Reply on RC2

Dear Walter D'Alessandro

Thanks for your comments again. According to your comments, we added the supplement and analysis of the literature data from 2013 to 2025 to make the data more representative. On this basis, the conclusion of the original manuscript has been revised to weaken the connection between gypsum and seismic activity, and emphasize the sensitive indication of gypsum to the intensity of water-rock interaction. The main replies are as follows. Note: *Italic blue* is the comment. Black is the reply.

I am sorry to say that reading the reply of the authors my opinion regarding the manuscript did not change. My main criticism relates to the fact that it is not possible to evidence anomalies in groundwater composition related to seismic events having data collected only one time. The authors try to compare their data with other taken from literature but the comparison is not straightforward because no background values have ever been defined. The mean values utilised seem artificially created and, in my opinion, do not represent "normal" values.

I am still convinced that the manuscript in this form has to be rejected.

Reply: Thanks! We sincerely appreciate your critical feedback and fully acknowledge the limitations of single-time sampling in establishing seismic-hydrogeochemical correlations. To address this concern rigorously, we have implemented the following revisions:

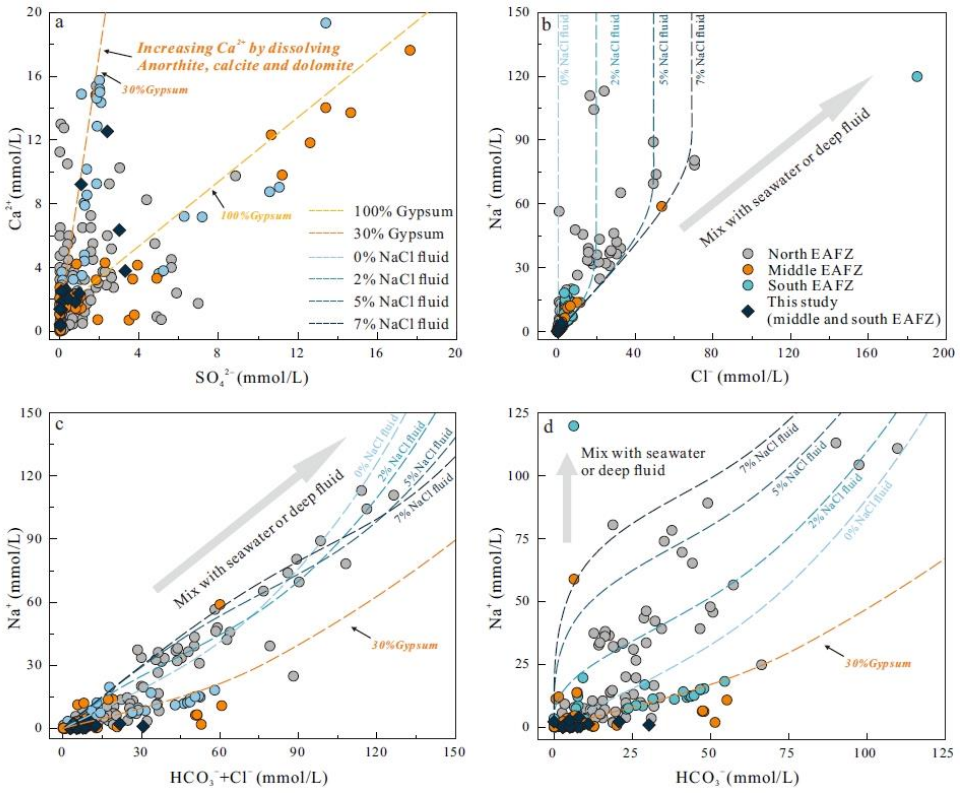

Fig. 1 Characteristics of chemical components of geothermal waters in the EAFZ, during water-rock interaction. The diamond is the measured value of geothermal waters. The dashed line is the numerical simulation result of PHREEQC. a: Ca^{2+} vs SO_4^{2-}, b: Na^+ vs Cl^-, c: Na^+ vs HCO_3^-+Cl^- and d: Na^+ vs HCO_3^-. The sources of literature data and the simulation calculations are detailed in Annex I.

1. Investigation and analysis of historical hydrogeochemical data in the study area (Fig. 1): A comprehensive compilation of groundwater chemistry data from the East Anatolian Fault Zone (EAFZ) spanning 2013-2023 has been integrated. This reveals systematic spatial hydrogeochemical patterns:

Northern EAFZ: Mixed shallow/deep circulation with igneous rock-dominated water-rock interactions.

Central-Southern EAFZ: Shallow circulation dominated by sedimentary mineral

dissolution (e.g., gypsum, carbonates), with localized seawater influence.

These distinct regimes provide a robust framework for interpreting tectonic-hydrogeochemical linkages, mitigating reliance on isolated measurements.

2. Revised Interpretation of Gypsum Significance:

Following your suggestion, we have reframed the role of gypsum dissolution. Rather than asserting direct seismic causality, we now propose gypsum as a sensitive indicator of water-rock interaction intensity – a process modulated by both climatic (e.g., rainfall) and tectonic drivers. This rephrasing: (1) Removes overinterpretations of single-event correlations, (2) Highlights the need for future systematic monitoring to disentangle tectonic vs. hydrological signals. Preserves gypsum's potential as a tectonic proxy while adhering to evidence-based claims.

