Dear Reviewer,

We thank you for your valuable feedback and constructive comments on our study.
Below, you will find our responses to each of your questions and remarks. Additionally, a PDF containing all our answers to the comments is attached as a supplementary file.
Thank you again for your time and consideration.
Best regards,

Mathilde Banjan and co-authors

The manuscript by Banjan et al. shows an interesting lake paleoseismic study in a very poorly known (from a paleoseismic point of view) region, showing the complexity of such settings. While showing its value, this study also underscores the need for more lacustrine studies in order to definitely validate or reject some of the proposed hypotheses. The paper itself is written in a clear way and is particularly well illustrated. I do have the impression that some of the available literature on Alpine lakes as well as other lakes with similar issues around the world have not been included, as I indicated throughout the annotated manuscript attached. Additionally, while most of the techniques and concepts applied in this paper are established and validated in lake paleoseismic studies around the world, I have some questions with regards to some of the specific approaches and interpretations here. I list my main concerns below, and added some smaller remarks in the attached file. Nevertheless, I do believe all the necessary data is presented in the paper, and that it could still become significant once these concerns are addressed.

1- Although log-ratios are often used for interpreting XRF data, it is advisable to use centered log-ratios (as also explain by the reference cited here in the methodology) - especially if you base your core-to-core correlations partly on the absolute abundance of a certain element in the core. It is not clear if you used this approach, as the single element XRF values are not plotted in figure 6 (as was mentioned in the text).

As expressed in the caption below Fig.6, the core-to-core correlations for the AIG17III and AIG16-05 sediment cores are based on IRM data (magnetic data) and not XRF data.

While we understand the importance of centered log-ratios (CLR) for compositional data analysis to avoid matrix effect, simple log-ratios are effective for general trends and comparisons in geochemical data (Weltje et al., 2015). In Fig.4, the general trend along depth suffices for a visual comparison of geochemical variation across different facies. Therefore, we used a simple ln ratio (cf. lines 235-239).

2- While the full age model is shown in the manuscript, it is not entirely clear how it was constructed. This should be placed more upfront. Additionally, integrating such a large number of dating techniques for the long core (especially also the varve counts, which is not clear how you incorporated these), using the very simplistic clam model is probably not the ideal way. I strongly advice to use Bacon instead, which also does not require to manually define outliers.

The full age-depth model (Fig.8) shown in the manuscript is based on:
- short-lived radioelements (cf. lines 271-279, Fig.7);

- paleomagnetic data (cf. lines 293-302, SM-3);
- radiocarbon dating (data available in Table 2 from Banjan et al. (2023)).

These different time-constraints are highlighted in the section 3.5. of the manuscript (lines 159-166).
The varves counts is visible and available in Fig.7 (page 16), but just for the upper part of the core in comparison to short-lived radionuclides, as varves are not continuous over the whole sediment sequence, thus they are not used for age modeling.

Regarding the choice of Clam, different programs exist for age-depth modelling (Bacon, Bchron, Clam and OxCal included). Clam R packages employ classical statistical methods (Blaauw, 2010), whereas the three others use Bayesian statistics (Bacon: Blaauw and Christen, 2011; Bchron: Haslett and Parnell, 2008; OxCal: Bronk Ramsey, 2009).
Wright et al. (2017) compared the relative performance of these different programs for age modelling and found that no single modelling package outperforms all others, but an ensemble approach can exploit different model strengths to produce a 'consensus', illustrating that choosing the 'best model' is not a simple task (Lacourse and Gajewski, 2020). Uncertainty estimation differs considerably among models and Bayesian age–depth models mainly improve the assessment of uncertainties of age–depth models (Trachsel and Telford 2017). As we have less than two dates per millennium (18 ages for 14kyr), we selected a program which employs classical statistical methods: Clam R package as explained in the manuscript. Moreover this Clam age model is already published for AIG long core (Banjan et al., 2022), thus we do not want to change the chronology.

3- You seem to add a high confidence level for seismic triggering to any event deposit thicker than 2 cm, even though not all of them actually are, even in historical times. It is not clear how this is incorporated in the discussion, and if you left out these deposits for the section on recurrence statistics. And if not, how does this affect your results, as there could likely be more of those event deposits non-seismically triggered?

