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Economic life-cycle of porphyry copper mining

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ABSTRACT

The mining life-cycle comprises discovery, development, mining, and reclamation and is driven by a complex interplay of geology, technology, public policy, and market forces. It is played out at the level of individual mines as well as of industries as a whole. Porphyry copper mining is an industry in its own right because this deposit type is a major repository of the world's economic copper resources and is amenable to large-scale, cost-efficient mining. From its inception, porphyry copper mining has pushed the frontiers of mining technology to mine ever larger volumes of lower grade ores, such that the average grade of mined porphyry copper ore has fallen from 1.7 percent in 1905 to 0.65 percent in 2005. In any region, such as the southwestern United States, the industry life-cycle is driven by successive phases of exploration that discover successively smaller and less economic deposits until the introduction of new technology creates opportunities for the discovery and development of concealed or deeper deposits. We have seen three exploration phases in the southwestern United States: (1) outcropping deposits; (2) shallow, concealed deposits; and (3) deep, concealed deposits. Each of the last two phases has been less economic relative to the previous phase such that entering new, unexplored regions in search of outcropping deposits has been generally more attractive than searching for concealed deposits, except in the vicinity of already developed porphyry copper mines. On a global basis, the time from discovery to production has decreased dramatically, although the time from a development decision to production has remained constant.

INTRODUCTION

Porphyry copper mining, which dominates global copper production, is a mineral industry in its own right: it is based on a particular mineral deposit-type with special characteristics associated with a unique suite of technologies used to find and mine these deposits. Economic porphyry copper deposits are subject to depletion, as are individual regions that host these deposits. Given the limited number of deposits in a region, under a given set of economic and technological circumstances, the potential for discovery of another economic deposit may be so low that that region if effectively "depleted" and exploration will shift to other regions. Thus, we can also speak of a life-cycle for porphyry copper mining on a regional and, ultimately, a global scale.

A unique characteristic of porphyry copper deposits is the disseminated nature of the copper mineralization, with variable tenor such that significant portions of a deposit may be of a lower grade than can be economically mined. Large, potentially economic resources readily accessible at existing mines are a significant investment alternative to exploration for new deposits. A long-standing characteristic of the porphyry copper industry has been substantial investment in cost-saving technology that transforms lower quality resources into reserves. The payoff from this investment has been substantial as almost all porphyry copper mines have continued operation well beyond depletion of their originally identified reserves. To accommodate this near-ubiquitous life-extension of porphyry copper mines, we can extend the classic mine life-cycle model of discovery-exploration-mining-reclamation to

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include technological innovation leading to life-extension and even re-development of old porphyry copper mines.

Porphyry copper deposits have been mined for about 100 years, raising the question of where we are in terms of a global life-cycle for porphyry copper deposits. A brief review of the history of porphyry copper mining shows a rough parity between adding new reserves to existing mines and developing newly discovered deposits. In any unexplored region with significant potential for discovery of porphyry copper deposits, there are likely some "world-class" deposits that will be "cherry-picked" early in the regional life-cycle. The timing of exploration of such regions has depended greatly on political and economic factors such that individual regions are at very different stages in their life-cycle at any given point in time. As the number of unexplored regions decline, we can look to the oldest region – the southwestern United States – for the future of porphyry copper mining: ongoing technical advances, most incremental, some revolutionary, that will permit economic production from lower-grade, metallurgically more troublesome, and ever deeper deposits.

THE MINING INDUSTRY LIFE-CYCLE

When considering the role of cost-saving innovation that can extend mine life, visualization of the mining life-cycle is more difficult. Instead of a "cycle" that is actually a linear progression from discovery to depletion, there may be many iterations of innovation producing reserve additions. Such innovations may be gradual, rather than discrete events, with concomitant gradual increases in reserves. The effects of this innovation may be difficult to disentangle from all the other factors – changes in metal prices, changes in tax and other government policies, changes in energy and labor costs – that affect the economics of mining. Innovation may also lag behind depletion, with some mines shutting down and even being reclaimed, then redeveloped much later based on new technology. Thus, the stage-by-stage approach to mining life-cycles must be modified to include these various possibilities.

Prospecting

Porphyry copper deposits must be found before they are mined, but this is no trivial exercise. There is a significant role for technology in the search for deposits and advancements in this technology have increased the prospective area for discovery. Potential returns from prospecting are limited at two ends: (1) by geologic endowment, and (2) what kind of deposit is presently economic to mine. A relatively large number of deposits have not proven economic, showing that a greater technical ability to find deposits does not necessarily justify the time and expense of proving a deposit.

In the petroleum industry, the word "play" is often used to refer to a particular oil or gas endowment that is economically viable and under active exploration. For example, the search for natural gas in the Barnett Shale of north-central Texas was a significant gas play in 2008. This has not always been the case, because the technology to find and extract natural gas from these accumulations has only recently been developed. By correlating technology with endowment, we can classify the history of porphyry copper exploration as a series of overlapping exploration plays, each based on a geologic and economic concept of an exploration target.

