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Unveiling the temporal dynamics: A spatiotemporal prospectivity model for porphyry systems in Papua New Guinea and the Solomon Islands

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The tectonic setting of porphyry systems is influenced by the subduction style and history that impact the distribution and concentration of copper (Cu), gold (Au), and molybdenum mineralisation. Typically linked to the intrusion of arc-related magma into the upper crust along subduction zones, the formation of porphyry ore deposits is currently understood primarily through geological and geophysical observations of the overriding plate, creating a knowledge gap regarding arc metallogenic processes in convergence zones over time. In this study, we address this gap by investigating the connection between the formation of porphyry Cu-Au deposits and the evolution of subduction zones, utilising a range of features derived from a plate motion model and oceanic crust age grids. Incorporating 47 Cenozoic intrusion-related Cu-Au deposits located in Papua New Guinea and the Solomon Islands, we employ a spatiotemporal mineral prospectivity framework that leverages advanced machine learning methods to map prospective arc terranes. The model successfully predicts all known mineral occurrences in the testing set and identifies the most important features for predicting potential areas of porphyry mineralisation.

We observe that the obliquity angle of the relative motion vector in subduction zones plays a crucial role in distinguishing between mineralised (highly prospective) and barren areas (low prospective). This feature is recognised for its significant influence on a spectrum of geological processes, encompassing fluid flow dynamics, magmatic processes, and stress regimes. This influence extends to the transport of mineralising elements and the creation of favourable conditions for ore deposition, with the range of 25 to 90 degrees correlating with mineralised zones, suggesting that oblique subduction zones are more likely to be rich in mineralisation in the study area. Additionally, the length and curvature of arcs emerge as important features for identifying mineralised areas, with tightly curved arcs associated with higher compressional stress and fractures facilitating magma ascent and porphyry formation. The orthogonal component of the downgoing absolute plate velocity is also identified as a significant feature, with higher magnitudes associated with mineralisation, indicating that rapid convergence rates are optimal for porphyry system formation due to accelerated metasomatism and partial melting processes in the overriding plate.

The seafloor spreading rate of the subducting crust, computed at the time when the crust originally formed, is an additional important feature linked to mineralised areas. This preferentially occurs when crust formed in the range of 25 to 55 mm/yr (half spreading rate) is subducted. At lower spreading rates, there is a higher proportion of serpentinised mantle peridotite, adding water and carbon to the plate, which will be expelled during subduction, contributing to increasing hydrous melting in the mantle wedge and acting as a catalyst for porphyry deposits. In conclusion, the performance of our model underscores the potential of integrating plate motion models and machine learning to advance mineral exploration along subduction zones. This approach holds promise for more efficient, accurate, and sustainable exploration strategies in these geologically active areas.