The confidence level for seismic triggering of event deposits thicker than 2 cm is based on a multi-proxy approach, not only on thickness. As detailed in section 5.1. of the paper, the interpretation of these deposits as seismically induced is supported several characteristics:

- Visual observations of homogenite (Hm) and turbidite-homogenite (Tu+Hm) facies;
- Grain-size data trend in a Passega diagram;
- Geochemical signatures (XRF logarithmic ratios) indicating remobilization of sediment from lake slopes;
- High Anisotropy of Magnetic Susceptibility (AMS) foliation values, which have been associated with seiche effects in previous studies;
- Low Isothermal Remanent Magnetization (IRM) amplitudes.

The 2 cm threshold was chosen because it allows for reliable AMS measurements, which require a minimum sample volume. However, the paper does acknowledge varying confidence levels for different deposit thicknesses (Fig. 9), with deposits between 0.5 and 2 cm thick still considered of seismic origin, with moderate confidence.

Regarding the recurrence statistics, the analysis in section 5.3. focuses on event layers ≥0.5 cm thick, which includes both the high and moderate confidence deposits. This approach balances the need for a robust dataset with the acknowledgment of uncertainty in interpretation.
The paper does consider the possibility of non-seismic triggers, particularly for thinner deposits. The discussion in section 5.3. explicitly addresses the potential impact of changing sedimentation rates on the frequency of recorded events, acknowledging that this could lead to misinterpretation if not carefully considered.

Future work could include sensitivity analyses to assess how the inclusion or exclusion of moderately confident seismic deposits affects the recurrence statistics. Additionally, expanding the multi-proxy analysis to thinner deposits could help refine the criteria for seismic attribution across all deposit thicknesses.

4- Why do you consider PSA values? It is extremely difficult to determine threshold values based on quantitative ground motion parameters, as so far only intensity data was used and is available. Although I strongly encourage to move away from intensity, I do question why PSA is used instead of for example PGA or PGV. Considering the high uncertainties, why not start with an IPE test and evaluate local intensities at the lake rather than just epicentral intensities? And when you then move to PSA, why specifically 0.5 and 5 Hz? Are there any indications as to why these would be more relevant than others? As far as I understand, low-frequency shaking is amplified in sediments, so the conclusion that is made here on 5 Hz being more relevant seems questionable and not supported by other literature. Additionally, what do you consider as site effects (e.g. Vs30 values)? These should be used as input for the GMPEs I assume, and would also strongly impact the outcomes.

Here are several points in order to clarify the use of PSA values and selected methodology:

The use of Pseudo-Spectral Acceleration (PSA) values over Peak Ground Acceleration (PGA) or Peak Ground Velocity (PGV) was driven by the need to discuss a possible frequency-dependent response of lake sediments. PSA provides a measure of ground motion that can be specifically tied to different frequencies, making it interesting for understanding the sediment response at various frequencies. The use of PSA values is compatible with the dynamic behavior of sediments, which is key for identifying the potential for event deposit formation. This approach is consistent with methodologies employed in other studies focused on understanding sediment responses to seismic shaking (Strasser et al., 2013; Avşar et al., 2016; Moernaut, 2020).

The uncertainties associated with the development of Intensity Prediction Equations (IPEs) are of the same order as those for Ground Motion Prediction Equations (GMPEs), as demonstrated by Bakun and Scotti (2006), for France. This consideration supports the approach of using PSA values, which provide a more detailed analysis of the frequency content of seismic waves, over traditional intensity measures.

Regarding site effects, these were not directly considered (cf. lines 440-442). Considering specific site effects for Lake Aiguebelette would require a study, which is beyond the current scope of our work. A detailed analysis similar to that of Shynkarenko et al. (2023) would be necessary to fully integrate these factors. Consequently, our approach focuses on comparing relative PSA values rather than absolute values. It is important to note that site effects could indeed influence the frequency content of seismic waves, potentially affecting the results. This is why our analysis emphasizes relative differences, which helps to mitigate the impact of site-specific factors on our overall conclusions.

Site-specific factors such as Vs30 values (shear wave velocity in the top 30 meters of soil) are key for accurate ground motion prediction and were taken into account in our GMPE calculations. The GMPEs used (Akkar et al., 2014; Bindi et al., 2017) incorporate these site effects to provide a more accurate representation of ground shaking at the lake site. In each GMPE, different soil and rock conditions are included and in each case the same trend is observed respectively for low (0.5 Hz) and high (5 Hz) frequencies.