In Figure 1, the current known original resource of porphyry copper deposits in the western United States is plotted against the order (year) of their discovery. Larger deposits are larger targets, thus even if exploration were random the largest deposits are most likely to be found first. Exploration deliberately targets the largest deposits, hence we expect a strong size-bias or significant tendency for the largest deposits to be found first. Figure 1 shows a more complicated picture, with significant concentrations of large deposits in the beginning, in a middle period, and one very large deposit at the end. Using the play concept, the data in Figure 1 can be disentangled into three plays: (1) deposits exposed on the surface; (2) relatively shallow deposits concealed by valley-fill sediments; and (3) deeply buried concealed deposits. These plays are delimited by deposit type (porphyry copper), regional extent (only parts of the Western U.S. are prospective), by depth, structural position, grade, mineralogy, and a host of other minor factors, all conditioned on available and anticipated technology.

Play #1 – Exposed deposits. The first porphyry copper deposits recognized were well exposed, such as at Bingham Canyon, Utah, which was dissected by a steep canyon that cut through a large zone of supergene enriched copper mineralization. Other deposits, such as Miami-Inspiration, Arizona, were exposed but deeply weathered, such that their leached cappings contained little copper but held visual clues that copper minerals had been there. Testing these leached cappings by shaft sinking was too expensive, and churn drilling was quickly adapted to rapidly and cheaply test and prove out large deposits under these extensive cappings. By the 1920s, almost all of these targets had been found and tested and this play was exhausted.

Play #2 – Concealed deposits. Within the Basin and Range Province of the western United States, many porphyry copper deposits occur beneath pediments, relatively thin layers of valley fill sediments on bedrock along the margins of much deeper basins. There is usually no visual surface expression of copper mineralization or related alteration in these circumstances. The application of new geophysical and geochemical technologies, as well as advances in core drilling by the 1950s, enabled regional exploration for this kind of concealed deposits in the western United States. The first such discovery seems to be the San Manuel deposit, found in 1944 and proved in 1948. Although these deposits are deeper than deposits found in the past, advances in open pit and underground mining methods from the 1940s to 1960s allowed many of these deposits to be mined.

Play #3 – Deep deposits. If a porphyry copper deposit is deep enough, not even its outermost alteration envelopes will

