content (higher in D6b) and type (more algal in D6a versus more macrophyte in D6c), the nature of the lamination (better defined in D6a and D6c), and the presence of carbonate (more common in D6b).

Specific Comments 1.6 In the paleoclimate section, what ages are used to define the Medieval Climate Anomaly and the Little Ice Age? I know these events mostly as Northern Hemisphere climate anomalies. How are they expressed in the Southern Hemisphere in terms of temperature and precipitation?

R: The MCA was defined using records from California and Argentina (Stine et al., 1991). Less than a handful of records have been used to describe anomalies during the MCA and LIA from central Chile (e.g. von Gunten L. et al., 2009). They provide quantitative evidence for the presence of a MCA as warm summers between AD 1150 and 1350, and a cool period corresponding to the "Little Ice Age" starting with a sharp drop between AD 1350 and AD 1400 and ending around 1850 CE. There are even fewer precipitation reconstructions, mostly based on tree ring records. In our LdM record, a phase of increased productivity (warmer?) occurred prior to 1400 CE and it would have been during the MCA. Pollen data for the last 700 years in LdM show the highest percentages of Poaceae and High Andean Steppe taxa suggestive of a displacement toward lower elevations of the high-altitude vegetation belts from 1570–1920 AD. Although these results suggest a shift toward more wetter/colder conditions during la LIA, we remain cautious because of the low resolution of this sampling interval and the lack of local pollen rain surveys.

Specific Comments 1.7 L601-602: How are these rhyodacite eruptions linked to your L2 and L1 lapilli deposits?

R: Unfortunately, we are not able to give a precise answer as we do not have detailed geochemical analyses of the tephra layers. A collaboration in this regard is in progress.

Specific Comments 1.8 L616-620: Why is the two-phased structure of the LIA not discussed in the main text if it is in the conclusions? Similarly, solar irradiance is brought up directly afterwards as a centennial-scale climate forcing but not discussed in the main text. Expanding on these points in the discussion would be important if they are to remain as conclusions.

R: We have included the discussion of the two-phases structure of the LIA and the relationship with solar irradiance in the main text.

2. Technical Corrections

2.1 L6: remove "is" and make date plural (i.e. "dates"): Done 2.2 L7: add "the" before "Early Holocene", change "were" to "was" Done 2.3 L8: reverse order of major hydroclimate transitions (i.e. oldest to youngest) Done 2.4 L21: add "in" before "terrestrial ecosystems" and "as well as" before "atmospheric and ocean circulation" Done 2.5 L33: It seems like a word is missing – a hazard to regional xxx in central Chile. Add "the" before "last deglaciation". Done. We have changed the paragraph to: "..., does show that this is a natural hazard for the society and the economy of central Chile."

2.6 L170-172: These are not complete sentences and need some rewriting.

"Table 2 summarizes the main characteristics of the LdM lacustrine facies. The finer grain size of facies D1 and D2 and the absence of littoral components (i.e macrophyte remains), with variable clastic input, particularly higher during deposition of D2. Coarser grain size and the abundance of macrophytes remains setting for facies D3 compared to D1 and D2. Facies D3, D4 and D5 are organized in dm-thick sequences and they are macrophyte-dominated (D5, D3) to diatom-dominated environments (D4) (Fig. S5)." We have changed the sentences to: "Table 2 summarizes ... The finer grain size of facies D1 and D2 and the absence of littoral components (i.e., macrophyte remains) indicate deposition in relatively deeper water. Coarser grain size and the abundance of macrophyte remains suggest a more littoral depositional setting for facies D3 compared to D1 and D2. Facies D3, D4 and D5 are organized in dm-thick sequences and range from macrophyte-dominated (D5, D3) to diatom-dominated environments (D4) (Fig. S5)."

2.7 L173: Delete "they" Done

2.8 L175: I think it should read "Well-defined troughs in BioSi values occur at. . .". There are extra words here that make the meaning of the sentence unclear. Done We have changed the paragraph to: Well-defined troughs in BioSi values occur at the base (432-433 cm), middle (364-366 cm), and top (313-316 cm) of unit 5, and are often associated with volcanic facies (Figure 4).