Regarding the choice of frequencies, while the decision to use 0.5 Hz and 5 Hz may seem arbitrary, it was guided by the need to represent both low and high-frequency content. These specific frequencies are commonly used as proxies in the literature to capture the effects of low and high-frequency seismic waves (e.g., Atkinson, 2008). The selection was not meant to be an absolute measure but rather a practical approach to see how historical earthquakes compare across a spectrum of frequency content. Lower frequencies (0.5 Hz) are relevant for assessing long-period waves that travel further and have significant effects on sediment layers. Higher frequencies (5 Hz) are relevant for assessing the impact of near-field, high-energy seismic waves that can trigger immediate and localized sediment disturbances. Lake sediments can respond differently to various frequencies of ground shaking, and modeling PSA at these two frequencies is representative of a spectrum of seismic energy that could influence sediment deposition processes. This approach of using multiple frequencies to assess seismic response is supported by studies such as Kremer et al. (2017), who emphasize the importance of considering both low and high-frequency content when evaluating seismic shaking impacts on lake sediments. Their work demonstrates that different frequency ranges can trigger distinct sedimentary responses, which aligns with the approach of examining both 0.5 Hz and 5 Hz PSA values.

Based on the PSA approach, the results indicate that high-frequency shaking, particularly at 5 Hz, is more relevant for triggering event deposits in Lake Aiguebelette, and thus, it is not always the low-frequency shaking that is most effective (Fig. 11).

5- I agree that historical earthquake catalogs are often incomplete. However, using this as the only argument to discard the potential for the Basel earthquake to have resulted in an event deposit seems questionable. Even more so considering the ESTI approach does not rule out a deposit at all. Are there any other indications as to why you do not consider this earthquake as a likely trigger? If not, I don't see an objective reason to discard it.

Another rationale (lines 460-463) for discarding the potential for the 1356 CE Basel earthquake to have resulted in an event deposit is visible in Fig.11.

For the 1356 CE Basel earthquake, the epicentral distance to the site is 255.3 km with a Mw of 6.5 +/- 0.54. We note that the 1887 CE Ligurian earthquake has a comparable epicentral distance of 258.4 km and a Mw of 6.7 +/- 0.59. If the Basel earthquake had resulted in an event deposit, it is highly probable that the Ligurian earthquake would have caused one as well, yet it did not.

Additionally, Lake Aiguebelette appears to be more sensitive to high-frequency shaking. The Basel earthquake, given its epicentral distance to the lake, would likely produce lower-frequency shaking.

6- With distance, high-frequency shaking is consistently attenuated faster than low-frequency shaking. So the fact that PSA values are lower for 5 Hz for distant earthquakes compared to closer earthquakes, and not so much for 0.5 Hz, does not really present a solid argument as to why nearby events would more likely trigger the event deposits in Lake Aiguebelette. This entirely depends on which frequency content lake sediments respond to (related to my previous point). Of course, the PSA5 would become attenuated faster than the PSA0.5, so there will always be a stronger difference with distance for PSA5.

Here are two arguments (energy distribution and historical evidences) as to why nearby events would more likely trigger the event deposits in Lake Aiguebelette:

(1) The energy distribution of an earthquake typically has more high-frequency content near the source. This results in higher ground acceleration and shaking intensity near the epicenter, which is more likely to disturb and rework sediments to create event deposits, near the source. Near-field ground motion often includes higher peak ground accelerations and velocities that can be more effective in causing sediment disturbance (Boore, 2003).

(2) Historical earthquakes show a higher likelihood of near-field events causing significant geological and sedimentary disturbances compared to far-field events. Studies on lake sediments in seismically active regions often show a higher correlation between event deposits and nearby earthquakes. This observation supports the idea that the intensity and characteristics of near-field shaking are more effective in triggering these deposits (Goldfinger et al., 2008).

Additionally, the response of Lake Aiguebelette's sediments could be influenced by site-specific factors such as sediment composition, layering, and water depth. These factors can determine the sensitivity of the sediments to different frequencies of seismic shaking. Further site-specific studies (that are not included in this article, but will be the object of future research) are necessary to understand the dynamic response of the lake sediments to seismic activity accurately (Shynkarenko et al., 2023).

7- You do not discuss on why some event deposits consist only of homogenites, and other homogenites plus turbidites. This clearly involves different depositional processes, and might help further distinguish seismic from non-seismic deposits? A seismic seiche without turbidite seems to rather implausible, in my opinion.

