

Dear Editorial Office of HESS and Prof. Dai

We wish to express our sincere gratitude for the editorial team's diligent handling of our manuscript and extend particular appreciation to Prof. Dai for your judicious oversight throughout the review process. In response to the insightful comments and suggestions from Prof. Tuncay Taymaz, we have thoroughly revised the manuscript. All the revised contents have been marked in **red** in the manuscript.

Major revisions include:

1. Consistent naming for the 2023 Turkish earthquake.
2. Replace Türkiye with Turkey.
3. Expanded the reference materials of the study area and corrected the incorrect citations.
4. The fracture zone and place names in the model diagram (Figure 9) have been highlighted.

In short, after fully and effectively communicating with the reviewers, we modified the possible problems in our manuscript according to the suggestions of the reviewers, so that the analysis of data in the manuscript is more rigorous and the extension is appropriate

We sincerely wish the current version meets your standards and welcome further guidance.

Finally, I would like to thank HESS editorial Department and Dai Editor-in-Chief for their hard work.

Sincerely

Zebin Luo

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Point-by-point response to comments:

Note: *Italic blue* is the comment. Black is the reply, and **important sentences are bolded**.

Red indicates the position of the modification information in the newly submitted revised draft.

Reply to referee comments

Referee #5: Taymaz, Tuncay ttaymaz@gmail.com

*nominated 27 Jul 2025, accepted 29 Jul 2025, report 09 Aug 2025***Report #2**

Manuscript HESS-2024-395 titled "Gypsum as a potential tracer of earthquake: a case study of the Mw7.8 earthquake in the East Anatolian Fault Zone, southeastern Turkey" is timely, interesting and fills the gap over the 2023 Kahramanmaraş Earthquake Doublet and it should be published after minor-moderate revisions. Nevertheless, I have the following comments to be addressed before its acceptance and/or publication at the EGU journal of HESS.

Reply: Thanks! Thank you for your recognition of our research. Based on your suggestions, we have made detailed revisions to the manuscript. The detailed content is as follows.

Overall Comments: I summarize below notes that should be corrected through the main text, figures and supplementary on-line materials.

(1) The earthquake is named The 2023 Kahramanmaraş Earthquake Doublet. Please also check further readings of ISC Event Bibliography page under URL <https://www.isc.ac.uk/cgi-bin/FormatBibprint.pl?evid=625613033>

Reply: Thanks! Thank you for your professional expression, which is of great significance for unified description and subsequent research. We have uniformly corrected the relevant expressions in the manuscript. **(Lines 16-18, 47-49, 55-56, 107-108, 200, 363-364, 415-416).**

(2) The national country name is Türkiye (TÜRKİYE) both in Turkish and English as approved by the UN-General Assembly a few years ago. Thus, Turkey (TURKEY) should be replaced accordingly throughout the text.

Reply: Thanks! We have corrected all the relevant expressions in the manuscript to "Türkiye". Specifically: (Line 3, 45, 81, 85).

(3) The running title of the manuscript is a bit confusing! What would be a meaningful one? How about the one below?

Gypsum as a potential indicator/warning of earthquake phenomenon: a case study of the Kahramanmaraş Mw7.8 earthquake doublet in the East Anatolian Fault Zone, southeastern Türkiye

Reply: Thanks! We need to clarify a misunderstanding here. You may have reviewed the initial draft we submitted (uploaded on 12 Dec 2024). Your revision of the title was based on the initial draft. In the final submission version, we have changed the title to "Anhydrite Dissolution Dynamics as a Hydrogeochemical Tracer of Seismic-Fluid Coupling: Insights from the East Anatolian Fault Zone, Türkiye" (uploaded on 22 Jul 2025). The revised title is more focused on the relationship between hard gypsum and seismic fluids. We hope you will approve of the revised title.

(4) Key-Points can be as below:

1- Geothermal fluids are modified by major earthquakes in the EAFZ, including energy and materials.

2- Geothermal fluids are diluted by infiltration of a large amount of shallow cold water in the EAFZ.

3- Shallow sedimentary minerals like gypsum could be used as precursory anomaly indicators of earthquakes.