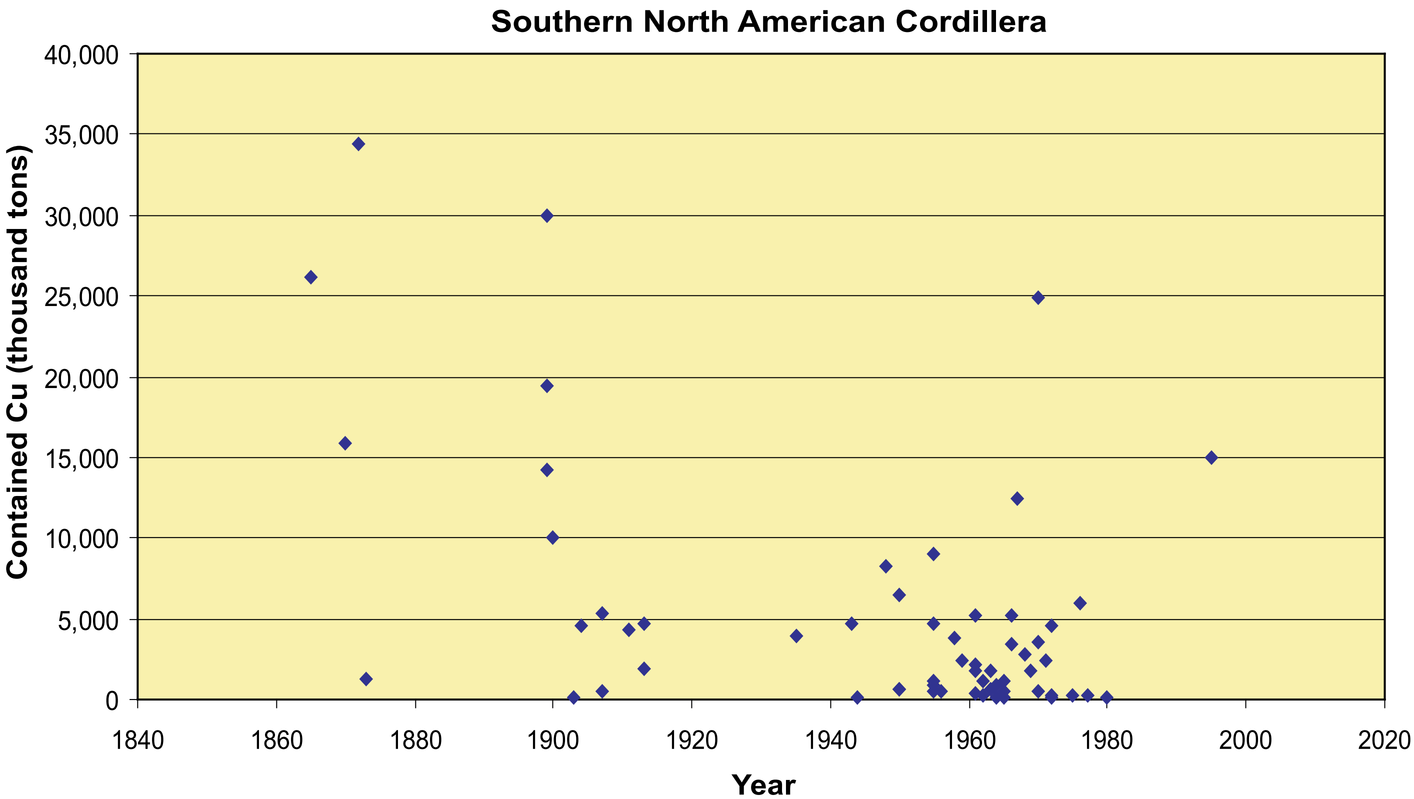


Figure 1. Plot of the size of porphyry copper deposits in the southwestern United States versus year of discovery. Data from Long (1995).

be exposed in bedrock. The discovery of these deep deposits has so far been largely serendipitous, occurring during routine exploration within known districts. The most recent of these discoveries, the Resolution deposit, with more than 1.5 billion metric tons of 1.5 percent copper ore, shows the potential for deep exploration, even if the technology to find and mine these deposits is marginal. Given that Play #1 is exhausted, and Play #2 likely so, the future of new deposit discovery in the Western United States lies with Play #3.

Exploration

Deposits, when found, must undergo extensive and lengthy testing to prove resources and develop an economic strategy for mining and processing. At various times, exploration has required significant research and development to reach the goal of an economically viable mine. For example, the Inspiration mine in Arizona required significant advances in block-cave mining methods, development of a flotation method for recovering chalcocite in a concentrate, and adapting smelters to handle fine-grained and wet flotation concentrates. At other times, the process of exploration has been a routine application of drilling, assaying, modeling, metallurgical testing, and mine design.

Development

Once a deposit is explored, tested, and the mine designed, it is built as expeditiously as possible – a lot of capital is tied up before production begins. Development does not usually end when a porphyry copper mine is put into commercial production. Stripping is often an ongoing process in open-pit mines, just as workings are continuously extended in underground mines. Continued exploration and cost-saving technology can lead to the periodic development of satellite deposits and mine extensions.

Mining

Mining begins the production phase, initially based on original reserve and mine design. Mining begins when an economic reserve is proved up, not after an entire deposit or district is fully explored. The large size of porphyry copper deposits, which include significant amounts of sub-economic material, almost ensures partial delineation due to the high costs involved in exploration. Hence, mining of porphyry copper deposits is often conducted in parallel with local exploration, further mine development, and research towards improving the technology used.

Life extension and depletion

An analysis of the history of mining and reserve additions at a porphyry copper mine often shows a see-saw between depletion and replenishment. Any mining firm approaching depletion faces a choice between local exploration for reserves that can be mined using, or by adding to, existing capacity, or exploration for a new deposit. Capital costs for extending the life of an existing mine are often more competitive than that for developing a new mine. The tradeoff is mainly one of relative risk, often between developing technology to mine a lower-quality resource versus that of finding a new resource that can be developed into a mine with relatively little technological risk.

Reclamation

Modern environmental regulations require some degree of reclamation after mining is terminated. Generally, all physical plant facilities are removed, tailings storage facilities are capped, waste dumps recontoured and vegetated, and underground workings sealed. Backfilling of pits is often uneconomic and socially undesirable due to the large energy expenditure required and lack of any economically important post-mining use for the land. Reclamation policy, however, does not usually acknowledge the possibility of mine redevelopment if significant resources remain.

Redevelopment

Mines are sometimes shut down or even abandoned for lengthy periods of time and then redeveloped with old workings extended, new plant installed, and a resource converted to a reserve. Most old mines are brought back by new technology combined with re-recognition of a resource that was long forgotten. An example is the Tyrone mine in New Mexico, at the site of the old Burro Mountain Mine. Tyrone is a low-grade porphyry deposit developed in the 1960s on a resource known but not considered economically significant in the 1920s when the Burro Mountain mine exhausted its high-grade ores.

Reclassification

A reserve can be returned to a resource for many reasons, including a sustained decline in metal prices, increased taxes, burdensome regulations, increasing energy and labor costs, etc., for which no offsetting technical innovation can be realistically or economically attempted. More pernicious to the mining industry are governmental or social actions that render a reserve or resource unavailable to mining. Known as sterilization, these actions raise serious concerns about sustainability, particularly according to the principle that nothing should be done today that harms the ability of future generations to use a resource. As a durable material, copper is lost to society only by wastage in use or by keeping it in the ground forever. Mining engineers laud their technological accomplishments in conserving copper, through better extraction technology and recycling, but society at large gives little or no thought to condemning mineral resources through land-use decisions that favor urbanization or preservation, even though land, scenic, and wildlife resources are significantly more abundant than economic mineral deposits.

