

Optimizing Subsurface Mapping of the Zaberah Bauxite Deposit: A Low-Frequency GPR Integration for High-Resolution Ore Characterization

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The Zaberah bauxite deposit, situated 500 km northwest of Riyadh, serves as a critical pillar for Saudi Arabia's aluminum industry and a defining stratigraphic marker within the Cretaceous Arabian Platform. Hosted in the Early Cretaceous Formation, the deposit originated during a significant depositional hiatus and sea-level low-stand, creating a 22-meter paleo-weathering profile. Despite a resource base of 252 Mt in the South Zone, the ore body presents extraction challenges due to its thin geometry and burial under 5–10 meters of Wasia Formation overburden. Traditional exploration relies on grid-pattern diamond drilling, which despite its point-accuracy, remains "blind" to lateral discontinuities and "pinch-and-swell" variations. This dependency leads to fragmented geological models, high operational costs, and significant environmental degradation, including habitat loss and soil erosion. To address these challenges, this study evaluates Ground Penetrating Radar (GPR) as a non-invasive, high-resolution alternative to enhance subsurface mapping while reducing ecological impacts. A low-frequency 25 MHz GPR system was utilized to achieve the 10-meter penetration depth required to identify the 1-meter-thick bauxite horizon through arid terrain. The results indicate that the 25 MHz antenna successfully mapped subsurface architecture at depths between 3 and 10 meters, providing continuous profiles in areas of low drilling density. A high correlation was observed between radargram reflectors and borehole lithology, with GPR identifying structural offsets and thickness variations (0.8–5 m) often overlooked by standard kriging models. The correlation between bauxite depths measured in boreholes and those calculated from GPR sections shows an error range of 2% to 8%. This integration reduces ore dilution risks and could decrease required drill density by approximately 15-20% without compromising geological confidence. Ultimately, this research confirms low-frequency GPR as a cost-effective tool for characterizing strata ore bodies, transitioning the Zaberah deposit from isolated data points into a high-fidelity 3D volume for optimized mine planning.