Reply: Thanks! We agree to adopt your professional advice.

(5) Abstract needs to be simplified and language should be as plain as possible to streamline the message right.

Reply: Thanks! As mentioned earlier, the version you reviewed might be the initial draft. In the final submitted manuscript, we have completely rewritten the abstract. The specific abstract is as follows:

" **Abstract:** Pre-seismic turbidity and salinity anomalies in groundwater were documented at HS04 and HS14 monitoring wells and/or springs along the East Anatolian Fault Zone (EAFZ) following the 2023 Mw 7.8 and Mw 7.6 Turkey earthquakes. By synthesizing hydrogeochemical datasets (2013-2023) with

post-seismic responses, we unravel fault-segmented groundwater evolution: (1) Northern Na-Cl and Na-HCO₃ type waters result from mixing of mantle-derived magmatic fluids (0-7% contribution) with shallow groundwater, governed by volcanic rocks-carbonate dissolution; (2) Central-southern Ca-HCO₃ and Ca-Na-HCO₃ systems reflect shallow circulation with localized inputs from evaporites (Increased SO₄²⁻ concentration caused by dissolution of anhydrite), ophiolites (Mg²⁺ anomalies), and seawater. PHREEQC simulation shows that the dissolve-precipitation equilibrium of anhydrite is sensitive to the variation of water-rock reaction intensity in the Central-southern segments of EAFZ. Coseismic permeability changes disrupt the solubility equilibria of anhydrite, driving hydrochemical anomalies. We propose that seismic stress redistribution induces fracture network reorganization, thereby disrupting anhydrite solubility equilibria. Given its tectonic sensitivity and widespread occurrence, anhydrite dissolution dynamics emerge as a potential tracer for hydrogeochemical monitoring in active fault zones. We propose a novel research paradigm wherein regional hydrogeological surveys identify applicable target indicator horizons, enabling continuous monitoring and establishment of region-specific evaluation metrics to ultimately achieve early warning capabilities for geohazard precursors."

(6) Introduction should enhance the background reading a bit further. Thus, I advice inclusion of scholarly written articles on the Eastern Anatolia / Türkiye) and speciafally the 2023 Kahramanmaraş earthquake doublet below for readers' convenience.

Besides, a local seismologist and/or geologist would be useful to be among co-authors in ortder to avoid misunderstanding and naming and labeling the geographical locations. Here is an example at line 48 "Qahraman, Marash and Hatay! I can see that the authors are trying to say "Kahramanmaraş and Hatay". Similar examples can be listed at large numbers ...

Reply: Thanks! Thank you for your suggestion. In the latest submitted manuscript, we have supplemented the literature on "2023 Kahramanmaraş earthquake doublet", and have carefully checked the city name and other details. (Lines 56-58; 108-109)

Ding, H.Y., Zhou, Y.J., Ge, Z.X., Taymaz, T., Ghosh, A., Xu, H.Y., Irmak, T.S., Song, X.D. (2023). High-Resolution Seismicity Imaging and Early Aftershock Migration of the 2023 Kahramanmaraş (SE Türkiye) Mw 7.9 & 7.8 Earthquake Doublet. Earthquake Science, Vol. 36(6), 417-432, <https://doi.org/10.1016/j.eqs.2023.06.002>.

Goldberg, D.E., Taymaz, T., Reitman, N.G., Hatem, A.E., Yolsal-Çevikbilen, S.,

Barnhart, W.D., Irmak, T.S., Wald, D.J., Öcalan, T., Yeck, W.L., Özkan, B., Thompson-Jobe, J.A., Shelly, D.R., Thompson, E.M., DuRoss, C.B., Earle, P.S., Briggs, R.W., Benz, H., Erman, C., Doğan, A.H., Altuntaş, C. (2023). *Rapid Characterization of the February 2023 Kahramanmaraş, Türkiye, Earthquake Sequence*. *The Seismic Record*, Vol. 3(2), 156–167, <https://doi.org/10.1785/0320230009>.

