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Gradient-Based Joint Inversion of Magnetotelluric and Seismic 1D Data to Constrain Natural Hydrogen Reservoir in São Francisco Basin

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Introduction

In the context of natural hydrogen exploration, identifying potential pathways, reservoirs, and traps require geophysical techniques capable of resolving both structural features and resistivity contrasts associated with hydrogen migration and accumulation. The use of joint inversion helps to reduce the intrinsic ambiguities of individual geophysical methods by combining their complementary sensitivities. While seismic methods are effective in imaging structural discontinuities and stratigraphic boundaries, magnetotelluric (MT) method contributes by depicting resistivity contrast zones that may indicate pathways related to hydrogen migration.

Usually, the seismic method is the most widely used for petroleum and gas exploration. However, there are situations in which it presents limitations. One example is the low-velocity layer (LVL) scenario, where low-velocity sediments lie beneath high-velocity basalt layers. Another example is the presence of volcanic rock cover over sedimentary sequences, as observed in the Mata da Corda Group of the São Francisco Basin. In such cases, seismic imaging becomes challenging or ineffective. Due to the limitations of the seismic method, the MT method emerges as an alternative solution for LVL geological settings. The resistivity contrast between metamorphic and volcanic rocks and the overlying sedimentary layers is enhanced by the typically high resistivity of the sedimentary sequences and the low resistive response of the underlying metamorphic and volcanic units.

Method and/or Theory

For the MT modeling, we used Wait's recursion formula to compute the transfer function (impedance) at the top of the N-th layer. The equation is solved iteratively, starting from the bottom layer, which is assumed to be a homogeneous half-space, and recursively propagating the solution upward through the overlying layers until the surface. For the seismic modeling, we used a travel-time equation for critically refracted rays propagating along a multilayered horizontal interface. The formulation considers a ray that travels along the top of the N-th layer. In geophysics, an inversion problem is based on the idea of finding the best model that fits observed data. This process involves adjusting a calculated response to match the observed curves. Several gradient-based algorithms are widely used in the literature, such as the Levenberg-Marquardt, Newton, Gauss-Newton, and conjugate gradient methods. This work adopts a joint inversion approach based on a cross-gradient method. To test the methodology, the geological context of H2 potential in the São Francisco basin is modeled. We discretize the study area based on a real scenario where thickness and physical parameters are assigned (resistivity and velocity) based on available well logs.

Results and Conclusions

Single inversions show good estimates of the parameters for MT and seismic, and preliminary results on the joint inversion are promising when working with more complex geological settings and when noise is added which make an important tool for exploring real context for hydrogen exploration in the São Francisco basin and other geological settings.