Production history of the Bingham mining district, Salt Lake County, Utah — an update

Preprint · September 2018

DOI: 10.13140/RG.2.2.28618.00966

1 author:

Ken Krahulec
Utah Geological Survey

PRODUCTION HISTORY OF THE BINGHAM MINING DISTRICT, SALT LAKE COUNTY, UTAH: AN UPDATE

Ken Krahulec
Utah Geological Survey

ABSTRACT

The Bingham mining district is located in the northeastern Basin and Range Province of north-central Utah, immediately southwest of Salt Lake City. Mineralization in the district is genetically related to a small Eocene quartz monzonite porphyry stock. Lead-silver in the district was first recognized in 1850, placer gold production began in 1864, and successful lead-silver production followed a few years later with the arrival of the railroad. The production of high-grade copper-gold ore started in 1897. In 1904, Utah Copper became the first flourishing low-grade porphyry copper operation in the world using block caving, but soon switched to large-scale open pit methods a few years later. Since the advent of open pit mining of the porphyry copper orebody, the major advances in mining, milling, and smelting at Bingham include the completion of a dedicated railroad to the mill (1911), recovery of sulfuric acid from smelter gases (1917), mills converted from gravity to flotation (1921), suppression of pyrite in the concentrator (1927), recovery of molybdenite (1936), reduction in stripping ratio (1986), installation of an in-pit crusher and ore conveyor (1988), and construction of a new Outokumpu smelter (1992). After nearly a century of production, the exploitation of Bingham's considerable lead-zinc-silver ores ended in 1971. Exploration in the 1980s discovered the Barney Canyon and Melco sediment-hosted gold deposits that operated into the early 2000s. In 2008, Kennecott announced the discovery of an important high-grade molybdenum resource (roughly 600 million tons at 0.1% Mo) at depth under the Bingham pit.

On April 10, 2013, two massive landslides carried about 145 million tons of waste rock from the northeast wall into the bottom of the open pit. The Manefay slides changed the face of the mine forever and have hampered mine production to the present day (August 2018). Nonetheless, the operation remains profitable and the current expected mine life has been extended to 2027.

Bingham is the most productive mining district in the U.S. and ranks as roughly the top copper, second largest gold, third largest silver, third largest molybdenum, and fifth largest lead producing district in the U.S. District metal production includes over 3.2 billion tons of porphyry ore averaging approximately 0.72% Cu, 0.057% MoS_2, 0.012 opt Au, and 0.09 opt Ag; 32.8 million tons of lead-zinc-silver-gold ores with recovered grades of 6.8% Pb, 2.8% Zn, 3.65 opt Ag, and 0.041 opt Au; and an additional 30.6 million tons of 0.06 opt Au in distal disseminated sedimentary rock-hosted gold ores. The remaining reserves and resources include 837 million tons of porphyry copper-molybdenum-gold in the open pit, an additional 400 million tons of deep high-grade copper-gold skarn ores, and a deep estimated 600-million-ton molybdenum deposit.

INTRODUCTION

The Bingham mining district is located in the Oquirrh Mountains of north-central Utah, 20 miles southwest of Salt Lake City, Utah (Fig. 1). The Oquirrh Mountains lie near the eastern margin of the northeastern Basin and Range Province. Mineralization in the district is genetically related to a small Eocene quartz monzonite porphyry stock. This stock was on the eastern margin of a wave of Eocene magmatism that spread outward from a center near Carlin, Nevada. The Bingham district is zoned outward from a giant porphyry copper-molybdenum-gold deposit through copper-gold skarn, pyrite halo, lead-zinc-silver vein and replacement deposits, to distal disseminated sedimentary rock-hosted gold ores (Babcock and others, 1995; Porter and others, 2012; Krahulec, 2015).

Kennecott's Bingham Canyon ore is delivered to an in-pit crusher and leaves the pit on a 5-mile-long (partly underground) conveyor to the Copperton Concentrator. At Copperton, the ore is milled and a copper concentrate and separate molybdenite concentrate is produced. The mill bags the dried molybdenite concentrate on site. The copper concentrate and the mill tailings are both carried north (about 14 and 12 miles, respectively) from Copperton in separate slurry pipelines. The tailings are contained in a 9000-acre impoundment north of Magna. The copper concentrate is processed into copper anodes in the Kennecott Outokumpu flash smelting and converting furnaces at the north end of the Oquirrh Mountains. Sulfuric acid is generated from the smelter off-gases at an adjacent acid plant. The copper anodes are sent by rail to the Kennecott refinery about two miles away. The anodes are placed in the tank-house and converted through an electrolytic purification process to copper cathodes. The tank-house slimes are then processed in the refinery for gold and silver. Very minor platinum and palladium are recovered from these processed slimes off site.

DISTRICT HISTORY

Bingham has played a crucial role in the history of Utah, mining in the American West, and the initial development of the large, open-pit, porphyry copper mines. Following the initial discovery of mineralization in the area about 1850, the staking of the first mining claim in 1863 ultimately led to the exploitation of Bingham Canyon's lode deposits (Table 1). Following a few years of successful but relatively minor placer gold production, the exploitation of Bingham's significant lead-copper-silver-gold vein and carbonate replacement ores (Fig. 2) began in earnest with the completion of the transcontinental railroad near Ogden, Utah in 1869, the arrival of a branch line to Salt Lake City the following year, and a rail extension to Bingham in 1873 (Butler, 1920). The exploitation of these vein and carbonate replacement ores continued until they closed in 1971 due to a lack of smelting capacity in the western U.S. (Krahulec, 1997).

Apparently, the first recognition of potential low-grade copper ores in Bingham Canyon is credited to Enos Wall. In 1887, Wall started staking claims in the bottom of Bingham Canyon. These claims became known as the Wall Group. In 1896, Samuel Newhouse and Thomas Weir uncovered high-grade, supergene enriched, copper replacement ore (12% Cu, 0.2 ounces per short ton (opt) Au, and 2.8 opt Ag) in their Highland Boy gold mine in Carr Fork of Bingham Canyon. The Highland Boy copper mine was the beginning of major copper production from the district (Krahulec, 1997).