Goldberg, D.E., Taymaz, T., Yeck, W.L., Barnhart, W.D., Yolsal-Çevikbilen, S., Irmak, T.S., Öcalan, T., Özkan, B., Erman, C., Doğan, A.H., Altuntaş, C. (2023). *Supporting Data and Models for Characterizing the February 2023 Kahramanmaraş, Türkiye, Earthquake Sequence*: U.S. Geological Survey Data Release, USGS–ScienceBase, <https://doi.org/10.5066/P9R6DSVZ>.

Hu, J., Liu, M., Taymaz, T., Ding, L., Irmak, T.S. (2024). *Characteristics of Strong Ground Motion from the 2023 Mw 7.8 and Mw 7.6 Kahramanmaraş Earthquake Sequence*. *Bulletin of Earthquake Engineering*, Vol. 22(2), <https://doi.org/10.1007/s10518-023-01844-2>.

Liu, J., Huang, C., Guohong, Z., Shan, X., Korzhenkov, A., Taymaz, T. (2024). *Immature Characteristics of the East Anatolian Fault Zone from SAR, GNSS and Strong Motion Data of the 2023 Türkiye-Syria Earthquake Doublet*. *Scientific Reports – Nature*, Vol. 14(1), 10625. <https://doi.org/10.1038/s41598-024-61326-6>.

Liu, C., Lay, T., Wang, R., Taymaz, T., Xie, Z., Xiong, X., Irmak, T.S., Kahraman, M., Erman, C. (2023). *Complex Multi-Fault Rupture and Triggering During the 2023 Earthquake Doublet in Southeastern Türkiye*. *NATURE Communications*, Vol. 14, 5564(2023), NCOMMS-23-18990. <https://doi.org/10.1038/s41467-023-41404-5>.

Melgar, D., Taymaz, T., Ganas, A., Crowell, B., Öcalan, T., Kahraman, M., Tsironi, V., Yolsal-Çevikbilen, S., Valkaniotis, S., Irmak, T. S., Eken, T., Erman, C., Özkan, B., Dogan, A. H., Altuntaş, C. (2023). *Sub- and Super-Shear Ruptures During the 2023 Mw 7.8 and Mw 7.6 Earthquake Doublet in SE Türkiye*. *Seismica*, Vol. 2(3). <https://doi.org/10.26443/seismica.v2i3.387>.

Melgar, D., Ganas, A., Taymaz, T., Valkaniotis, S., Crowell, B., Kapetanidis, V., Tsironi, V., Yolsal-Çevikbilen, Ocalan, T. (2020). *Rupture Kinematics of January 24, 2020 Mw 6.7 Doğanlı-Sivrice, Turkey Earthquake on the East Anatolian Fault Zone Imaged by*

Space Geodesy, Geophysical Journal International, Vol. 223(2), 862–874, <https://doi.org/10.1093/gji/ggaa345>.

Okuwaki, R., Yagi, Y., Taymaz, T., Hicks, S.P. (2023). Multi-Scale Rupture Growth with Alternating Directions in a Complex Fault Network During the 2023 South-Eastern Türkiye and Syria Earthquake Doublet. *Geophysical Research Letters*, Vol. 50(12), e2023GL103480, <https://doi.org/10.1029/2023GL103480>.

Ren, C., Wang, Z., Taymaz, T., Hu, N., Luo, H., Zhao, Z., Yue, H., Song, X., Shen, Z., Xu, H., Geng, J., Zhang, W., Wang, T., Ge, Z., Irmak, T.S., Erman, C., Zhou, Y., Li, Z., Xu, H., Cao, B., Ding, H. (2024). Super-Shear Triggering and Cascading Fault Ruptures of the 2023 Kahramanmaraş, Türkiye Earthquake Doublet. *SCIENCE*, Vol. 383(6680), 305-311. <https://doi.org/10.1126/science.adi1519>.

Taymaz, T., Ganas, A., Yolsal-Çevikbilen, S., Vera, F., Eken, T., Erman, C., Keleş, D., Kapetanidis, V., Valkaniotis, S., Karasante, I., Tsironi, V., Gaebler, P., Melgar, D., Ocalan, T. (2021). Source Mechanism and Rupture Process of the 24 January 2020 Mw 6.7 Doğanşol-Sivrice Earthquake obtained from Seismological Waveform Analysis and Space Geodetic Observations on the East Anatolian Fault Zone (Turkey), *Tectonophysics*, Vol. 804, <https://doi.org/10.1016/j.tecto.2021.228745>.