2.9 L282: change "dominant" to "dominate" Done We have changed the paragraph to: Poaceae dominate throughout, especially in unit 3 and Amaranthaceae dominate after unit 3. Ephedra is the main component principally in the part upper of unit 5. 2.10 L282: change "occurred" to "occurs" Done 2.11 L299: Capitalize "unit" as it is the first word of the sentence Done 2.12 L305: remove "a" after "Establishing" Done 2.13 L307: add "to" before "degassed" Done 2.14 L335: add "age" after "pre-Holocene" Done 2.15 L336: change "as" to "to" Done 2.16 L337: change "forming" to "formed" Done 2.17 L352: seems like a word is missing. Maybe add "although" before ". . .if this emplacement would have been related. . ." Done 2.18 L395: add "and" before "reflect" Done 2.19 L397-399: I think the final sentence of the paragraph should be two and read as the following "The decrease in TOC and the less abundant calcite occurrences indicate a less productive environment towards the end of this phase. Simultaneous decreases in Ephedral/Poaceae values indicate increased aridity." Done 2.20 L519: change "shown" to "show" Done 2.21 L542: remove "also" Done 2.22 L546: remove the second "in" Done L555: add either "in/of" after "fluctuations" Done 2.23 L564: change "concomitant to" to "concomitant with" Done 2.24 L565: Spell out LIA here since it's the first time it is mentioned Done 2.25 L569: This sentence is long and needs rephrasing in the beginning. Done We have changed the paragraph to: The LdM sequence offers a continuous record of volcanic activity in the basin (Figure 5d) which can be compared to that previously described by Andersen et al. (2017) (Figure

5e). Nevertheless, the assignment of these events found in the lake sequence (Figure 3) to dated volcanic eruptions (Singer, 2014; Singer et al., 2018) is not straightforward and will require considerably more geochemical fingerprinting of individual tephras.

2.26 L599: add "the" before "Holocene Phase" Done 2.27 Sources: Walker, M., Head, M.J., Lowe, J., Berkelhammer, M., Björck, S., Cheng, H., Cwynar, L.C., Fisher, D., Gkinis, V., Long, A., Newnham, R., Rasmussen, S.O., Weiss, H., 2019. Subdividing the Holocene Series/Epoch: formalization of stages/ages and subseries/subepochs, and designation of GSSPs and auxiliary stratotypes. Journal of Quaternary Science 34, 173-186.

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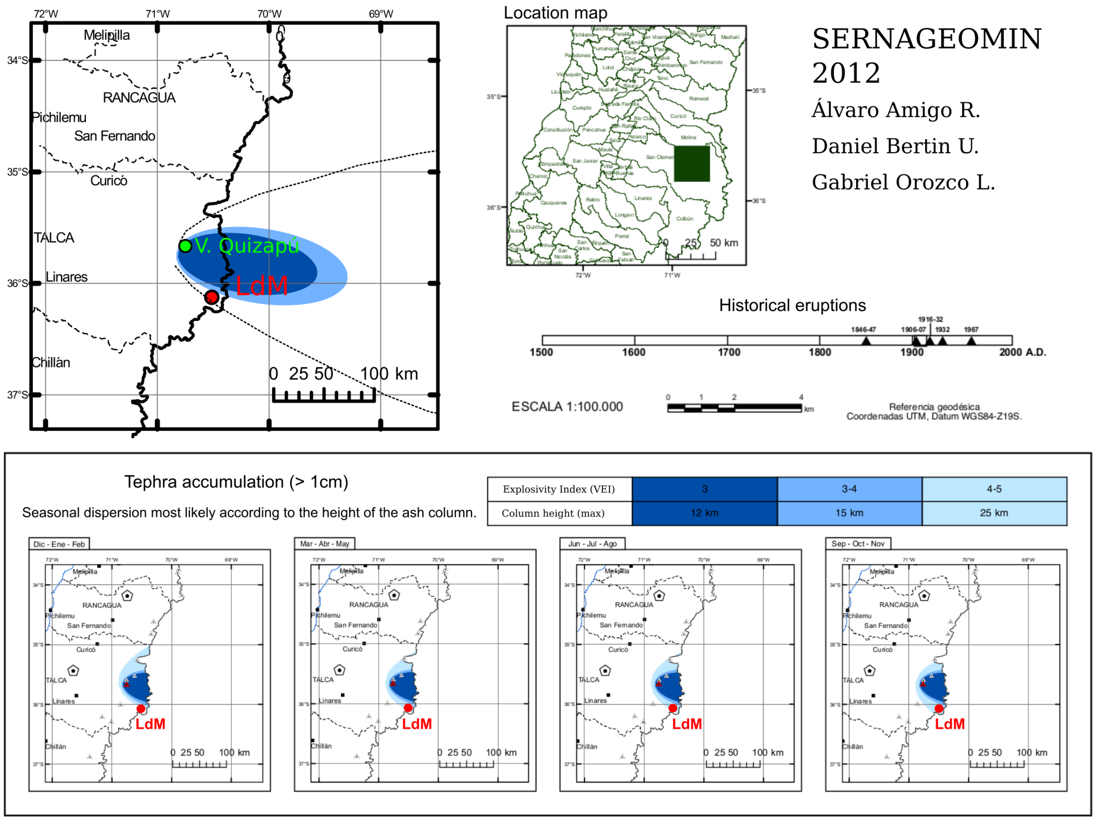