About this time, Daniel Jackling and Robert Gemmell examined the Wall Group for Joseph DeLamar, who owned the Mercur gold mine on the southwest side of the Oquirrh Mountains. Their initial report cited an indicated reserve of 15 million tons at 2.2% copper and 0.02 opt gold. However, Jackling and Gemmell could not interest anyone in the property until 1903, when Spencer Penrose and Charles MacNiell, who

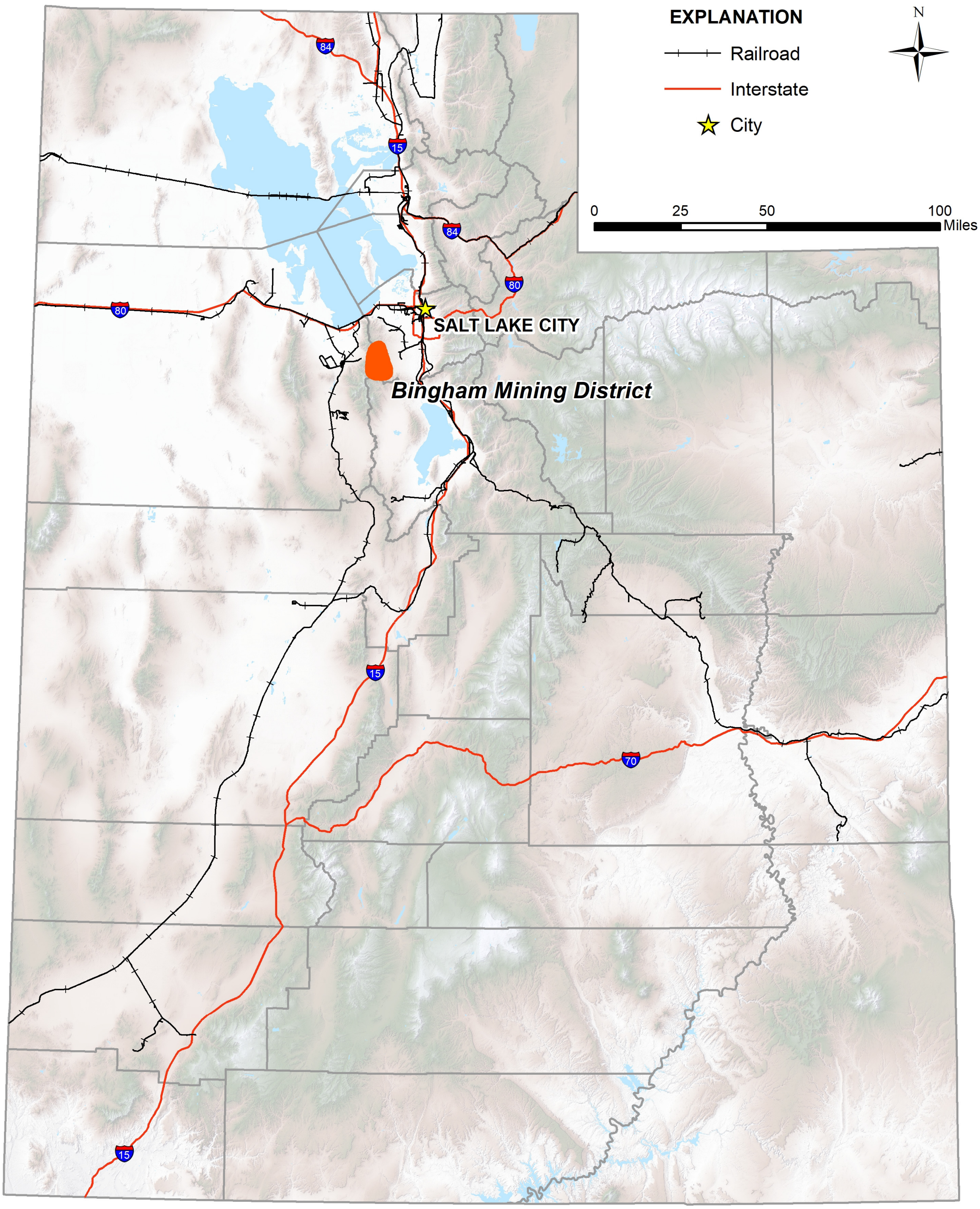


Figure 1. *Location map of the Bingham mining district, Salt Lake County, Utah.*

Table 1. *Significant historical developments in the Bingham mining district.*

Year	Event
1850	Initial discovery of mineralization in Bingham Canyon
1863	Jordan is the first mining claim staked in the present state of Utah
1864	West Mountain mining district organized
1864	Placer gold is Bingham's first economically produced metal
1868	Utah’s first base metal production is copper from very near the center of the present pit
1869	The transcontinental railroad is completed, and a line reaches Salt Lake City the following year
1870	The improved rail transportation facilitated the smelting of lead-silver ore
1873	The railroad is extended to lower Bingham Canyon
1874	Shallow oxide silver-lead ores are exhausted, and concentrators are built for sulfide ores
1880	Attempts to recover gold from ores by amalgamation/leaching are hampered by the presence of copper
1880	Discovery of gold in Barneys Canyon, north of Bingham
1887	Enos Wall is the first person to recognize the development potential of the low-grade copper ores
1895	Individual mining claims are consolidated into large claim blocks to be worked together
1896	Newhouse and Weir attempt to develop Highland Boy oxide gold mine, but discover high-grade copper-gold sulfide carbonate replacement deposit and start copper-gold production the next year
1897	Newhouse sells the Highland Boy, acquires the adjoining Stewart gold mine, and forms Boston Consolidated
1899	Highland Boy builds the first copper smelter for Bingham ores
1903	Jackling acquires the Wall property for Penrose and MacNeill, and Utah Copper Company is incorporated
1905	Utah Copper and Boston Consolidated start large-scale mill construction
1906	Steam shovels start stripping leached capping at both the Utah Copper and Boston Consolidated copper mines
1906	American Smelting & Refining Company builds the Garfield copper smelter for Bingham porphyry ores
1907	Steam shovels from both Utah Copper and Boston Consolidated reach enriched copper ore
1910	The Utah Copper Company acquires Boston Consolidated
1911	Utah Copper builds the Bingham & Garfield Railroad to the mills and smelter at the north end of the range
1912	Bingham is the "largest developed ore body in the world"
1915	Kennecott Copper Corporation acquires 25% of Utah Copper in a stock swap
1917	Sulfuric acid by-product is recovered from smelter gases
1921	In the post-war recession Bingham closes, but the mills are converted from gravity to flotation processing
1927	Suppression of pyrite in mills begins, increasing grade of concentrates
1928	Precipitation plant completed at Bingham Canyon for the recovery of copper from the dump water runoff
1932	Depth of the Great Depression causes production slowdown
1936	Utah Copper becomes an operating division of Kennecott Copper Corporation
1936	Molybdenite recovery circuit added to concentrators
1943	Bingham reaches record copper production for the Allies during WWII
1947	Copperton & Garfield Railroad constructed to replace the old Bingham & Garfield Railroad
1960	A $100 million mill expansion is announced
1970	$300 million is dedicated for a new smelter
1971	Nearly 100 years of continuous lead-zinc-silver production at Bingham comes to an end
1979	Carr Fork underground copper-gold skarn opened by Anaconda, but only operates for 18 months
1985	Copper prices reach historic lows in real dollar terms and Bingham is closed
1985	Barneys Canyon gold rediscovered
1986	The Bingham Canyon mine is reopened and the smelter resumes operation under a new labor agreement
1988	A $350 million modernization project comes on-line with an in-pit crusher, ore conveyor, and Copperton mill
1989	Barneys Canyon gold mine production starts
1992	Nearly $1 billion is dedicated to the expansion of mills and the construction of a new smelter and refinery
1995	Kennecott discovers subeconomic porphyry copper system ten miles southwest of Bingham near Stockton
1996	Initiation of $460 million tailings impoundment enlargement project
2001	Barneys Canyon gold mine ceases mining
2002	North Concentrator is permanently closed
2004	Kennecott's Daybreak residential project breaks ground
2006	Bingham has record molybdenum production and net profits
2008	Discovery of the deep molybdenum resource under the pit
2013	Manefay landslide deposits 145 million tons of waste in the bottom of the pit
2013	Bingham open pit produces three billionth ton of copper ore
2018	Start of the south wall pushback (SWP) to extend mine life to 2027