These revisions align the manuscript's conclusions with its evidentiary scope while preserving its novel contribution: establishing a spatially resolved hydrogeochemical baseline to guide future seismotectonic monitoring in the EAFZ. We are grateful for your insightful critique, which has significantly strengthened the study's rigor and communication of limitations.

The data could be used to create a simply report without stressing the potential of gypsum as earthquake tracer. The data could be used for future researches in the area. I don't know if there is a form in which this could be done for this journal. Maybe the editor can suggest solutions.

Reply: Thanks! We thank you for your constructive suggestion to refocus the manuscript's scope. In accordance with your guidance, we have rigorously revised the

narrative to prioritize hydrogeochemical process characterization over speculative seismological linkages:

Reframed Research Objectives: The study's primary aim is now explicitly stated as establishing hydrogeochemical signatures across the EAFZ's tectonic segments. All claims regarding earthquake precursory signals have been removed, with emphasis shifted to documenting spatial patterns in water-rock interaction processes. The term "earthquake tracer" has been systematically replaced with "sensitive indicator of water-rock interaction intensity" throughout the text. A new statement clarifies that gypsum's tectonic relevance requires validation through future systematic monitoring, aligning with your call for caution in interpretation.

These modifications ensure the manuscript now functions as both a stand-alone hydrogeochemical benchmark study and a catalyst for hypothesis-driven seismic monitoring research. We fully defer to the Editor's judgment on whether this revised scope aligns with the journal's aims and welcome further adjustments if needed.

Comments on authors' reply

Line 13: to affirm that you have measured abnormal groundwater ion concentrations you need to compare them with a series of data before and after the seismic event. Evaporite dissolution happens also in the absence of seismic activity, it is therefore impossible to affirm that high sulfate concentrations in groundwater are related to the earthquakes

Reply: Thanks! We deeply appreciate your rigorous methodological critique regarding causality attribution. The revisions below directly address this fundamental concern:

After more than a month of research, we have a new understanding of the conclusions in the original draft. Indeed, even with video data of pre-earthquake macroscopic anomalies, it is difficult to form a complete causal chain in the absence of pre-earthquake data. After in-depth discussion by all co-authors, we propose that our data can only account for the dissolution of gypsum during the water-rock reaction. Gypsum may therefore indicate changes in the intensity of the water-rock reaction. As for the controlling factors of the variation of water-rock reaction intensity, we cannot define exactly. Considering that the sampling time was one month after the earthquake and obvious groundwater anomalies were observed before the earthquake, we believe that seismic activity may affect the variation of water-rock response intensity. Therefore, it is necessary to further study the possibility of gypsum as a tracer of tectonic activity.

Line 44: even if sampled one hour after the earthquake my comment would have been the same. If you don't have data of at least one other sampling, but ideally many samplings covering different seasons both before and after the event, you cannot make inferences on the effects of the earthquake on the water chemistry

Reply: Thanks! As mentioned earlier, we have revised this understanding to reinterpret the data in a more rigorous way.

Line 47: your data before the earthquake do not refer to the single sites you sampled, so no comparison can be made

Reply: Thanks! Through GPS comparison, we confirmed that at least 3 sampling sites had been reported (Table 1 in the first response). However, as you said, the literature data is from 10 years ago, its reference value may be subject to study, and it may not be

possible to make valid comparisons. So, we took the last 10 years of data and collected it more likely, and compared all the data we collected with our results (Fig. 1).

Lines 48-51: no one can deny the existence of a large suite of visible effects of seismic activity on groundwaters but for the advancement of knowledge these have to be described in detail and quantified. You cannot use the simple fact of a water whitening (among other things also confusing the sites) claiming this was due to gypsum dissolution without having the possibility to analyse the water chemistry

Reply: Thanks! After analyzing 10 years of data in study area, we determined that the main controlling factor of the macro anomaly is gypsum, and there may also be the influence of Calcite, albite, potassium feldspar, etc.

Lines 52-59: of course I agree that both Sr and S isotopes can be used as good source indicators. But again if you have a single measurement you cannot make any inference about the influence of the earthquake on the groundwaters

Reply: Thanks! In the revised conclusion, we focus on the relationship between the reaction intensity of gypsum and water-rock. So Sr, S and other isotopes are effective, and we are conducting supplementary experiments, which can be completed in April 2025.

Lines 75-78: You compared samples from three of your sampling sites with samples taken at the same sampling sites about ten years before. Results: one site registered a strong increase, another remained almost stable and the third one had a sharp decrease. You still cannot be sure that the changes are related to the earthquake, you have to exclude other possible processes. For example, do the composition of the groundwaters

change seasonally? Has the composition of the water decadal trends related to long periods of drought or water exploitation? Does the well tap aquifers from different levels with different composition and permeability that mixing in the well may change the composition of the water during pumping?