Taymaz, T., Ganas, A., Berberian, M., Eken, T., Irmak, T.S., Kapetanidis, V., Yolsal-Çevikbilen, S., Erman, C., Keleş, D., Esmaeili, C., Tsironi, V., Özkan, B. (2022). The 23 February 2020 Qotur-Ravian Earthquake Doublet at the Iranian-Turkish Border: Seismological and InSAR Evidence for Escape Tectonics, *Tectonophysics*, Vol. 838, <https://doi.org/10.1016/j.tecto.2022.229482>.

Taymaz, Tuncay, Eyidogan, H. and Jackson, J.A. (1991). Source Parameters of large earthquakes in the East Anatolian Fault Zone (Turkey), *Geophysical Journal International-Oxford*, 106, 537-550.

Tung, S., Sippl, C., Shirzaei, M., Taymaz, T., Masterlark, T., Medvedev, I. (2024). Structural Controls on Fault Slip Models of the 6 February 2023 Kahramanmaraş, Türkiye Earthquake Doublet With Finite Element Analyses. *Geophysical Research Letters*, Vol. 51(16), e2023GL107472, <https://doi.org/10.1029/2023GL107472>.

Wang, Z., Zhang, W., Taymaz, T., He, Z., Xu, T., Zhang, Z. (2023). Dynamic Rupture

Process of the 2023 Mw 7.8 Kahramanmaraş Earthquake (SE Türkiye): Variable Rupture Speed and Implications for Seismic Hazard. Geophysical Research Letters, Vol. 50(15), e2023GL104787. <https://doi.org/10.1029/2023GL104787>.

Wu, F., Xie, J.J., An, Z., Lyu, C.H., Taymaz, T., Irmak, T.S., Li, X.J., Wen, Z.P., Zhou, B.F. (2023). Pulse-Like Ground Motion Observed During the 6 February 2023 Mw 7.8 Pazarcık Earthquake (Kahramanmaraş, SE Türkiye). Earthquake Science, Vol. 36(4), 328-339, <https://doi.org/10.1016/j.eqs.2023.05.005>

Xu, C., Zhang, Y., Hua, S., Zhang, X., Xu, L., Chen, Y., Taymaz, T. (2023). Rapid Source Inversions of the 2023 SE Türkiye Earthquakes with Teleseismic and Strong-Motion Data, Earthquake Science Vol. 36(4), 316–327, <https://doi.org/10.1016/j.eqs.2023.05.004>.

Yolsal-Çevikbilen, S., Taymaz, T., Irmak, T.S., Erman, C., Kahraman, M., Özkan, B., Eken, T., Öcalan, T., Doğan, A.H., Altuntaş, C. (2024). Source Geometry and Rupture Characteristics of the 20 February 2023 Mw 6.4 Hatay (Türkiye) Earthquake at Southwest Edge of the East Anatolian Fault. Geochemistry, Geophysics, Geosystems, Vol. 25(10), e2023GC011353, <https://doi.org/10.1029/2023GC011353>.

Zhang, Y., Tang, X., Liu, D., Taymaz, T., Eken, T., Guo, R., Zheng, Y., Wang, J., Sun, H. (2023). Geometric Controls on Cascading Rupture of the 2023 Kahramanmaraş Earthquake Doublet. NATURE Geoscience, Vol. 16, 1054-1060(2023), NGS-2023-04-00727. <https://doi.org/10.1038/s41561-023-01283-3>.

Zhou, J., Xu, Y., Zhang, Y., Feng, W., Taymaz, T., Chen, Y-T., Xu, C., Xu, B., Wang, R., Shi, F., Shao, Z., Huang, Q. (2025). Geometric Barriers Impacted Rupture Processes and Stress Releases of the 2023 Kahramanmaraş, Türkiye, Earthquake Doublet. Communications Earth & Environment - Nature, Vol. 6, Manuscript No. 56(2025), <https://doi.org/10.1038/s43247-025-02004-x>.

