My Final Comprehensive Review Report

Dear Editor,

Peace be upon you; I am writing to submit my technical review of the manuscript titled "Novel insights into deep groundwater exploration by geophysical estimation of hard rock permeability".

The paper presents a significant advancement in hydro-geophysics by demonstrating the use of controlled-source audio-frequency magnetotellurics (CSAMT) to estimate two- and three-dimensional permeability (K) distributions at depths exceeding 1 km. While previous geophysical approaches like vertical electrical sounding (VES) and electrical resistivity tomography (ERT) are generally restricted to shallow depths less than 500m, this study successfully bridges the gap between regional mapping and site-specific, high-resolution modeling for deep aquifers in crystalline and sedimentary terrains. So, the current study is scientifically rigorous, utilizing 116 core samples across three lithologies (granite, hornstone, and sandstone) to establish a strong empirical correlation between resistivity and permeability $\{R^2 = 0.96\}$. Whole manuscript was written in a highly technical and professional academic style. Furthermore, the authors successfully argue that CSAMT bridges the resolution-depth gap that MT and TDEM cannot fill in resistive hard rock settings. However, they rightly emphasize that the derived empirical constants are site-specific and must be recalibrated for new geological environments.

Despite these strengths mentioned above, I have identified a few areas, in my point of view, where the manuscript would benefit from clarification and refinement.

ETQ-1 Although the authors correctly identify this as a limitation and use a probabilistic framework to show that uncertainty increases significantly beyond the calibration limit. Authors should try to address the extrapolation uncertainty associated with applying a relationship calibrated at 0–200 meters to depths reaches 1.3 kilometer.

ETQ-2 There is an inherent scale difference between centimeter-scale core samples and 50-meter scale of CSAMT blocks. This inherent scale explains some of the scatters in the K-ρ dataset, as a core might miss fracture corridors captured by the geophysical signal. The authors should consider expanding their discussion in Section 4.9 (Scale effects in permeability estimation) to more explicitly address the following points:

- ✓ Quantifying the Representative Elementary Volume (REV), The authors should emphasize that because core samples (50 mm × 100 mm cylinders) primarily capture intrinsic rock matrix properties, they may inherently underestimate the flow capacity in crystalline terrains where fractures dominate. Conversely, CSAMT inversions represent a bulk effective property that integrates both matrix and fracture contributions over a much larger volume (about 2.5 Km^2). Whereas, I believe that, explicitly stating that the core data may not reach the REV of a fractured rock mass would add theoretical depth to the explanation for the dispersion of the dataset.
- ✓ The impact on statistical anomalies; I suggested relating the scatters in the K-ρ plot (Fig. 5) to different specific geological scenarios. to help readers understand that the "discrepancies" are actually physically meaningful reflections of geological heterogeneity rather than mere measurement error.
- ✓ Bridge the Scale Gap by, for example, recommending integrating intermediate-scale data, such as packer tests, in future work to reconcile matrix-scale measurements with field scale connectivity.

ETQ-3 The model assumes fresh groundwater at depth based on regional data. A sensitivity analysis reveals that if fluid resistivity were halved due to salinity, the inferred permeability could increase by a factor of 2 to 18 depending on the formation resistivity, which is a critical consideration for deep-seated aquifers. In addition to the authors, in the current study, focuses on K without mentioning the aquifer storage parameters like specific yield, which are essential for a complete groundwater resource assessment. So, I suggest that the discussion regarding the sensitivity of the model to groundwater salinity and the limitations in characterizing aquifer storage should be more explicitly highlighted to ensure the results are not over-generalized. Like the future integration of Nuclear Magnetic Resonance (NMR) or other logging tools to better characterize storage capacity alongside permeability.

Finally, the paper is scientifically sound and provides a valuable workflow for deep groundwater assessment. So, My Final Decision is **Accept with Minor Revisions**

Thank you for the opportunity to review this impactful work.