When sampling sediment cores, it is possible to capture either the turbidite or the homogenite, depending on the samping location. Due to variations in current strength and topography, sediment gravity flows can transport and deposit sediments unevenly across a basin. As a result, one core might archive a turbidite layer while another core nearby might capture a homogenite layer instead (Stow and Smillie, 2020; Piper, 1978). This variability in sediment deposition is a well-recognized phenomenon in sedimentology (Stow et al., 2001).
The occurrence of homogenites without accompanying turbidites in some records can be attributed to the nature of the depositional environment and the energy of the triggering event. Seismic seiches can produce homogenites without a significant turbidite if the shaking is sufficient to rework the sediment but not strong enough to trigger a full-scale turbidity current (Mulder and Alexander, 2001).

The absence of a turbidite does not necessarily rule out a seismic origin for the event deposit. The differential preservation of these deposits in various cores can be related to the spatial variability (of the processes) within the basin.

It is necessary to add that a seismic seiche without a turbidite is not implausible as shown in Lake Bourget (Chapron et al., 1999).

8- Throughout the paper, you never consider the process of surficial remobilization for turbidite deposition. Although the thicker event deposits might still relate to slope failures, especially the thinner ones might rather be attributed to this surficial process. The fact that event deposit material originates from within the lake only strengthens the possibility for surficial remobilization. It would be beneficial to elaborate on this, as in this particular case, sedimentation rate would not be relevant for turbidity current generation and thus further advocating for a seismically quiet period in stage 2.

It would be beneficial to include a point about surficial remobilization in the discussion section of this paper for turbidite deposition. During seismically quiet periods, surficial processes could generate turbidity currents, leading to the deposition of thinner turbidites. This could support the observation of sediment layers that are not directly linked to significant seismic events during the historical and recent times. This point will be added to the discussion section.

However, in the Passega diagram (Fig.5) we can see that the data for events thicker than 0.5 cm follow the same trend, suggesting a common depositional process.

9- For the recurrence statistics calculations, it would make more sense to focus only on the long core to avoid having a change of recording sensitivity in the recent period that is covered by one of the pilot cores.

The sensitivity of recording seismic events in lake sediments is influenced more by the variation in sedimentation rates rather than the specific cores used. By including both the long core and the pilot cores, the goal is to provide a more robust understanding of the seismic record. As mentioned in the manuscript, sedimentation rates can vary and significantly impact the sensitivity of the lake sediments to record seismic events (Wilhelm et al., 2016; Rapuc et al., 2018).

To mitigate any potential bias in recording sensitivity, we carefully correlated the pilot cores with the long core using various proxies and age-depth models. This approach ensures that the data from the pilot cores are seamlessly integrated with the long core, providing a continuous and consistent seismic record. The pilot cores, such as AIG20-01, provide valuable high-resolution data for recent periods, complementing the long core data and enhancing the overall accuracy of the seismic chronicle.

Previous studies have demonstrated the importance of using multiple cores to enhance the resolution and accuracy of seismic event chronologies in lacustrine environments. For instance, Strasser et al. (2013) and Moernaut et al. (2014) highlight the benefits of integrating data from various cores to capture a complete and detailed record of seismic events over different time scales.

10- How do your periods of seismic quiescence and activity relate to other Alpine regions? For example, also in Carinthia, some clustering of events and quiet periods have been proposed.

We identified three main stages:

1) From -9890 to -2000 yr cal CE: A period of relatively consistent seismic activity;
2) From -2000 to 0 yr cal CE: A period of seismic quiescence (with no event layers ≥0.5 cm thick recorded);
3) From 0 to 2017 yr cal CE: A period of increased seismic activity.

The study by Daxer et al. (2022) in Carinthia (Austria), also identified periods of clustered seismic activity and quiescence. Phases of enhanced regional seismicity are observed, including two high-frequency periods at ca. 12.8 ka BP and ca. 3.5 ka BP.
While the timing of these periods does not exactly match our results, it supports the observation that seismic activity in the Alpine region could be characterized by alternating periods of increased seismic activity and relative quiescence.

Our observation of increased seismic activity from 0 to 2017 yr cal CE is compatible with the trend of increased seismicity in the late Holocene observed in several Alpine lakes. Kremer et al. (2017) highlight an increase in mass movement occurrences in Swiss lakes during the past 4000 years, which they partly attributed to increased seismicity. While we can see some broad similarities with other Alpine records (periods of increased seismicity and periods of relative quiescence), the specific timing and duration of active and quiet periods can vary regionally. This highlights the importance of such studies in the Alpine region to better understand the spatial and temporal variations in seismic activity.

The increase in sedimentation rate could be linked to enhanced erosion driven by human activities, such as agriculture and deforestation, which can lead to more frequent and thicker sediment deposits (Arnaud et al., 2016)

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