HIP-FEM: A Hierarchical, Induced Polarization Finite Element Method for analysis of thin, dispersive, geoelectric features

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SUMMARY

One of the persistent challenges in computational geophysical electromagnetics is balancing the tension between the high computational cost of maximizing geologic realism and the necessity of rapid throughput of simulation results, whether for inversion, "real-time" decision making, experiment design, or construction of machine learning training sets. To this end, considerable effort has been spent over the decades on various effective medium methodologies, exotic reformulations of Maxwell's equations in terms of non-local (fractional) operators, and a growing expanse reduced order model approaches. Here we expand on the latter by focusing on the hierarchical finite element approach (Weiss, 2017; Beskardes et al., 2021) and its extension to the physics of induced polarization through review of the relevant mathematics and analysis of model studies inspired by relevant and challenging mineral exploration scenarios. The occurrence of alteration halos around massive mineral bodies or mineral alteration along the complex fluid migration pathways in a leach pile or fault zone represent instances where the conductive feature of interest is intrinsically "thin" when compared to the surrounding geologic structures. Such conductive features – often with frequency-dependent electrical properties – discretize naturally in the hierarchical finite element framework which decomposes the electrical model into bulk contributions from volumetric elements, supplemented by infinitesimally thin contributions associated with the elements' facets and edges where needed. This avoids the costly volumetric discretization of the latter and lies at the heart of the method's overwhelming efficiency. The application and extension of the method we describe here represents a novel contribution toward further tilting the balance of geologic realism in the analyst's favor while addressing the future of mineral exploration in developing tools to meet the demands of an emergent and global, green energy economy.

Keywords: mining geophysics, induced polarization, fractures, finite element modeling

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