There are other factors that can place prospective territory and known resources off limits, generally for a period of time. Most notable are mining and investment laws, tax and fiscal policies that render investment in mining unattractive given the risks involved and the presence of more attractive alternatives. The very intelligent liberalization of these laws in certain Latin American countries since the 1980s, followed by the discovery and development of several world-class porphyry copper deposits, has had a very significant impact on porphyry copper mining.

ECONOMIC CHARACTERISTICS OF PORPHYRY COPPER DEPOSITS

Porphyry copper deposits are abundant, with at least 646 deposits identified world wide (Singer and others, 1995) and are an almost ubiquitous feature of volcanic arcs above subduction zones. Comparison with other types of copper deposits (Table 1, Fig. 2) shows that porphyry copper deposits, although of lower grade than many other types, are much larger and thus contain appreciably more copper resource. This is demonstrated by Long and others (2005) who show that 72 percent of cumulative copper production in the United States has come from porphyry copper deposits, which likewise contain 70 percent of United States copper resources.

The large tonnage and relatively low-grade of porphyry copper deposits is a reflection of their fundamental geologic nature as large volumes of rock with disseminated copper minerals. The abundance of disseminated copper minerals tends to vary across such deposits, generally in a systematic way such that the volume of mineralized rock increases with decreasing cutoff grade. Table 2 illustrates this phenomenon for the Regalito deposit in Chile. As Table 2 shows, this trend does not extend down to zero, at some point the amount of lower grade material drops off dramatically, as shown in this case where dropping the cutoff grade from 0.4 to 0.2 percent copper adds very little to the resource.

Porphyry copper deposits are often significant repositories of other economically valuable metals, such as gold, molybdenum, and silver. Thus, in the United States for example, porphyry copper deposits are the major source of these metals compared to other deposits types. Long and others (2000) reported that porphyry copper deposits account for 7 percent of the gold and 7 percent of the silver produced to date in the United States.

In economic terms, these special features add up to a potential for a long-lived mine at production levels that make

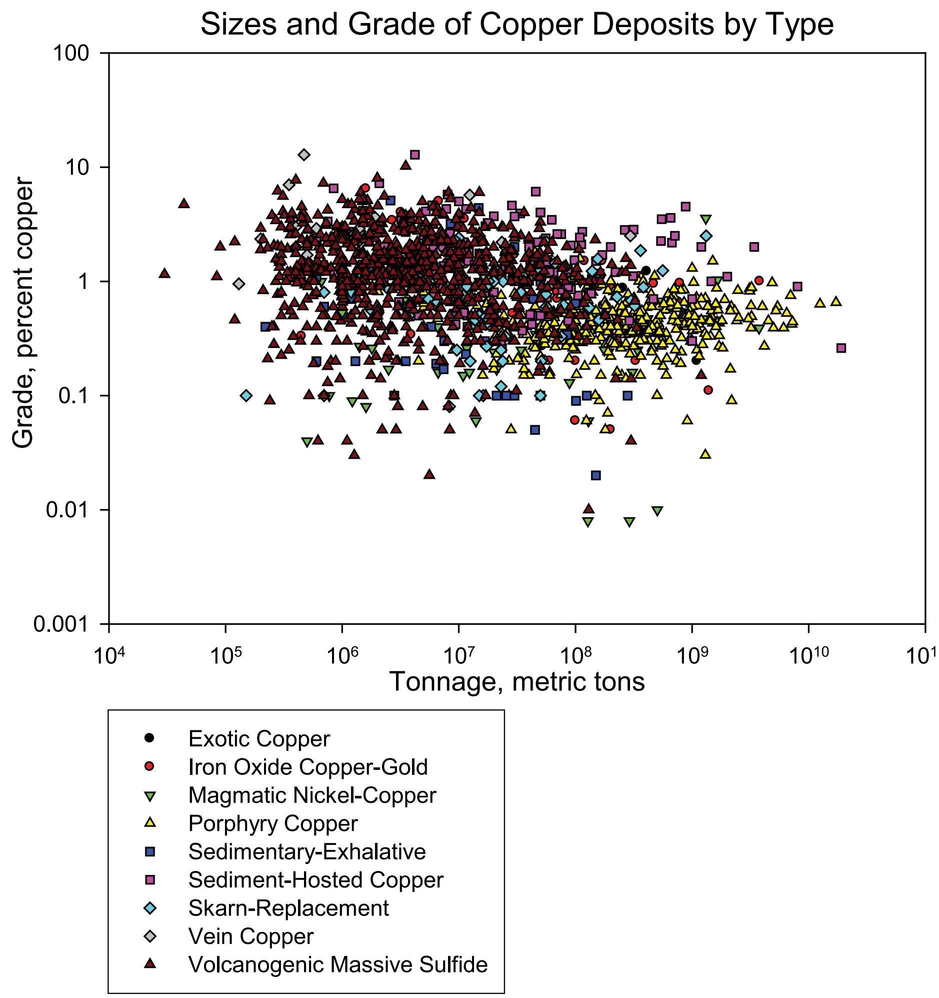


Figure 2. Grade-tonnage comparison of porphyry copper deposits with other deposit types. Data from Barnes and Lightfoot (2005), Davidson and Large (1998), Eckstrand and others (1995), Franklin and others (2005), Gutzmer and Walters (2005), Lefebure and Höy (1996), Long (1995), Meinert and others (2005), Selley and others (2005), Sillitoe and Perelló (2005), Singer and others (2005), and Williams and others (2005).