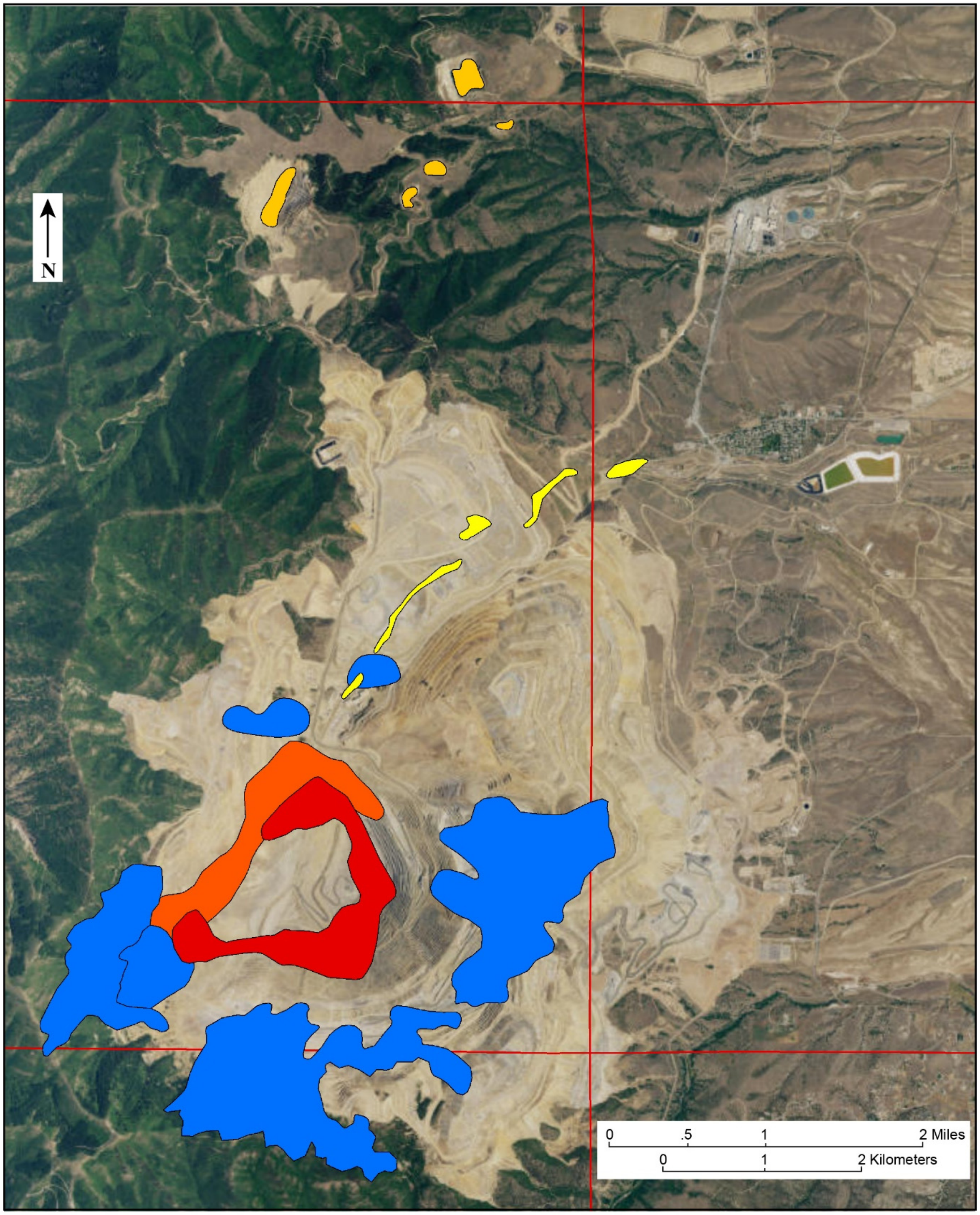


Figure 2. *Primary mineral deposits of the Bingham mining district, Salt Lake County, Utah: Red – Bingham porphyry Cu-Mo-Au deposit; Orange – North Ore Shoot and Carr Fork Cu-Au skarns (projected to surface); Blue – Pb-Zn-Ag replacement deposits (projected to surface); Bright Yellow – placer Au deposits in Bingham Canyon; and Gold – Barneys Canyon distal disseminated Au deposits to the north. Air photo base from Google Imagery.*

had made considerable money in the Cripple Creek mining district of Colorado, acquired the Wall Group. Initial test results were sufficiently encouraging for them to organize the Utah Copper Company to exercise this option and development began immediately. Surprisingly, despite the initial development cost, the experimental nature of the mill, and the interest due on the loan, Utah Copper had a positive net income of $142,488 in its first year of operation. Steam shovel stripping operations began in August 1906 at Utah Copper's mine and open-pit ore was first shipped in June 1907 (Krahulec, 1997).

While a significant part of the history of the Bingham Canyon open-pit operation is a record of gradual changes toward a larger and more-efficient operation, such as the increasing size of shovels, trucks, and mills, there have also been several significant advances in technology worth note here. First, the switch from gravity to flotation processing in the mills in the early 1920s resulted in a significant increase in copper recovery (Fig. 3.A.). This was followed a few years later by a marked increase in concentrate grade with the advent of selective flotation and the repression of pyrite from the concentrate. The addition of molybdenite circuits in 1936 began the recovery of this important byproduct (Fig. 3.A.). The in-mine conversion from rail haulage to trucks began in the 1960s with truck haulage of waste, but rail haulage of ore to the Bonneville Concentrator continued until 2001. Following a brief mine closure in 1985-86, a geotechnical study prompted a dramatic reduction of the stripping ratio (Fig. 3.B.). This was followed by the completion of an in-pit crusher, ore conveyor, and new Copperton Concentrator in 1988. The 1990s marked the completion of a new Outokumpu smelter and a significant enlargement in the capacity of the tailings ponds (Krahulec, 1997).