Reply: Thanks! We think your question about the manuscript is something we must take into account. Therefore, we give up the original conclusion and discuss the relationship between gypsum and water-rock reaction intensity instead.

Lines 89-91: this seems a forced solution. The selected samples contain all very low sulfate which seems not necessarily being representative of the whole study area. Two out of 8 selected samples are hyperalkaline waters which for their nature contain extremely low sulfate values due to their very negative redox potential. Furthermore, why didn't you include also the data of Yuce et al 2014? The mean sulfate value of that dataset would be 121 mg/L, more than an order of magnitude higher than that obtained with the ad hoc solution from the Baba et al dataset.

Reply: Thanks! Your advice has been of great help to us. According to your suggestion, we have collected and analyzed the data of the last 10 years. The results confirmed the dissolution of gypsum in the middle and south section.

Lines 120-121: the reliability of the data has not been questioned but the representativeness still remains doubtful

Reply: Thanks! In order to make the study more representative, the data of the study area in the past 10 years are used to discuss the water-rock reaction process.

Line 130: A nearly 1000 km tectonic system cannot be considered a single hydrothermal

system

Reply: Thanks! As you said, it is really not a system. The north section is a mixture of shallow groundwater and deep fluids, and igneous rocks participate in water-rock reactions. The central and southern part is the mixing of shallow groundwater and seawater, and sedimentary minerals such as gypsum participate in water-rock reaction.

Lines 135-142: the cited examples of studies which identified changes in groundwater composition related to earthquake are well known. But differently from your study, the researcher took tens of samples before the seismic events obtaining a clear signal that can be related to the earthquake

Reply: Thanks! Although we do not have pre-earthquake data, considering that we have observed pre-earthquake macro anomalies, coupled with the analysis of all data from the study area in the past 10 years. We believe that the data are sufficient to support our revised conclusion that gypsum can be used as a tracer of the intensity of water-rock reactions, and it is necessary to further investigate the possibility of gypsum as an indicator of tectonic activity.

Line 149: You did not answer to my question. Have the samples been filtered in the field and before acidification?

Reply: Thanks! Yes, we confirm.

Lines 170-171: if the filtration is not made at the time of sampling you may loose some of the dissolved metals due to precipitation of secondary minerals and/or to adsorption on the walls of the container. Furthermore, if filtration is made after acidification the result may be falsified by acid dissolution of suspended material

Reply: Thanks! We are responsible for all sample collection, pre-processing and data quality

Line 172: this method is used only for δD

Reply: Thanks! The analysis method of $\delta^{18}O$ is supplemented.

Lines 225-226: You cannot consider a nearly 1000 km long fault system as a single continuous structure. Furthermore, the complex geology of the area changes frequently the rock types present along the fault system. Add also the changing climatic and hydrologic conditions and you cannot consider samples collected many tens of km apart as pertaining to the same system.

Reply: Thanks! As you said, it is really not a system, we have answered earlier.

Lines 235-237: to have a chain you need all rings to be connected. You don't have evidence that the water-rock reaction balance has been disrupted by the earthquake. Gypsum or other evaporite rocks are naturally present in many of the lithostratigraphic sequences of the area and when they are part of aquifers, their dissolution contributes naturally to the saline content of the circulating groundwater without the influence of seismic activity. If you consider the data of Yuce et al 2014, you see that in the area many of the collected waters have high sulfate concentrations with values even exceeding your highest value. So there is no evidence of gypsum dissolution as a consequence of the seismic events.

Reply: Thanks! We have abandoned the conclusion that the gypsum can be inferred from the seismic effects of the data collected. We now propose that gypsum can reflect the intensity of water-rock reaction. Considering that the sample collection time was

about one month after the earthquake, it is necessary to further study the possibility of gypsum as an indicator of seismic activity.

Lines 301-301: I repeat again, even if you analysed a sample taken one hour after the earthquake, this could not confirm that the whitening and turbidity of the water before the seismic event was due to an increased sulfate content

Reply: Thanks! Although the data in this study maybe limited, we still observed the dissolution of gypsum by analyzing the data of 10 years in the study area together, but we could not determine whether it was caused by seismic activity. Therefore, we have expressed our conclusions more rigorously.

Line 307: I don't understand how you have fixed it. The video refers to the sampling site HS15 which, as shown in your table, has the lowest sulfate concentration. This video is not a proof of a sulfate anomaly for two reasons: 1) you don't have the concentration of sulfate at the time of the whithening and 2) the concentration you measured one month after was only 1.21 mg/L

Reply: Thanks! There should be a misunderstanding here. We have stated in the first response that the macroscopic anomaly originates from HS14, which has a SO_4^{2-} concentration of 316.61mg/L.

Lines 311-312: You are missing the main point: you have no evidence of variations that can be related to the earthquake

Reply: Thanks! We've revised our conclusions to be more precise.

Line 327: The problem is that normal values have not been defined. In terms of time you don't have enough samples that you can surely correlate with yours. But the same

holds true in terms of space, only 16 samples along a structure many hundred km long is not enough

Reply: Thanks! We have weakened the focus on time and only discussed the water-rock reaction process of gypsum. 10 years of data is sufficient to support spatial representativeness.