a significant contribution to meeting demand for copper and certain economically valuable by-products. The very first porphyry copper mine developed, the Bingham Canyon mine, is still in production, with operations planned to 2018, for a total of 114 years, during which time the mine will have produced something like 20 million metric tons of copper. There are, not surprisingly, significant resources remaining in the Bingham Canyon district that could be mined underground were such investment warranted. Given that the initial reserve at Bingham Canyon was 31,000,000 metric tons averaging 1.98 percent copper (614,000 metric tons contained copper), its life-extension is entirely due to ongoing reduction in mining costs through economies of scale and other innovations that permitted mining larger tonnages of lower-grade rock.

Table 1. Comparison of porphyry copper deposits with other principal deposit types for copper, showing that porphyry copper deposits are the most important repository of copper resources among the various types. Data used in this table is the same as used in Figure 2.

Deposit Type	Number of Deposits	Contained copper (10^3 metric tons) Median	Contained copper (10^3 metric tons) Maximum
Exotic copper	13	422	4,990
Iron-oxide-copper-gold	44	409	38,100
Magmatic nickel-copper	53	70	46,742
Porphyry copper	**465**	**908**	**111,150**
Sedimentary-exhalative	44	38	650
Sediment-hosted copper	157	263	72,000
Skarn and replacement	75	82	33,000
Vein copper	22	36	7,400
Volcanogenic massive sulfide	785	41	4,293

COG % Cu	Material tonnes	Grade Cu %	Cu tonnes
0.2	42,990,000	0.61	262,000
0.4	41,173,000	0.62	255,000
0.6	20,254,000	0.73	148,000
0.8	4,204,000	0.88	37,000

Table 2. Mineral resources of the Regalito deposit, Chile, 1994 (Eggleston and others, 2005), illustrating the increasing size of porphyry copper deposits with lower cutoff grades, down to some limiting cutoff grade.

The history of most porphyry copper mines follows that of Bingham Canyon. Hence, reserve growth – measured by the ratio of current reserves plus past production to original reserves – is a significant factor in porphyry copper mining (Fig. 3). It is hard to discern trends in this graph, but the data does suggest that the more recent the discovery, somewhat less reserve growth is expected given that deposits are more extensively explored initially – due to lower exploration costs, lower cutoff grade to start with, and a generally higher expectation for mine output.

Porphyry copper industry life-cycle

Porphyry copper mining began in the western United States, thus this region is much further along in the porphyry copper life-cycle than the rest of the world. New technologies were required to mine this new deposit type, and technological advancement has been a characteristic feature of porphyry copper mining ever since. Eventually investment opportunities, given a set of technologies, economic conditions, and resources, are exhausted and the industry starts to wither away unless a transformational technology is found that renews the life-cycle. A brief review of the history of porphyry copper mining in the western United States illustrates these cycles and the ultimate fate of the industry as a whole.

Bingham Canyon. The porphyry copper industry began at Bingham Canyon in 1904 with a new deposit type and a new business model, large-scale mining and processing to cut unit costs, and some new technology to make it happen, including steam shovels. Timing was exquisite as global demand for copper, driven by ongoing electrification of the developed countries, was rising at a four percent rate and capacity at existing mines was not keeping up. At Bingham Canyon, a large body of 1.5 to 2 percent copper ore outcropped on both sides of a deep canyon, which required a very low strip ratio and allowed for downgrade transportation of ore. Large-capacity steam shovels had recently been developed for construction of the Panama Canal and the first open-pit iron mines in Minnesota and Michigan. Rail was used to transport ore to a conventional gravity concentrator, except that capacity limitations on existing crushing and grinding machinery required constructing 12 independent concentrators or sections of 500 short tons per day capacity, installed in parallel. The mine was an economic success from the start, paying millions in dividends.

Business model applied 1908-1915. Knowledgeable investors were impressed by the profitability of Bingham Canyon and were quick to apply that business model elsewhere. Other deposits were shortly found, but with differences in depth and mineralogy that forced the development of new, transformational technology. A prime example was the Inspiration Consolidated Copper Company in Arizona. A large body of chalcocite ore had been developed but was too deep for open-pit mining with the technology of the day. The newly invented block-caving system of underground min-

