## Data-Driven Geometallurgy at Tujuh Bukit: Integrating Hyperspectral Core Imaging, SEM/MLA, Dynamic Rebound Hardness, and Machine Learning for Processing Design Optimisation

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In the evolving discipline of geometallurgy, the integration of high-resolution mineralogical datasets and data-driven analytics has reshaped the understanding of ore deportment and its impact on mineral processing. This study extends a previous machine learning-based silicate alteration framework to support metallurgical design by incorporating multi-source datasets, including hyperspectral core imaging (Corescan), quantitative mineralogy (SEM/MLA), multi-element geochemistry (Geochem), and dynamic rebound hardness (Equotip) data.

The research focuses on the Tujuh Bukit Cu-Au porphyry deposit, Banyuwangi, East Java, Indonesia, which hosts 1.7 Bt at 0.5% Cu and 0.5g/t Au. The geological setting comprises multi-phase diorite and tonalite intrusions within a volcano-sedimentary host rock, exhibiting potassic, phyllic, and propylitic alteration overprinted by structurally controlled advanced argillic alteration. These overprints influence the mineralogical expression of copper and gold, creating heterogeneous ore domains with variable flotation responses.

Since 2019, 156,909 linear metres of Corescan, along with Equotip data, have been used to build robust alteration facies through unsupervised machine learning. Nine key alteration minerals and hardness features were clustered using the K-means algorithm, creating consistent domains. These domains were then predicted in historical drill data (without Corescan or Equotip) via Neural Network and AdaBoost algorithms using geochemical and/or Equotip inputs, expanding the 3D alteration model coverage.

Geochem-based sulphide calculations and SEM/MLA analyses were integrated to validate sulphide associations across domains. Results show a strong correlation between alteration and metal deportment: in primary porphyry zones, Cu and Au are mainly hosted in chalcopyrite and bornite. As advanced argillic overprinting progresses, Cu and Au become associated with covellite, chalcocite, enargite, digenite, and occasionally occur as fine inclusions within pyrite and gangue minerals such as quartz and muscovite.

By integrating machine learning with multi-source datasets, this study establishes robust geometallurgical domains, supporting process design optimisation and demonstrating machine learning’s scalability in geoscience.