Fig. 1. Location map and regional isopachs for compared to a VEI index = 3; 3-4; 4-5; thickness in cm.

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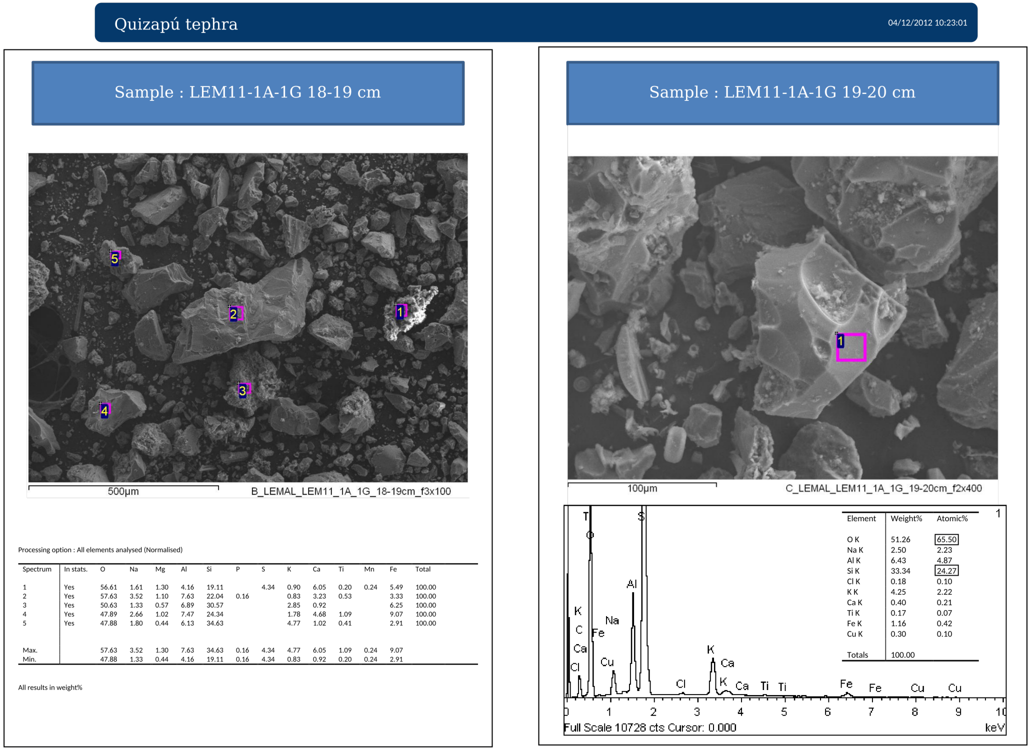

Fig. 2. Field-emission scanning electron microscope (FESEM) image and energy dispersive X-Ray spectroscopy (EDX) elemental analysis of tephra T1 in LEM11-1A-1G core. General Research Support Service-SAI, Univ

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