Exploration has continued to play an integral role in the history of the Bingham district. In the 1970s, deep drilling along the northern edge of the porphyry deposit resulted in the discovery of the Carr Fork (Anaconda) and North Ore Shoot (Kennecott) copper-gold skarn deposits (Cameron and Garmoe, 1987; Harrison and Reid, 1997). Gold exploration in the 1980s delineated the Barneys Canyon distal disseminated gold deposits about five miles north of the copper mine (Fig. 2), and production from these gold deposits began in 1989 (Gunter and Austin, 1997). In 1995, a new porphyry copper system was discovered ten miles southwest of Bingham near Stockton (Krahulec, this volume). In 2008, Kennecott announced the discovery of an important molybdenum resource (roughly 600 million tons at 0.1% Mo) at depth under the Bingham pit (Rio Tinto, 2009; Austin and Ballantyne, 2010).

On April 10, 2013, two massive landslides carried about 145 million tons of waste rock into and across the bottom of the open pit. These are the largest mining-induced landslides in history. These slides, named the Manefay landslides, started in the northeast corner of the open pit—the first at 9:30 p.m. was larger (nearly 100 million tons), and the second followed a little over an hour and a half later. The second slide was followed 11 minutes later by a small, shallow earthquake (about magnitude 2.5) beneath the mine, induced by the rapid weight displacement of the slides (Pankow and others, 2014; Moore and others, 2017). Notably, the Manefay slides resulted in no injuries or deaths, but they significantly changed the face of the mine and caused hundreds of millions of dollars of damage to the operation.

Fortunately, Kennecott was prepared and had a sophisticated network of geotechnical monitors in place at the mine. These monitors showed instability in the area of the slide beginning in November 2012, but it became more threatening in early 2013. The area of the slide showed increasing movement and when it reached a rate of about 2 inches per day on April 10 all employees were evacuated from the mine at 11 a.m. and a press release was issued at 2:38 p.m. warning that a slide was imminent (Pankow and others, 2014; Moore and others, 2017).

Figure 3.A. Bingham mine life annual head grades.

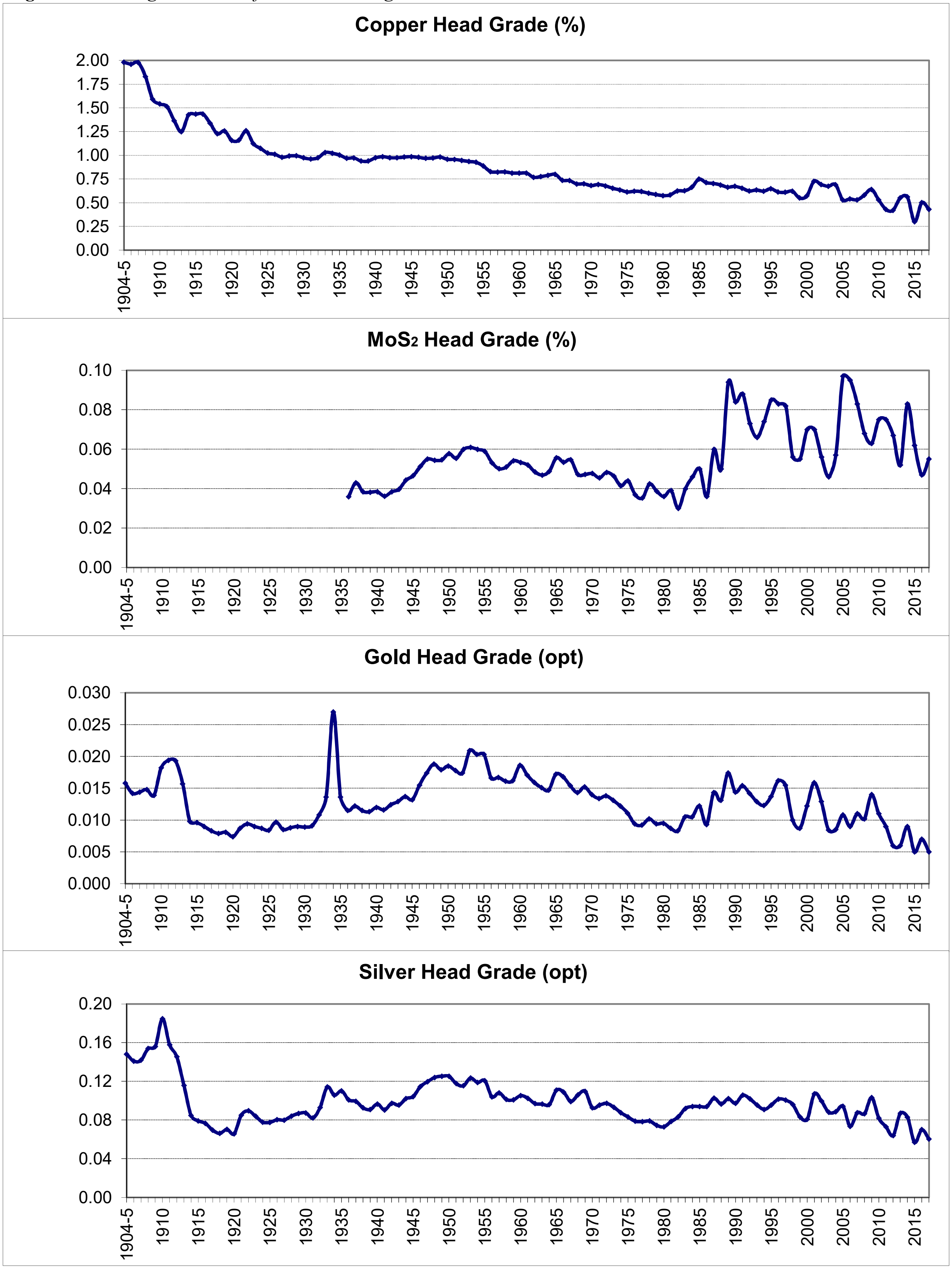
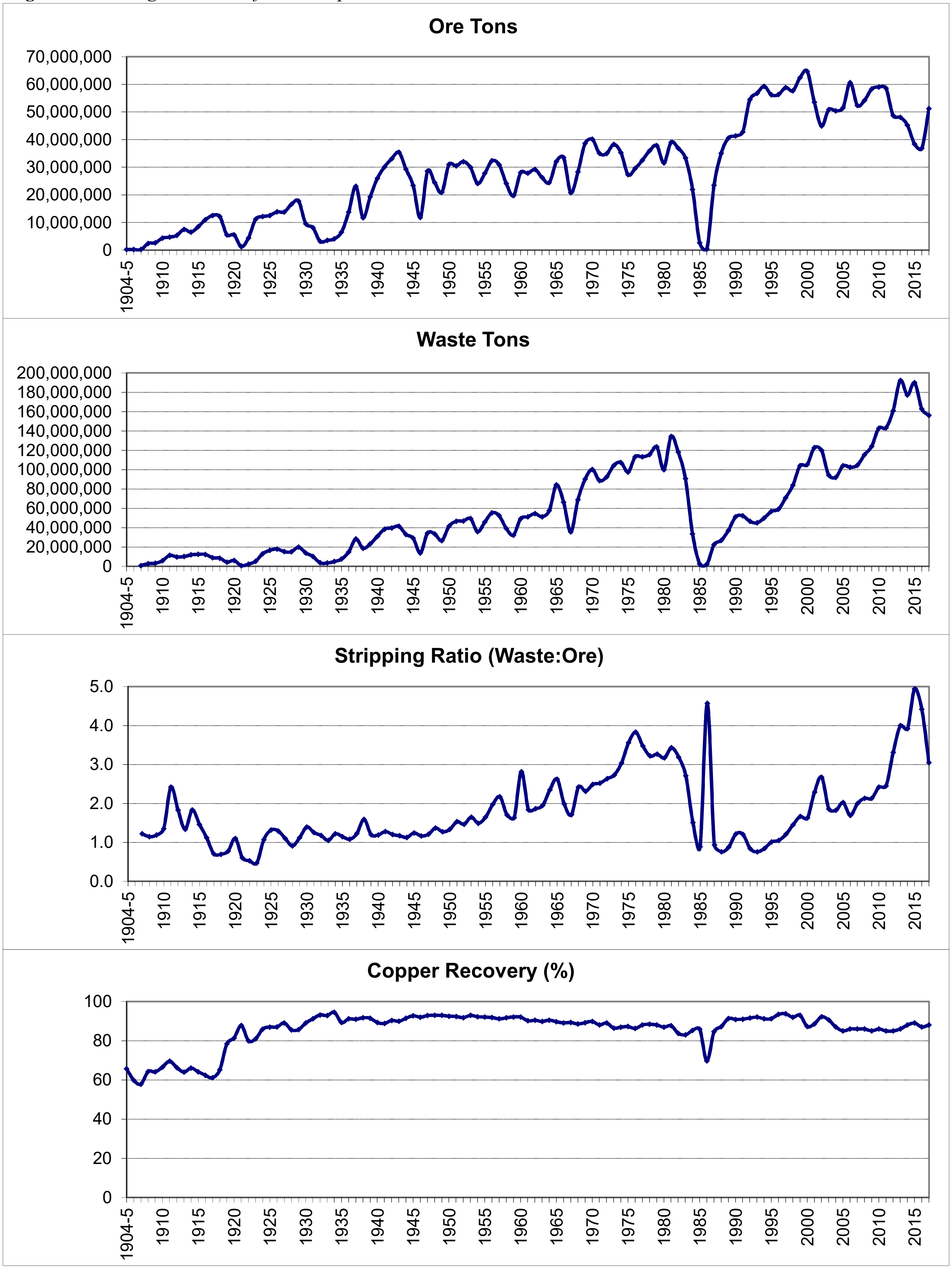


