0.3 grams per tonne gold, and 2 grams per tonne silver. Remaining reserves at the time of consolidation were 6 million tonnes of 0.46 percent copper ore based on a 0.25 percent copper cutoff grade; these have probably been exhausted.

The Lornex Deposit was discovered in 1964, brought into production in 1972 (Waldner and others, 1976), and consolidated into the Highland Valley Copper Partnership in 1986. Production prior to consolidation was 273 million tonnes of ore averaging 0.4 percent copper, 0.016 percent molybdenum, and 2 grams per tonne silver with a remaining reserve of 185 million tonnes of ore averaging 0.43 percent copper, 0.011 percent molybdenum, and 2 grams per tonne silver at a cutoff grade of 0.26 percent copper and a stripping ratio of 2 to 1.

The Valley Copper Deposit was discovered in 1966, and by 1975 exploration had delineated 790 million tonnes of ore averaging 0.48 percent copper to a depth of 442 meters (Osatenko and Jones, 1976). Production began in 1983, and 25 million tonnes of ore averaging 0.5 percent copper, 0.005 percent molybdenum, 0.03 grams per tonne gold, and 3.65 grams per tonne silver were milled prior to consolidation in the Highland Valley Copper Partnership. Some of this ore likely came from the nearly depleted Bethlehem Mine.

Highmont was discovered in 1962 and consists of six separate ore bodies (Reed and Jambor, 1976), one of which was mined from 1981 to 1984 and yielded 28 million tonnes of ore averaging 0.18 percent copper and 0.028 percent molybdenum. Remaining reserves in 1985 were 117 million tonnes of ore averaging 0.27 percent copper and 0.045 percent molybdenum in two ore bodies with four other ore bodies not yet fully explored.

Located one kilometer south of the Bethlehem Mine, the JA Ore Body was discovered in 1971 and has not been mined. Some 286 million tonnes of ore averaging 0.43 percent copper and 0.017 percent molybdenum have been delineated. About 115 to 135 million tonnes of this ore could be recovered from an open pit with a stripping ratio of 2.4 to 1 (McMillan, 1976b). Other unmined deposits in the district include Ann, with 48 million tonnes of ore averaging 0.27 percent copper, and Minex, with 36 million tonnes ore averaging 0.2 percent copper (McMillan, 1976a).

Island Copper. Copper mineralization was found at Island Copper in 1965, and by 1969 exploration had delineated significant reserves (Cargill and others, 1976). Production of 272 million tonnes of ore averaging 0.44 percent copper, 0.015 percent molybdenum, 1.5 grams per tonne silver, and 0.2 grams per tonne gold from 1971 to 1990 would seem to have nearly exhausted the initial reserve of 257 million tonnes of 0.52 percent copper at a stripping ratio of 2.4 to 1.

Princeton Area. The Copper Mountain and Ingerbelle (Similco) Porphyry Copper Deposits are located about 2 kilometers apart on opposite sides of the Similkameen River. Copper Mountain was staked in 1892, but significant reserves were not outlined until 1923. From 1925 to 1957, 31,55 million tonnes of ore averaging 1.08 percent copper was produced. Production was mainly from underground, but 1.956 million tonnes of 0.76 percent copper were mined from several open pits (Fahrni and others, 1976b). About 1 million tonnes of 0.5 percent copper remained on the waste dumps in 1954.

Ingerbelle was staked in 1897, but significant porphyry copper mineralization was not delineated until 1966. Similco produced 112 million tonnes of ore averaging 0.43 percent copper, 2 grams per tonne silver, and 0.22 grams per tonne gold from 1970 to 1989. Year-end reserves in 1989 were 155 million tonnes averaging 0.41 percent copper at a strip ratio of 2.07 to 1.

Oregon and Washington

Porphyry copper and related breccia pipe deposits of the Cascade Range of Washington and Oregon have been explored intermittently from the early 1960's to the present day. None have been brought into production, but the Bornite Breccia Pipe located in the North Santiam Mining District in Oregon is currently under development. Reserves and resources have been reported for ten porphyry copper and breccia pipe deposits (table 1). The Glacier Peak Deposit is now within the Glacier Peak Wilderness Area. Exploration activity at the Margaret Deposit in the Saint Helens Mining District in Washington was curtailed after the eruption of Mount Saint Helens in 1980.

SOUTHERN CORDILLERA

Arizona

Arizona and southwestern New Mexico contain the largest concentration of porphyry copper deposits in the United States. Sixteen of these porphyry copper deposits have been developed in a significant way, and an additional fifteen (table 2) contain substantial reserves and resources.

Ajo (New Cornelia), Arizona. Exposed oxide ores at Ajo were mined by Spanish colonists as early as 1750. Porphyry copper potential was recognized by 1911 and developed into an open pit mine by 1917 (Gilluly, 1946). Nineteen million tonnes of carbonate ores averaging 1.17 percent copper was leached from 1911 to 1930. Sulfide ores milled from 1911 to mine closure in 1984 amounted to 388 million tonnes averaging 0.8 percent copper, 0.005 percent molybdenum, 2.4 grams per tonne silver, and 0.34 grams per tonne gold at a strip ratio of 1.2 to 1 (Annual reports and SEC Forms 10K of the New Cornelia Copper Co., Calumet and Arizona Mining Co., and Phelps Dodge Corp.). At least 15 million tonnes of stockpiled low-grade sulfide ores was leached at various times. Remaining open pit resources in 1984 were 190 million tonnes of ore averaging 0.50 percent copper.

