# Supergene Enrichment Processes in Porphyry Systems: The Case of the Booubyjan Porphyry Copper(-Gold) Deposit, Southeast Queensland

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The Booubyjan porphyry Cu(-Au) deposit occurs in the Esk Trough, a narrow, NNW-trending Early Permian to mid-Triassic tectonic basin within the northern New England Orogen in southeast Queensland. It occurs adjacent to the NNW-trending Perry fault and is crosscut by the ENE-trending Darling River lineament, with these structures possibly influencing emplacement of the Booubyjan system and other porphyries in the region, such as Coalstoun.

The geology of the Booubyjan area is dominated by the Middle Triassic Mt. Marcella Volcanics, formed from calc-alkaline andesitic lavas and pyroclastics with comagmatic I-type porphyritic stocks that include diorite, quartz diorite, monzonite, and granodiorite. Hydrothermal alteration is extensive and covers an area greater than 5 $km^2$, centered on porphyritic apophyses in roughly concentric zones. The alteration assemblages are complex due to overprinting relationships, but generally grade outward from prograde potassic (biotite-magnetite ± K-feldspar) and inner propylitic (actinolite-epidote) to phyllic (quartz-sericite-pyrite-anhydrite ± pyrophyllite ± dickite), outer propylitic (chlorite-carbonate-gypsum ± epidote), and overprinting argillic (kaolinite-quartz ± smectite) types. Hypogene mineralization consists of disseminated and vein-hosted chalcopyrite ± bornite ± pyrite, and is associated with transitional potassic to phyllic alteration, typically overprinted by propylitic alteration. Hypogene grades of up to 0.3% to 0.6% Cu are largely structurally controlled along ENE-trending structures normal to the NNW-trending Perry fault and hosted within the intrusives, the volcanic country rocks, and local magmatic-hydrothermal breccias.

The Booubyjan deposit has undergone a substantial increase of copper grades near surface through supergene enrichment processes. Values up to 0.85% to 1.1% Cu occur at shallow depths (21–29 m), forming a blanket with a thickness of 13 to 28 m, extending laterally over an area of at least 0.8 $km^2$. The ore mineralogy of the supergene blanket is dominated by chalcocite ± digenite ± covellite rimming pyrite. Copper enrichment occurs when pyrite is oxidized by meteoric fluids, resulting in generation of sulfuric acid, which leaches Cu minerals such as chalcopyrite. Subsequent redeposition of Cu occurs below the water table, where the pH is higher and more reducing compared to the vadose zone. Such enrichment mechanisms play a vital role in the economic viability of many porphyry deposits around the world by significantly increasing Cu grades, and the mineralogy is easier to process by heap leaching methods. Enrichment of Cu by supergene processes is only possible where the pyrite content is sufficient to generate enough sulfuric acid to keep Cu in solution until it reaches the water table. At Booubyjan, it is likely that pyrite contents were higher in zones of phyllic alteration, now manifested at the surface in the form of leached caps. These are dominated by clay minerals, mainly kaolinite at the surface and smectite at depth (due to progressive neutralization of the descending solutions), as well as residual and secondary silica. The caps also contain variable proportions of secondary Fe phases (hematite, goethite, jarosite—the occurrence of which depends on the pyrite-chalcopyrite ratio), and trace cupriferous neotocite. Leached caps at Booubyjan also correlate well with Cu soil anomalies, many of which remain untested for supergene mineralization by drilling.