Figure 3.B. *Bingham mine life annual production statistics.*



Despite the best efforts, the slides resulted in significant damage to both the mine's fixed infrastructure, including the main haul road, and somewhat surprisingly, to its fleet of mobile equipment, which had been moved to the far side of the pit. Damage to the fleet included 3 of the 13 shovels, 14 of the 100 haul trucks, and some other ancillary equipment including drills, bulldozers, and graders (the haul trucks cost approximately $5 million and shovels about $45 million each); some of which were eventually recovered, repaired, and returned to service.

The headwall of the Manefay slides was 1150 feet high, and the slide was 9840 feet long with a total drop of about 2975 feet. The slides failed mainly along the Manefay series beds at the base of the Upper Pennsylvanian Bingham Mine Formation that dipped moderately northwest into the pit. The slide was somewhat larger than Kennecott anticipated, but more importantly, instead of acting like a rock fall or slump as previous smaller pit-wall failures had, this slide acted more fluidly as a rock avalanche. This fluidity resulted in the slide reaching speeds in excess of 70 mph and advancing considerably farther to the southwest across the pit bottom than anticipated resulting in the damage to the parked equipment (Pankow and others, 2014; Moore and others, 2017).

Initial work after the slides consisted of assessing the situation and developing a plan to stabilize the headwall of the slide so that it would be safe to work below it. Because the in-pit crusher and underground ore conveyor were not damaged, ore production resumed just 17 days after the slide. The other priority was to re-establish the main haul road into the pit. The new haul road was about ¾ mile long, 150 feet wide, and required the removal of about 6 million tons of landslide debris, but was completed in just 7 months, largely as a result of the rapid innovative development and implementation of over 20 pieces of remote-controlled heavy equipment in areas that were still not safe for employees to work.

Remarkably, Bingham continued to produce moderate amounts of ore following the slides in 2013 and 2014, but in 2015 a reappraisal of the overall stability of the east side of the open pit required a massive waste rock stripping program to reduce the angle of the pit slopes and the risk of future failures. This required most of the mine equipment to be used in this waste stripping operation, resulting in little new ore production and the highest stripping ratio (4.9:1 waste:ore) in the 110-year history of Bingham's open pit mining operations. The stripping ratio remained very high in 2016 but declined in 2017 (Fig. 3.B).

Moving forward, Bingham still has about 710 million tons of ore primarily hosted in and under the south wall of the pit. Mining this reserve will push the south wall of the pit about 1000 feet farther south and the bottom of the pit 300 feet deeper. This gives the mine a remaining life of 9 years, through 2027, with improved copper and molybdenum grades, which should return Bingham to the position of one of the largest annual copper and molybdenum producers in the U.S. in 2019.

PRODUCTION AND PRESENT RESERVES

The Bingham mining district is Utah's largest producer of copper, gold, molybdenum, silver, lead, and zinc (Table 2). Bingham ranks among the five largest mining districts in the U.S. for copper (1), gold (2), silver (3), molybdenum (3), and lead (5) production (Long and others, 1998).

The copper head grades for over a century of annual production from the Bingham porphyry copper deposit (Fig. 3.A.) have decreased very gradually from nearly 2% Cu in 1904-05 to below 0.5% today (2018). This trend is due to some supergene-enriched ore in the early years, compounded by more efficient operations with lower cutoff grades in later years, and continues with lower copper grades in the current resources (Table 2). Silver head grades show a similar but more erratic decline. However, the annual head grade for molybdenite, while erratic, shows an increase in grade since it began being recovered in 1936 until 2005-06. This is due to higher molybdenite grades overlapping with, and extending below, the primary copper zone, which have been encountered since approximately 1987. This trend has reversed since 2006. The gold head grade does not correlate well with either the copper or molybdenum trends. Gold shows a modestly higher grade zone (>0.015 opt Au) was mined from about 1946 to 1969. This higher grade gold zone was sandwiched below the supergene copper zone and above the higher grade molybdenum zone. The isolated gold grade spike in 1934 (see Fig. 3.A.) was the result of a brief attempt to high-grade some gold ore during the Great Depression when the U.S. dollar was devaluated against gold. Declining gold grades continue in both the current mineable reserves and future resources.