Bagdad, Arizona. Copper mineralization related to the Bagdad Deposit was first discovered in 1882. Disseminated ores were discovered during underground exploration in 1907 (Anderson and others, 1955). Bagdad was developed as an underground mine in the 1920's and converted into an open pit mine in 1947. Production from 1929 to 1992 was 308 million tonnes of sulfide ore averaging 0.53 percent copper, 0.012 grams per tonne molybdenum, and 1.4 grams per tonne silver at a strip ratio of 1.25 to 1 (Bogart, 1990; annual reports and SEC Forms 10K of the Bagdad Copper Corp. and Cyprus Minerals Co.). From 1951 to 1992 some 171 million tonnes of ore averaging 0.36 percent copper was leached. Year-end reserves in 1992 were 1,117 million tonnes of ore averaging 0.37 percent copper and 0.012 percent molybdenum.

Bisbee (Warren District), Arizona. The Warren District is best known for its production of rich copper and zinc-lead car-

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Production and Reserves of Cordilleran (Alaska to Chile) Porphyry Copper Deposits

R. V. KIRKHAM

KEITH R. LONG *U.S. Geological Survey, Tucson, Arizona*

ABSTRACT

Since the Bingham Canyon, Utah, copper mine was opened in 1904, developed Cordilleran porphyry copper deposits have produced over 15 billion tonnes of ore containing more than 150 million tonnes of copper. Reported reserves and resources at these mines in 1991 exceed 42 billion tonnes of ore containing 280 million tonnes of copper. An additional 41 billion tonnes of reserves and resources containing 217 million tonnes of copper are known from 129 unmined deposits. By comparison, reported reserves at 11 porphyry copper mines in 1915 stood at 1.4 billion tonnes containing 25 million tonnes of copper.

Sustained exploration and improvements in mining technology continue to add additional deposits and reserves. The latest innovation, heap-leaching of oxide ores, has converted billions of tonnes of low-grade resources into reserves.

A mine by mine compilation of Cordilleran porphyry copper production and reserves, including new data from recent exploration, the files of the Anaconda Mining Company, and other sources, permits regional comparison of the size, grade, and oxide content of these deposits. However, post-mineralization glaciation and weathering have had such a profound effect on the size and grade of the deposits that it is difficult to determine to what extent regional differences depend on factors affecting pre-erosion endowment.

INTRODUCTION

It is almost axiomatic that any regional compendium on porphyry copper deposits include a compilation of relevant production and reserve data. The most recent compilation of sizes and grades of porphyry copper deposits (Gilmour, 1982) predates a major restructuring of the North American copper industry during the 1980's, the widespread introduction of heap leaching of oxide copper ores, and the discovery, renewed exploration, and reevaluation of deposits all along the Cordillera from Alaska to Chile. This paper provides an update drawn from published information, the files of the Anaconda Mining Co. now located at the International Archive of Economic Geology at the University of Wyoming, and a recompilation of confidential production data reported to the U.S. Geological Survey and Bureau of Mines for selected districts such as Butte, Montana, for which production has not been adequately reported in the past.

Annual reports of mining companies to stockholders and annual reports by public mining companies to the Securities and Exchange Commission (SEC) are the principal source of production and reserves data. Summaries of these annual reports are widely reported in secondary sources such as mining industry trade journals and annual government reports on the mining industry and are generally more accessible than the original reports, particularly for the latter part of the 19th and early part of the 20th centuries. Reports to the SEC using Form 10K (domestic mining firms) or Form 8K (foreign mining firms listed on U.S. stock exchanges) are available on microfiche from commercial services and at major University libraries.

Files of the Anaconda Mining Company yielded information on reserves at Anaconda properties and information on reserves at properties held by competitors. Much of this data was previously reported by Long (1992). Production data for porphyry copper districts having several producers were derived in part from a recompilation of production data reported from 1902 to 1929 to the U.S. Geological Survey and since 1930 to the U.S. Bureau of Mines. Recompilation was necessary because published district totals mix porphyry and non-porphyry ores and report production solely in terms of recovered metals. The original data include metals contained in direct shipping ores and concentrates; original grades may be back calculated if recovery factors are available or can be estimated. These data are confidential at the level of individual producers and have been aggregated at the district level to disguise individual mine production.

Cumulative production and reserves are reported here for individual porphyry copper deposits, which may coincide with one or more mines. In a few instances post-mineralization faulting obscures the delineation of actual deposits, and several mines may have been developed on parts of one or more deposits. Where possible, production and reserve data for such deposits are disaggregated by mine so readers can apply their own preferred reconstruction. Production is given in terms of tonnage and grade of ore treated. Reserves and resources are the tonnage and grade of material above a specific cutoff grade, which may not always be reported.

The cumulative ratio of waste rock to ore mined is reported along with cumulative production. This ratio has changed with the widespread introduction of heap-leaching of low grade ores formerly classified as waste. To be consistent over time, all material not treated by conventional milling is classified as "waste" with the understanding that at some point all or part of this "waste" material may be treated economically by heap leaching. Where possible tonnage and grade of material treated or treatable by heap leaching is reported separately. Mill tailings and smelter slag, which are sometimes retreated at a later date, are excluded from cumulative production and reserves.

For purposes of comparison, Cordilleran porphyry copper deposits are divided into four regions of broadly similar metallogenesis and climate. Porphyry copper deposits of the northern Cordillera, including Alaska, Yukon, British Columbia, Washington, and Oregon, are Triassic through Tertiary in age and were eroded in an intermittently glaciated environment (Hollister, 1978). The southern Cordillera, including the Basin and Range province of the western United States and northwestern Mexico, contains mostly Laramide (Late Cretaceous to Paleocene) porphyry copper deposits eroded in generally semiarid environments. The northern Andes, from Panama to northernmost Peru, include Tertiary porphyry copper deposits subjected