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**Title: THE ECONOMIC LIFE-CYCLE OF PORPHYRY COPPER
MINING**

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Abstract: Mineral deposits are found, mined, and reclaimed. The mining life-cycle is driven by geology, technology, and market forces. There are two types of life-cycles: individual mines and industries. Porphyry copper mining is an industry due to geologic factors that govern investment and technological choices. As a major repository of the world's copper resources, porphyry copper deposits shape the copper industry as a whole. The industry was born when an attempt was made to make a mine out of a large, low-grade copper deposit in Bingham Canyon, Utah. Success there led to a rush of investment into the "porphyry coppers", despite technical and economic hurdles. This new industry required understanding a new deposit-type, a new business model using high mining rates to obtain economies of scale, and the invention of new mining and processing methods. As the industry settled into maturity, innovation turned to technology complementary to existing investments and gradual improvements rather than industry-changing leaps. The most significant innovation since the start of the industry was solution extraction of copper from leach solutions. This breakthrough was highly complementary to existing technology, by enabling profitable treatment of low-grade material and using sulfuric acid generated by smelters which otherwise would be discarded. The cumulative impact of gradual innovation has reduced cut-off grades from over 1% in the early 1900s to less than 0.2% today. An important feature of porphyry copper deposits is an increase in tonnage as cutoff grades approach zero. Declining cut-off grade permits mining of formerly uneconomic deposits and existing operations can augment their reserves. Innovation has led to increasing use of economies of scale, compensating for declines in average grade to maintain or increase metal output. We can expect much more of the same. Innovation must complement existing investments and increase economies of scale to handle lower grades and higher strip ratios. Resources accessible to current technology would be exhausted were it not for exploration and technical innovation that add to known resources. Porphyry copper deposits are numerous and the earth's surface is not fully explored for shallow deposits. Deep, blind deposits have been found during district exploration, but their systematic exploration awaits better technology. With this history in mind, we can recast the mining life-cycle in economic terms. Exploration and development is a research effort. In response to anticipated demand and ongoing depletion, mining firms find resources and learn how to mine them at a profit. Porphyry

copper mines are long-lived with ample time to convert marginal material to reserves and reduce costs. The technical innovation required does not result from random genius, but from sustained investment. Successful innovation is targeted at complementary technologies that advance the industry incrementally.