Bingham annual production statistics (Fig. 3.B.) over the life of the mine show some interesting trends. The annual tons of ore mined, while erratic, show a clearly increasing trend from the start of operations until the early 1990s, when production basically plateaued, at least temporarily. The stripping ratio and tons of waste mined increase similarly into the 1980s, when the operation was closed briefly in 1986. A geotechnical evaluation at this time resulted in decreased stripping and resulting fewer tons of waste mined; however, both have naturally increased in unison until the slide in 2013, when the stripping ratio increased dramatically (Fig. 3.B.). The copper recovery chart essentially shows a jump in recovery with the switch from gravity to flotation circuits from 1918 to 1921.

Bingham's annual production over the last ten years (2008-17) averages approximately 215,000 tons Cu, 16,800 tons MoS_2, 283,000 ounces Au, and 2,847,000 Ag. Not recorded here are associated production of significant volumes of sulfuric acid and minor amounts of rhenium, uranium, platinum, palladium, selenium, and tellurium. For 2017, Rio Tinto (2018) reported gross revenue on sales from Bingham of roughly $1,352 million and had 1734 employees.

Substantial reserves remain at Bingham (Table 2). As presently envisioned, the future of Bingham is for continued open-pit operation until at least 2027. The initiation of underground, block-cave mining of porphyry ore is also being studied and underground development could also eventually include the large, high-grade skarn resources of the North Ore Shoot and Carr Fork (Harrison and Reid, 1997; Gundy and others, 2009).

ACKNOWLEDGEMENTS

I am indebted to many people for their guidance and assistance in the construction of this history. I especially thank Kim Schroeder, Dan Bryant, and David Briggs for assistance with the compilation of production data. I am also grateful for reviews of this paper by Mike Hylland, Kim Schroeder, and Dave Tabet.

SELECTED BIBLIOGRAPHY

Austin, G., and Ballantyne G., 2010, Geology and geochemistry of deep molybdenum mineralization at the Bingham Canyon Mine, Utah, USA: Society of Economic Geologists Guidebook 41, p. 25–33.

Babcock, R.C., Jr., Ballantyne, G.H., and Phillips, C.H., 1995, Summary of the geology of the Bingham district, Utah, *in* Pierce, F.W., and Bolm, J.G., editors, Porphyry copper deposits of the American cordilleran: Tucson, Arizona, Arizona Geological Society Digest 20, p. 316-335.

Boutwell, J.M., 1905, Economic geology of the Bingham mining district, Utah: United States Geological Survey, Professional Paper 38, 413 p.

Butler, B.S., Loughlin, G.F., Heikes, V.C., and others, 1920, The ore deposits of

Table 2. *Bingham mining district - past production and current reserves through the end of 2017.*

	Au	
Placer gold deposits (1)	72,568	ounces

	Short Tons	Au opt
Barneys sediment-hosted gold (2)	10,780,000	0.046
Melco sediment-hosted gold (2)	17,277,000	0.070
BCS sediment-hosted gold (2)	2,542,000	0.042
Sediment-hosted gold production - Total	**30,599,000**	**0.060**

	Short Tons	Cu	Au opt	Ag opt	Pb	Zn
Lead-Zinc replacement - Production (3)	32,815,864	0.38%	0.041	3.65	6.8%	2.8%
Lead-Zinc replacement - Resources (4)	550,000	0.30%	0.040	4.00	10.0%	8.0%
Copper-rich lode - Production (5, 6)	5,888,244	2.05%	0.073	1.98	0.2%	0.0%
Replacement deposits - Total	**39,254,108**	**0.63%**	**0.046**	**3.41**	**5.8%**	**2.5%**

	Short Tons	Cu	Au opt	Ag opt	MoS_2
Copper-Gold skarn - Production (6)	8,914,592	2.20%	0.077	1.32	-
Copper-Gold skarn - UG* resources (7)	22,000,000	3.65%	0.047	-	-
Copper-Gold skarn - UG* resources (8)	382,777,000	1.85%	0.021	0.35	0.025%
Copper-Gold skarn - Total	**413,691,592**	**1.95%**	**0.023**	**0.35**	**0.023%**

	Short Tons	Cu	Au opt	Ag opt	MoS_2
Porphyry Copper - Production (9)	3,207,072,016	0.72%	0.012	0.09	0.057%
Porphyry Copper - OP* reserves (7)	710,010,000	0.47%	0.005	0.06	0.055%
Porphyry Copper - OP* resources (7)	126,787,500	0.32%	0.005	0.05	0.078%
Porphyry Copper Deposit - Total	**4,043,869,516**	**0.66%**	**0.011**	**0.09**	**0.057%**

* UG - Underground; OP - Open Pit

1. Total recovered ounces of placer gold from 1864 to 1919 (Butler and others, 1920).
2. Total production (Gunter and Austin, 1997; Bear Slothower, personal communication, 2002).
3. Recovered grades from 1863 to 1964 calculated from Rubright and Hart (1968) and production from 1965 to 1972 from James (1973).
4. Modified from estimate in James (1973).
5. Recovered grade estimate recalculated from Krahulec (1997) skarns.
6. Recovered grades from 1897 to 1908 calculated from Butler and others (1920), grades from 1909 to 1946 from Hunt and Peacock (1950) and estimated production from 1979 to 1981 from Cameron and Garmoe (1987).
7. Reserves and resources from Rio Tinto 2017 annual report (Rio Tinto, 2018).
8. Head grades from Harrison and Reid (1997).
9. Head grades from past production through 2009, includes the Boston Consolidated (Dan Bryant, personal communication, 2002).

Utah: United States Geological Survey Professional Paper 111, 672 p.

Cameron, D.E., and Garmoe, W.J., 1987, Geology of skarn and high-grade gold in the Carr Fork mine, Utah: Economic Geology, v. 82, p. 1319-1333.

Deino, A. and Keith, J.D., 1997, Ages of volcanic and intrusive rocks in the Bingham mining district, Utah, *in* John, D.A., and Ballantyne, G.H., editors, Geology and ore deposits of the Oquirrh and central Wasatch Mountains, Utah: Society of Economic Geologists Guidebook, v. 29, p. 91-100.

Gundy, K., Brobst, T., and Gaida, M., 2009, Bingham Canyon mine expansion evaluation, *in* Tripp, B.T., Krahulec, K.A., and Jordan, J.L., editors, Geology and geologic resources and issues of Western Utah: Utah Geological Association Publication 38, p. 125-132.