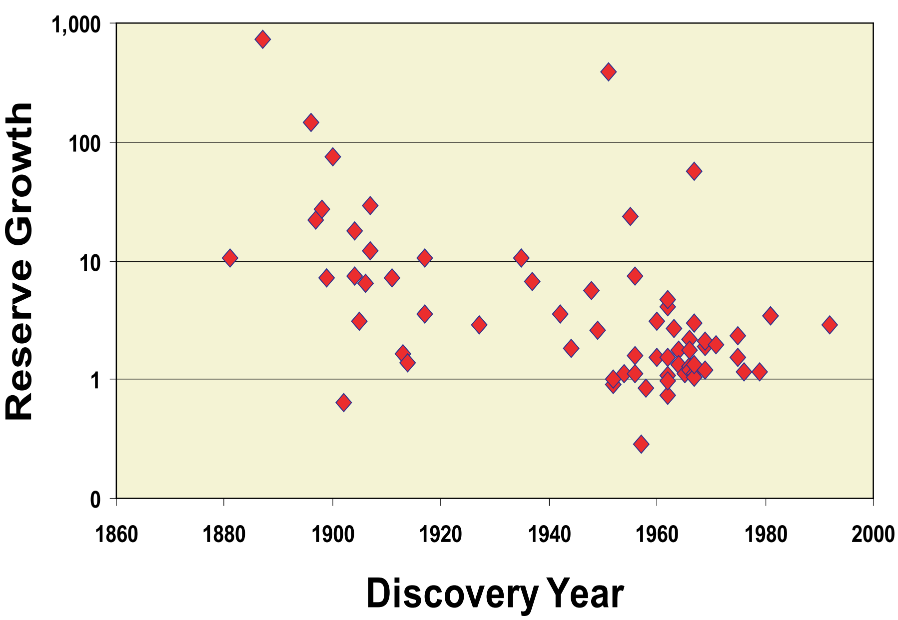


Figure 3. Reserve growth in porphyry copper deposits, 1880 to present. The graph shows the ratio between current resources plus past production to original reserves for each porphyry copper mine arranged by discovery date. About 20 percent of the mines shown have experienced reserve growth of a factor of 10 or better. Data from Long (1995), updated by author.

ing, wherein ore was undercut and allowed to cave by gravity into ore chutes, was adopted by the Company and increased in scale. During development, Inspiration took notice of the newly introduced flotation method of concentration, which promised to increase metallurgical recovery from the 65 to 70 percent obtained by conventional gravity methods to 80 percent or better. Inspiration developed the first commercial-scale flotation system for chalcocite ores. On these two major, and many lesser innovations, Inspiration built a mine that could produce copper at a cost of 8 cents per pound, better than the 8.5 cents per pound cost at Bingham Canyon, when copper sold for 25 cents per pound. The increasing oxide content of the ore eventually led the Inspiration company to develop a method of leaching followed by electrolytic recovery of copper as cathode in the 1920s, a feat not often accomplished elsewhere until the introduction of solution extraction in 1968.

Big payoff 1916-1919. Timing can be everything, and the first porphyry copper mines came on just in time for World War I, which artificially increased demand for copper, inflating prices and profits. Every porphyry copper mine experienced a spike in earnings during the war, which served to attract further investment in the industry.

Post-war bust 1920-1922. At the end of World War I, demand for copper fell precipitously and the copper industry was in a condition of gross overcapacity. As the low-cost producers, the porphyry copper mines all survived, and demand-supply balance was restored through closing older mines and a partial recovery of demand. However, the electrification of North America and Western Europe was largely complete and demand growth slowed considerably.

Industry matures 1923-1929. During the 1920s, the price of copper in 2006 dollars fell to a historically low level that was largely maintained through the rest of the century (Fig. 4). Copper capacity after the initial phase of porphyry copper development in the United States and Chile was practically enough to handle demand, and competition drove copper prices down toward a new, significantly lower real cost of producing copper. During this time, exploration for and development of new mines dropped to almost nothing and the porphyry copper industry settled into a routine of steady production, incremental innovation, and occasional development of known, accessible resources.

Great Depression 1930-1938. The Great Depression, which started in the United States where porphyry copper mining was centered, destroyed complacency and put the industry in survival mode. Significant development plans, such as the mining of porphyry ores at Morenci, Arizona, were put on hold, any funds for exploration dried up, and production was curtailed. Toward the end of the 1930s, copper demand began to recover as European countries prepared for war. At the same time, the U.S. Government began to subsidize some porphyry copper mine development through larger programs intended to boost employment.

WWII difficult years 1939-1948. The second World War should have been a boon for the porphyry copper mining industry given a dramatic surge in copper demand and consequent price escalation. It was a boon for producers in Chile, but the U.S. Government, in mobilizing the economy for total war, instituted policies that badly damaged the domestic mining industry. Copper prices were fixed at pre-war levels even though rapidly rising fuel, equipment, and labor costs were cutting deeply into earnings. Taxes on "excess" profits further constrained earnings. So much labor was siphoned off from mines by the war that a special program had to be instituted to grant deferments to draftees with mining experience. The numbers deferred were strictly limited and the porphyry