When discussing about the historical earthquakes the most prominent and established publications are provided by Prof.Dr. Nicholas N. Ambraseys' and yet again lack of trained seismologists among the research group led the authors with a falsified wrong citations!

Reply: Thanks! Thank you for your correction. We have revised the relevant references.
(Lines 108-109, 348-349, 356)

(7) Geological background is summarized with too limited and selected publications thus it does not necessarily provide the objective layout.

Reply: Thanks! We have enriched the geological background and supplemented the references. (Lines 108-109)

(8) Sampling and analytical methods should be developed further to detail the routinely collected samples and their analysis to guide novice young scientists.

Reply: Thanks! Compared with the initial draft, we have added precise GPS coordinates, the chemical pre-treatment process, the selection of instruments and standards, as well as the analysis errors. (Lines 117-139). Specifically includes:

" 16 samples of groundwater were collected in EAFZ, including hot springs, geothermal wells and river water. HS01-HS04 was collected from west to east along SF. HS07-HS16 was collected from north to south along EAFZ (Fig. 1). Detailed sample collection and testing methods can be found at Luo et al. (2023). In short, the water sample was taken with a 50 mL clean polyethylene bottle and the temperature and pH of the water were measured and recorded. Two samples were collected at each sampling site, one was added with ultrapure HNO₃ to analyse the cation content, and the other was used to analyse the anion content and isotopic composition. All samples need to be pre-treated with a 0.45 μm filter membrane to remove impurities before sampling.

The Hydrogen and oxygen isotopes were determined by a Picarro L2140-I Liquid water and vapor isotope analyzer (relative to Vienna Standard Mean Ocean Water (V - SMOW)). Precisions on the measured δ¹⁸O and δD value was ±0.2‰ (2SD) and ±1‰ (2SD) respectively (Zeng et al., 2025). The cation (Li⁺, Na⁺, K⁺, Ca²⁺ and Mg²⁺) and anion (F⁻, Cl⁻, NO₃⁻ and SO₄²⁻) were analysed by Dionex ICS-900 ion chromatograph (Thermo Fisher Scientific Inc.) at the Earthquake Forecasting Key Laboratory of China Earthquake Administration, with the reproducibility within ±2% and detection limits 0.01 mg/L (Chen et al., 2015). HCO₃⁻ and CO₃²⁻ was determined by acid-base titration with a ZDJ-100 potentiometric titrator (reproducibility within ±2%). SiO₂ were analysed by inductively coupled plasma emission spectrometer Optima-5300 DV (PerkinElmer Inc.) (Li et al. 2021). Trace elements were analysed by Element XR ICP-MS at the Test Center of the Research Institute of Uranium Geology. Multielement standard solutions (IV-ICPMS 71A, IV-ICP-MS 71B and IV-ICP-MS 71D, iNORGANIC

VENTURES) used for quality control. The analytical error margin of major cations and trace elements were less than 10%. **Strontium isotope ratios ($^{87}\text{Sr}/^{86}\text{Sr}$) were determined through triple quadrupole ICP-MS (Agilent 8900 ICP-QQQ) with a precision of ± 0.001 (Liu et al., 2020).**"

(9) Results adequately discuss the physical, chemical and isotopic compositions of geothermal water acquired are listed in Table 1.

Reply: Thanks!

(10) Discussion on (a) the origin of geothermal fluids and (b) water-rocks interaction are at a satisfactory level with proper citations.

Reply: Thanks!

(11) Figure 8 at page 24 is fantastic and it should be improved using thick red lines on the EAFZ and the Sürgü Fault to bring them front a bit to attentions of the readers. If possible a few geographical location of towns and major cities can be labelled. Here with respect to Figure 8, some of well established seismic tomography studies and maps should be cited/referred to display the link on geothermal fields and the deeper structures (see following articles below).