Gunter, W.L., and Austin, G.W., 1997, Geology of the Melco gold deposit, Oquirrh Mountains, Utah, *in* John, D.A., and Ballantyne, G.H. editors, Geology and ore deposits of the Oquirrh and Wasatch Mountains, Utah: Society of Economic Geologists Guidebook Series v. 29, p. 331-348.

Harrison, E.D., and Reid, J.E., 1997, Copper-gold skarn deposits of the Bingham mining district, Utah, *in* John, D.A., and Ballantyne, G.H. editors, Geology and ore deposits of the Oquirrh and Wasatch Mountains, Utah: Society of Economic Geologists Guidebook Series v. 29, p. 219 -238.

Hunt, R.N., and Peacock, H.G., 1950, Lead and lead-zinc of the Bingham district, Utah, Lead-Zinc Symposium, p. 81-85.

James, A.H., 1973, Lead and zinc resources in Utah, Utah: Geological and Mineralogical Survey, Special Studies 44, 66 p.

Krahulec, K., 1997, History and production of the West Mountain (Bingham) mining district, Utah, *in* John, D.A., and Ballantyne, G.H. editors, Geology and ore deposits of the Oquirrh and Wasatch Mountains, Utah: Society of Economic Geologists Guidebook Series v. 29, p. 275 -320.

Krahulec, K., 2015, Tertiary intrusion-related copper, molybdenum, and tungsten mining districts of the eastern Great Basin, *in* Pennell, W.M., and Garside, L.J., editors, New Concepts and Discoveries: Geological Society of Nevada 2015 Symposium CD, p. 219–250.

Long, K.R., DeYoung, J.H., Jr., and Ludington, S.D., 1998, Database of significant deposits of gold, silver, copper, lead, and zinc in the United States: U.S. Geological Survey Open-File Report 98-206A, 3.5” computer diskette.

Maughan, D.T., Keith, J.D., Christiansen, E.H., Pulsipher, T., Hattori, K., Evans, N.J., 2002, Contributions from mafic alkaline magmas to the Bingham porphyry Cu-Au-Mo deposit, Utah, USA: Mineralium Deposita, v. 37, no. 1, p. 14-37.

Moore, J.R., Pankow, K.L., Ford, S.R., Koper, K.D., Hale, J.M., Aaron, J., and Larsen, C.F., 2017, Dynamics of the Bingham Canyon rock avalanches (Utah, USA) resolved from topographic, seismic, and infrasound data: Journal of Geophysical Research—Earth Surface 122, p. 1-26, doi:10.1002/2016JF004036.

Pankow, K.L., Moore, J.R., Hale, J.M., Koper, K.D., Kubacki, T., Whidden, K.M., and McCarter, M.K., 2014, Massive landslide at Utah copper mine generates wealth of geophysical data: Geological Society of America GSA Today, v. 24, no. 1, p. 4-9.

Porter, J.P., Schroeder, K., and Austin, G., 2012, Geology of the Bingham Canyon porphyry Cu-Mo-Au deposit, Utah, *in* Hedenquist, J.W., Harris, M., and Camus, F., editors, Geology and genesis of Major copper deposit and districts of the world—A tribute to Richard H. Sillitoe: Society of Economic Geologists Special Publication 16, p. 127-146.

Rio Tinto, 2009, Rio Tinto 2008 Annual Report, Online, <https:// www.riotinto.com/documents/

AnnualReport2008.pdf >, accessed July 2018.

Rio Tinto, 2018, Rio Tinto 2017 Annual Report, Online, < https://www.riotinto.com/documents/RT_2017_Annual_Report.pdf >, accessed July 2018.

Rubright, R.D., and Hart, O.J., 1968, Non-porphyry ores of the Bingham district, Utah, *in* Ridge, J.D., editor, Ore Deposits in the United States 1933-1967: New York, American Institute of Mining Engineers, p. 886-907.

Waite, K.A., Keith, J.D., Christiansen, E.H., Whitney, J.A., Hattori, K., Tingey, D.G., and Hook, C.J., 1997, Petrogenesis of the volcanic and intrusive rocks associated with the Bingham porphyry Cu-Au-Mo deposit, Utah, *in* John, D.A., and Ballantyne, G.H., editors, Geology and ore deposits of the Oquirrh and Wasatch Mountains, Utah: Society of Economic Geologists Guidebook 29, p. 69-90.

Appendix. Bingham Canyon life of mine production statistics.

Year	Ore Short Tons	Waste Short Tons	Waste:Ore Ratio	Copper Short Tons	Molybdenum Short Tons	Gold Thousand Ounces	Silver Thousand Ounces
1904-5	216,769			2,814		2	17
1906	231,125			2,713		2	16
1907	183,569	768,675	4.19	2,100		1	11
1908	2,422,064	2,773,279	1.15	28,448		20	182
1909	2,674,271	3,170,478	1.19	27,236		21	221
1910	4,340,245	5,846,265	1.35	44,510		40	424
1911	4,680,801	11,320,905	2.42	49,218		40	408
1912	5,315,321	9,713,232	1.83	48,088		34	346
1913	7,519,392	10,043,290	1.34	59,970		28	317
1914	6,470,166	11,857,252	1.83	60,890		35	362
1915	8,494,300	12,381,759	1.46	78,094		37	413
1916	10,994,000	12,278,092	1.12	98,365		46	506
1917	12,542,000	8,872,670	0.71	102,428		49	537
1918	12,160,700	8,441,117	0.69	97,084		49	520
1919	5,538,700	4,284,666	0.77	54,617		29	293
1920	5,556,800	6,102,847	1.10	52,308		27	286
1921	1,220,700	737,815	0.60	12,415		7	73
1922	4,364,251	2,288,341	0.52	43,922		28	286
1923	11,167,800	5,227,861	0.47	101,493		73	701
1924	12,126,600	12,949,912	1.07	111,762		77	725
1925	12,538,300	16,488,080	1.32	111,489		78	770
1926	13,880,100	17,932,338	1.29	122,013		86	845
1927	13,811,500	15,149,189	1.10	120,482		89	884
1928	16,558,500	14,996,011	0.91	140,539		104	1,019
1929	17,724,100	19,821,357	1.12	151,007		116	1,167
1930	9,552,500	13,846,715	1.45	82,722		64	626
1931	8,147,764	10,180,181	1.25	71,378		54	535
1932	3,169,411	3,650,930	1.15	28,739		25	247
1933	3,521,425	3,362,061	0.95	33,661		35	347
1934	4,086,800	4,981,560	1.22	39,473		44	373
1935	6,529,800	7,483,981	1.15	58,397		68	597
1936	13,773,900	14,859,346	1.08	121,609	272	117	1,057
1937	23,119,800	28,292,291	1.22	204,384	2,454	202	1,912
1938	11,704,900	18,617,345	1.59	100,786	1,616	98	910
1939	19,310,200	23,111,402	1.20	165,836	3,091	159	1,494
1940	25,950,500	30,884,201	1.19	225,326	4,292	223	2,103
1941	30,090,400	38,380,432	1.28	263,150	4,717	242	2,251
1942	33,093,200	39,716,089	1.20	291,311	5,622	287	2,627
1943	35,375,800	41,308,996	1.17	309,613	5,885	306	2,822
1944	29,274,200	32,962,007	1.13	262,791	5,789	284	2,487
1945	23,361,000	29,002,916	1.24	213,564	5,154	228	2,029
1946	11,831,400	13,776,826	1.16	106,419	2,727	131	1,163
1947	28,539,300	34,359,084	1.20	256,355	6,933	364	2,969
1948	24,454,000	33,480,555	1.37	220,667	5,601	312	2,622
1949	20,922,300	26,581,965	1.27	190,790	5,028	268	2,215
1950	31,037,800	41,344,160	1.33	274,786	7,344	413	3,290