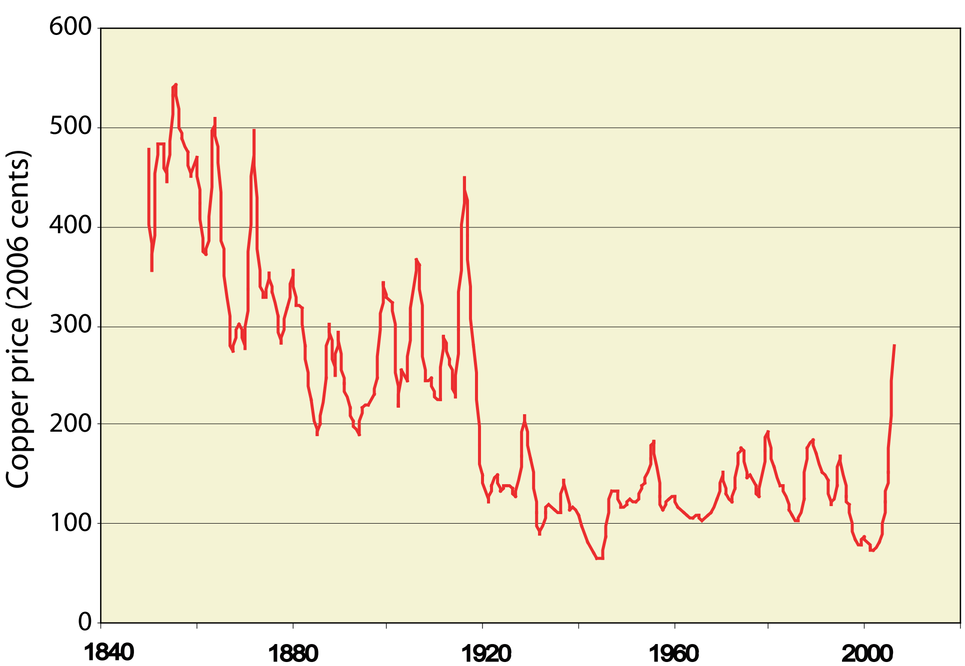


Figure 4. Real price of copper in the United States, in 2006 cents per pound, from 1845 to 2006. The price trends show a long period of relative real price stability from the 1920s, at historically low levels, reflecting the dominance of the copper industry by the porphyry copper industry. Data compiled by author from Minerals Yearbook. Gross National Product deflator is used.

copper mines largely operated under capacity for the duration of the war. Equipment and supplies were rationed as well, such that the high cost and unavailability of labor and materials forced a suspension of exploration and development efforts as well as long-term maintenance. At the end of the war, the United States was no longer a copper exporter but an importer, domestic mines under these economic constraints being unable to expand to meet demand.

Post-war renewal 1949-1982. It took a few years to rebuild labor forces and catch up on maintenance and development, but with the post-war economic boom in North America and reconstruction in Europe and Japan, United States copper producers began investing in new porphyry copper mines and expanding production at existing mines. Significant new technologies were introduced to deal with declining grades, including the widespread conversion of underground mines to open-pit mines using recently introduced large-capacity (24-ton) haul trucks. Open pit mining produced large amounts of dump material with low grades of copper, which prompted development of large-scale dump leaching operations. Old abandoned underground workings were given over to in situ leaching of old block-cave stopes, likewise full of low-grade material. New exploration plays were opened in British Columbia and a significant amount of exploration was done for concealed deposits in pediment areas of the Basin-and-Range province of the Western United States.

Crises and opportunity 1983-1998. Copper prices collapsed in 1983, forcing the United States section of the industry into an innovate-and-cut-costs or die mode. At the same time, high-grade deposits were being opened in Chile and elsewhere, which put even greater pressure on the older producers, largely concentrated in North America. This crisis accelerated the adoption of solution extraction technology in the United States, as producers introduced mine-for-leach operations and expanded leaching of old dumps.

Big turn around 1999-2006. At the end of the twentieth century, copper prices in real terms had fallen to almost their lowest point in history and then experienced the biggest increase since World War I (Fig. 4). Demand outstripped the ability of the industry to expand capacity, something almost unprecedented in an industry long plagued by cycles of overcapacity. Has the supply of economic deposits petered out? Or are there enough deposits but demand growth has outpaced the ability of the industry to develop new capacity? A look at some signs of industry maturity and lead times give insight into these questions.

Signs of maturity

Figure 5 shows that the decline in the average grade of mined porphyry copper ores leveled off in the 1970s as higher grade deposits were developed in Chile and elsewhere. This is the result of new mining in areas that were previously unavailable to exploration and development, with deposits of sizes and grades no longer to be found at or near the surface in the western United States. These regions, however, will also become exhausted with continued exploration. Leveille and Doggett (2006) analyzed the exploration play in Chile, which in only a couple of decades has progressed from cherry-picking the most attractive economic targets to exploration for less economically attractive concealed deposits. These cherry-picked world-class deposits, when mined, can survive 2001 prices, but to develop the more marginal deposits, which are readily available, would require significantly higher prices. These prices may tell us something about the prospects for any future cherry-picking.