Reply: Thanks! Thank you very much for your excellent suggestion. In the latest submitted manuscript, the model diagram is Fig. 9. According to your suggestion, we have **highlighted** and **bolded** the two faults, and marked the locations of the important nodes cities **(Lines 369-375)**. In the main text, we have added references to the seismic tomography studies and map literature of the research area. **(Lines 348-349)**

Confal, J.M., Taymaz, T., Eken, T., Bezada, M.J., Faccenda, M. (2025). Remnant Tethyan Slab Fragments Beneath Northern Türkiye. EPSL – Earth and Planetary Science Letters, Vol. 664, 119458, <https://doi.org/10.1016/j.epsl.2025.119458>.

Confal, J. M., Bezada, M. J., Eken, T., Faccenda, M., Saygin, E., Taymaz, T. (2020). Influence of Upper Mantle Anisotropy on Isotropic P-wave Tomography Images Obtained in the Eastern Mediterranean Region, Journal of Geophysical Research (JGR) – Solid Earth, Vol: 125(8), <https://doi.org/10.1029/2019JB018559>.

Confal, J., Faccenda, M., Eken, T., and Taymaz, T. (2018). Numerical Simulation of 3-D Mantle Flow Evolution in Subduction Zone Environments in Relation to Seismic Anisotropy Beneath the Eastern Mediterranean Region, Earth and Planetary Science

Letters (EPSL), Vol. 497, 50–61. <https://doi.org/10.1016/j.epsl.2018.06.005>.

Erman, C., Yolsal-Çevikbilen, S., Eken, T., Huang, Z., Taymaz, T. (2025). *Seismic Anisotropy Variations in the Eastern Mediterranean Sea Region Revealed by Splitting Intensity Tomography: Implications on Mantle Dynamics*. *Journal of Geophysical Research (JGR) – Solid Earth*, Vol. 130(3), e2024JB030331, <https://doi.org/10.1029/2024JB030331>.

Fichtner, A., Saygin, E., Taymaz, T., Cupillard, P., Capdeville, Y. and Trampert, J. (2013). *The Deep Structure of the North Anatolian Fault Zone*, *Earth and Planetary Science Letters*, July 2013, Vol: 373, pp. 109-117, doi:10.1016/j.epsl.2013.04.027.

Kind, R., Eken, T., Tilmann, F., Sodoudi, F., Taymaz, T., Bulut, F., Yuan, X., Can, B. and Schneider, F., (2015). *Thickness of the Lithosphere Beneath Turkey and Surroundings from S-Receiver Functions*, *Solid Earth*, 6, 971–984. www.solid-earth.net/6/971/2015/, doi:10.5194/se-6-971-2015.

Wang, H., Huang, Z., Eken, E., Keleş, D., Kaya-Eken, T., Confal, J. M., Erman, C., Yolsal-Çevikbilen, S., Zhao, D., Taymaz, T. (2020). *Isotropic and Anisotropic P-wave Velocity Structures of the Crust and Uppermost Mantle Beneath Turkey*, *Journal of Geophysical Research (JGR) – Solid Earth*, Vol. 125 (12), e2020JB019566, <https://doi.org/10.1029/2020JB019566>.

(12) *The relationship between geothermal fluid and earthquake forecasting section is attractive one, but it needs to be supported by other local and/or global examples. Thus, a refined discussion is needed.*

Reply: Thanks! We clarify two key points:

1. Regional specificity: **Anhydrite’s applicability is context-dependent** (e.g., evaporite-rich EAFZ).
2. Paradigm shift: The innovation is methodological – identifying region-specific target horizons (e.g., anhydrite here, serpentine elsewhere) for localized monitoring. We proposed that traditional tracers (He, Rn) and anhydrite serve complementary roles; multi-proxy approaches are essential for earthquake forecasting.

(13) *Conclusion and Outlook is well placed with proper setting of the conducted systematic element and isotope analysis on the hydrogeochemistry of geothermal fluid*

after the earthquake.

Reply: Thanks!

In SUMMARY, the manuscript HESS-2024-395 titled "Gypsum as a potential tracer of earthquake: a case study of the Mw7.8 earthquake in the East Anatolian Fault Zone, southeastern Turkey" is timely, interesting and fills the gap over the 2023 Kahramanmaraş Earthquake Doublet and it should be published after minor-moderate revisions.

9 August 2025

Tuncay Taymaz

Istanbul Technical University - Istanbul – Türkiye

Reply: Thanks!