Year	Ore Short Tons	Waste Short Tons	Waste:Ore Ratio	Copper Short Tons	Molybdenum Short Tons	Gold Thousand Ounces	Silver Thousand Ounces
1951	30,444,800	46,551,516	1.53	268,971	6,945	391	3,156
1952	32,036,100	46,910,576	1.46	277,773	8,042	403	3,279
1953	29,922,200	49,291,904	1.65	259,824	8,630	442	3,410
1954	24,079,400	35,856,641	1.49	205,619	6,683	361	2,598
1955	27,740,600	45,710,091	1.65	226,589	7,651	397	2,923
1956	32,321,100	55,209,730	1.71	245,714	7,650	379	2,924
1957	30,919,900	52,341,056	1.69	232,290	6,650	353	2,867
1958	24,086,800	39,045,654	1.62	182,305	5,458	280	2,143
1959	19,673,100	32,300,481	1.64	147,311	4,456	224	1,749
1960	28,060,300	49,221,324	1.75	209,546	6,411	352	2,624
1961	27,839,700	51,242,919	1.84	203,947	6,164	324	2,428
1962	29,175,000	54,454,286	1.87	202,636	6,112	299	2,412
1963	26,235,400	51,199,296	1.95	182,738	5,256	254	2,122
1964	24,456,400	57,497,136	2.35	174,638	5,229	243	1,939
1965	32,088,900	84,116,298	2.62	229,639	7,567	373	2,909
1966	33,477,700	66,304,900	1.98	219,559	7,060	364	2,885
1967	20,789,600	35,532,965	1.71	136,086	4,524	213	1,638
1968	28,343,900	68,786,040	2.43	175,172	5,358	265	2,250
1969	38,650,300	90,028,957	2.33	240,963	7,170	379	3,194
1970	40,147,500	100,195,997	2.50	245,298	7,634	355	2,904
1971	35,008,400	88,614,573	2.53	213,306	6,192	308	2,600
1972	34,951,700	92,452,181	2.65	210,714	6,746	318	2,682
1973	38,267,600	104,152,836	2.72	215,659	6,405	310	2,740
1974	35,277,300	107,389,674	3.04	194,755	4,628	255	2,419
1975	27,318,000	97,431,089	3.57	146,102	4,029	185	1,759
1976	29,567,100	113,213,082	3.83	158,039	3,226	168	1,793
1977	32,570,800	113,156,461	3.47	176,916	3,425	187	1,957
1978	35,937,700	115,625,007	3.22	190,562	4,860	219	2,224
1979	37,803,900	123,434,500	3.27	195,073	5,106	226	2,275
1980	31,578,500	99,976,515	3.17	157,787	3,665	174	1,766
1981	39,023,500	134,274,849	3.44	199,087	3,785	209	2,241
1982	36,877,600	118,011,880	3.20	193,049	2,560	177	2,162
1983	33,310,200	90,539,931	2.72	172,955	1,828	206	2,189
1984	21,963,700	33,566,100	1.53	124,038	1,703	145	1,514
1985	2,644,200	2,494,350	0.94	16,972	296	21	191
1986	444,900	2,086,050	4.69	2,207	6	3	29
1987	23,447,400	22,446,986	0.96	139,431	2,507	199	1,788
1988	35,041,833	26,688,301	0.76	209,906	949	305	2,518
1989	40,539,798	37,140,938	0.92	245,397	4,654	507	3,755
1990	41,341,940	51,030,720	1.23	252,542	5,739	420	3,379
1991	42,749,228	52,208,453	1.22	253,829	7,714	459	3,615
1992	54,524,742	46,531,639	0.85	310,909	9,529	532	4,318
1993	56,761,080	44,999,718	0.79	331,144	8,988	515	4,411
1994	59,291,955	50,000,000	0.84	335,645	9,620	510	4,358
1995	56,201,713	56,736,900	1.01	332,029	11,908	525	4,376
1996	56,330,004	59,063,400	1.05	322,152	12,308	615	4,739
1997	58,833,000	70,846,600	1.20	336,312	12,208	603	4,916
1998	57,646,600	83,646,933	1.45	328,706	6,981	366	4,247
1999	62,384,260	103,930,355	1.67	307,872	6,981	367	3,859
2000	64,663,123	105,148,397	1.63	325,950	11,122	529	3,939

Year	Ore Short Tons	Waste Short Tons	Waste:Ore Ratio	Copper Short Tons	Molybdenum Short Tons	Gold Thousand Ounces	Silver Thousand Ounces
2001	53,535,161	122,698,884	2.29	343,838	8,937	592	4,475
2002	44,885,696	119,966,099	2.67	286,257	6,671	412	3,663
2003	50,821,879	94,315,851	1.86	309,912	5,091	305	3,548
2004	50,400,000	92,041,110	1.83	290,729	7,490	308	3,584
2005	51,447,060	103,900,000	2.02	243,322	17,199	401	3,958
2006	60,600,000	102,400,000	1.69	292,824	18,522	523	4,214
2007	52,396,000	104,500,000	1.99	233,951	16,427	397	3,487
2008	54,170,000	115,351,000	2.13	262,395	12,821	368	3,414
2009	58,273,740	124,000,000	2.13	334,609	12,446	582	4,871
2010	68,332,332	142,814,574	2.09	275,405	14,222	466	3,754
2011	68,572,914	143,317,390	2.09	214,988	14,994	284	2,976
2012	48,646,393	161,019,561	3.31	179,924	10,322	200	2,086
2013	50,141,265	192,179,984	3.83	232,585	6,284	207	2,876
2014	46,999,102	177,168,866	3.77	225,202	12,679	260	2,935
2015	38,394,409	189,764,259	4.94	101,430	8,379	131	1,458
2016	36,843,000	162,716,449	4.42	168,321	3,086	153	1,943
2017	51,179,337	155,934,170	3.05	164,000	5,500	178	2,156
Total	**3,238,007,238**	**6,366,352,856**	**1.97**	**20,271,118**	**547,915**	**27,020**	**238,517**