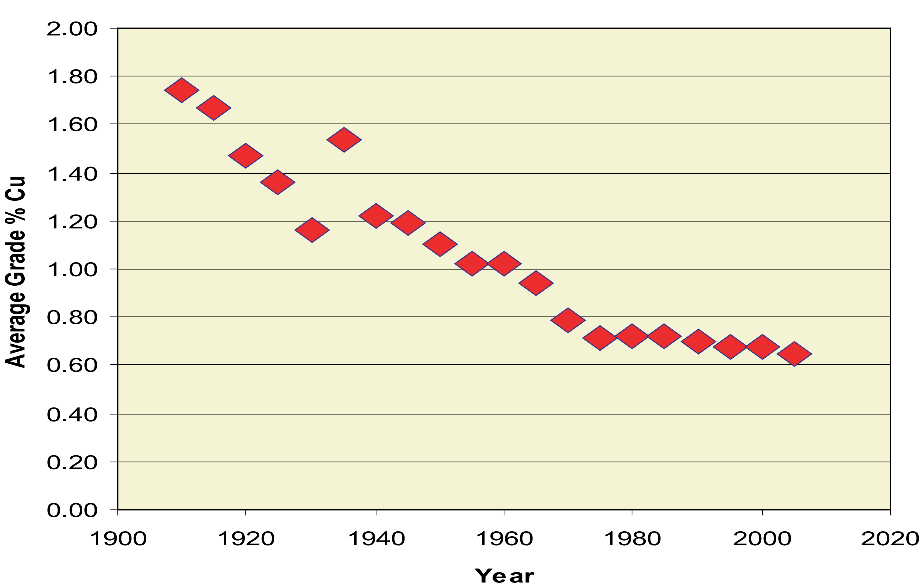
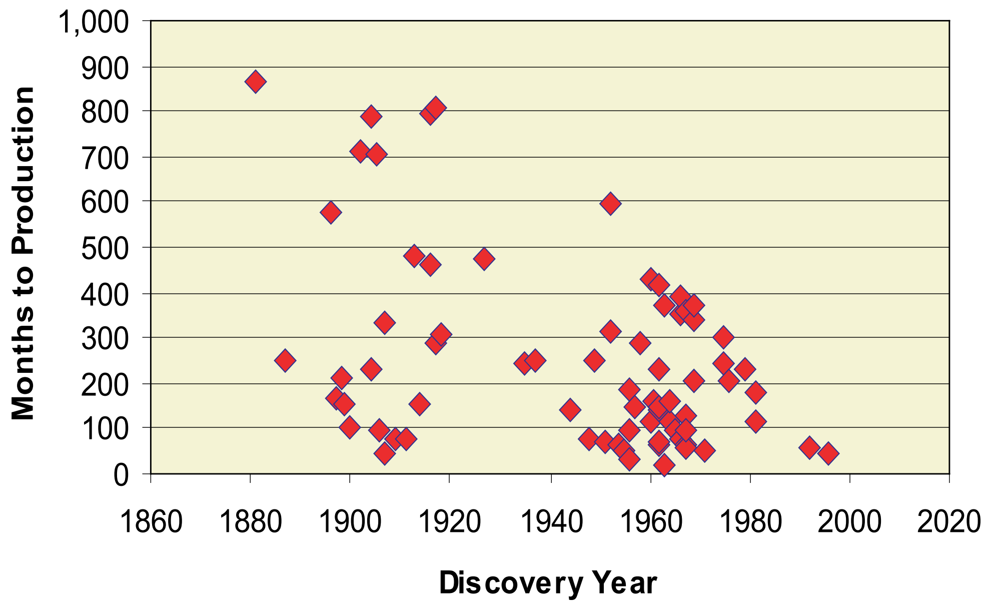


Figure 5. Average grade of porphyry copper ores mined in free-market economies, in weight percent copper, by five-year intervals from 1905 to 2005. The decline in average grade has slowed significantly since about 1975 due to the development of higher grade deposits in South America. Data from author.

Figure 6. Time from discovery to production of porphyry copper deposits, 1880 to present, measured in months. The overall, global trend is to shorten the time between discovery and production, although the time from the decision to develop a mine to production (not shown) has remained at an average of 30 months. Data from Long (1995) and updated by author.



Lead time

One reason sometimes given for demand outstripping supply is an increasing time required to find deposits and get them in production. The data in Figure 6 demonstrate that, globally, this is not the case. The time of discovery to production has shortened, although time from the decision to develop to production (not shown here) is remarkably stable at about 30 months on average. There is a significant exception to this global trend, namely the United States, where the last development of a previously undeveloped porphyry copper deposit was the Lakeshore mine in 1976. The Safford mine in Arizona, which will start production 2008, is the first new porphyry copper mine in the United States since Lakeshore mine. It will mine a resource first discovered in 1956, with regulatory approval beginning in 1994, and a decision to develop not made until February 1, 2006. That is a little over 50 years from discovery to production, including some 12 years of permitting, not an enviable record by global standards.

CONCLUSION

A review of the history of porphyry copper mining in the Western United States shows the future of porphyry copper mining globally. There will be a permanent shift from cherry-picking very large, shallow, low-cost deposits to pushing the technological envelope to make mining more economically marginal deposits profitable. The timing of this shift globally depends on the availability of untested porphyry copper exploration plays with potential for very large, shallow, high-grade deposits. Smaller, deeper, or lower grade, the resources of the future will push us ever further on the technological quest to cut costs. Our future is in the hypogene, the deep hard-to-find stuff, and our ability to get mining and milling costs down.

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