

COBALT

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Cobalt is a strategic and critical metal used in many diverse industrial and military applications. The largest use of cobalt is in superalloys, which are used to make parts for gas turbine engines. Cobalt is also used to make magnets; corrosion- and wear-resistant alloys; high-speed steels; cemented carbides (also called hardmetals) and diamond tools; catalysts for the petroleum and chemical industries; drying agents for paints, varnishes, and inks; ground coats for porcelain enamels; pigments; battery electrodes; steel-belted radial tires; airbags in automobiles; and magnetic recording media.

The United States did not mine or refine cobalt in 2002. However, a small number of mining operations produced negligible amounts of byproduct cobalt as intermediate products. Since 1993, sales of excess cobalt from the National Defense Stockpile (NDS) have contributed to U.S. and world supplies. In 2002, U.S. consumption of cobalt decreased significantly from that of 2001.

World refined cobalt production continued to increase in 2002. The Cobalt Development Institute reported that although estimated world demand for cobalt increased in 2002, it was less than total estimated world cobalt availability (refinery production plus NDS releases) (Cobalt Development Institute, 2003d). This imbalance between supply and demand resulted in a continued downtrend in annual average cobalt prices (Inco Ltd., 2003, p. 18).

Salient U.S. and world cobalt statistics for 2002 and the previous 4 years are listed in table 1. With the exception of prices and reported production from foreign countries, all quantity and value data in this report have been rounded to no more than three significant digits. Totals and percentages were calculated from unrounded numbers.

Legislation and Government Programs

The Defense National Stockpile Center (DNSC), U.S. Department of Defense, held seven sealed-bid cobalt offerings during fiscal year 2002 (October 1, 2001, through September 30, 2002). In June, DNSC introduced a new sales format for cobalt—the Basic Ordering Agreement (BOA). Under the BOA format, prospective purchasers prequalified for bidding by showing that they had adequate financial resources, a satisfactory performance record with DNSC, and a satisfactory record of integrity and ethics. DNSC offered cobalt on a periodic basis, depending on market needs. Each Tuesday morning any cobalt for sale would be posted on DNSC's Web site. Prequalified prospective purchasers would send in quotes by facsimile before a specific date and time, and the DNSC would accept or reject the quotes within two business days (Defense National Stockpile Center, 2002a, p. 7, 9). DNSC awarded cobalt under this format each month from June through

September. During the fiscal year, the DNSC sold 1,210 metric tons (t) of cobalt cathode, granules, and rondelles valued at nearly \$19 million (table 2). This represented 44% of the 2,720-t (6-million-pound) maximum allowed for sale under the fiscal year 2002 Annual Materials Plan (AMP). As of the end of the fiscal year, 214 t of cobalt had been sold, but not shipped from the stockpile (U.S. Department of Defense, 2003, p. 6, 12-13, 54). The AMP for fiscal year 2003 (October 1, 2002, through September 30, 2003) maintained the maximum allowable sale of cobalt at 2,720 t (Defense National Stockpile Center, 2002b).

During calendar year 2002, DNSC held one negotiated and five sealed-bid cobalt offerings. BOA awards were made each month from June through December, with the exception of October and November. During this period, DNSC sold 1,320 t of cobalt cathode, granules, and rondelles valued at \$19.6 million. On December 31, the total uncommitted cobalt inventory held by the DNSC was 6,190 t, all of which was authorized for eventual disposal.

Production

With the exception of negligible amounts of byproduct cobalt produced from mining operations in Missouri and Montana, the United States did not mine or refine cobalt in 2002. For example, minor amounts of cobalt present in the ores mined for platinum-group metals at the Stillwater Complex of southern Montana were recovered from converter matte at Stillwater Mining Co.'s refinery and sold as a byproduct. In November, Russia's Open Joint Stock Company Mining and Metallurgical Company Norilsk Nickel entered into definitive agreements to acquire 51% of Stillwater Mining Co. (OJSC MMC Norilsk Nickel, 2003a, p. 11; Stillwater Mining Co., 2003, p. 14-15).

Formation Capital Corp. of Vancouver, British Columbia, Canada, continued to work on the mine permitting process for its Idaho Cobalt Project in Lemhi County, ID. The project entailed developing cobalt-copper-gold deposits in the Idaho Cobalt Belt in the central part of the State. The diluted proven and probable reserves and inferred resources for the project were estimated to be 2.86 million metric tons (Mt) grading 0.602% cobalt, 0.45% copper, and 0.5 grams per metric ton gold. The company's initial plan of operations described separate underground mining operations to extract ore from two deposits and a flotation mill to process the ore nearby. In September, Formation Capital completed the purchase of a hydrometallurgical complex approximately 320 kilometers (km) (200 miles) north of the cobalt project in Big Creek, ID, from Sunshine Precious Metals, Inc. The complex included a silver refinery, which used pressure-leaching technology. Formation planned to renovate the refinery to toll refine silver materials from other companies to generate cash flow, while retrofitting

the refinery to process concentrates from the Idaho Cobalt project. Once retrofitted, the refinery would have the capacity to produce approximately 2,000 metric tons per year (t/yr) of cobalt products. Formation planned to produce approximately 1,500 t/yr of cobalt as cathode and/or cobalt compounds, such as carbonate, hydroxide, or oxide, with initial production beginning in late 2004 (Forest Service, U.S. Department of Agriculture, 2001; Formation Capital Corp., 2001, 2002; Bending, 2002, p. 2, 6, 8-9, 13).

Cominco Engineering Services Ltd. continued to evaluate a proprietary hydrometallurgical process to treat ores from the Mesaba deposit in northeastern Minnesota. Mesaba is a large undeveloped copper-nickel deposit in the Duluth Complex of northeastern Minnesota, which is a large layered mafic intrusion. Mesaba was estimated to contain resources of more than 700 Mt of ore grading 0.46% copper and 0.12% nickel accessible by open pit mining and an additional 300 Mt of higher grade resources, which could be mined by underground methods. Cobalt, platinum-group metals, and other precious metals are also present (Cominco Ltd., 2001; Teck Cominco Ltd., 2003, p. 25).

In August, U.S. Cobalt Inc. of Denver, CO, announced that future production from the Madison cobalt mine, near Fredericktown, MO, would not be economic if cobalt prices remained at less than \$7 per pound. In addition, because U.S. Cobalt had been unable to renegotiate the environmental indemnity agreement with property owner Anschutz Mining Corp., Anschutz terminated the exploration with option to purchase agreement, thereby canceling all of U.S. Cobalt's rights to the property. U.S. Cobalt stated that as a result of these factors, it was shifting its efforts away from developing the Madison cobalt mine and towards evaluating opportunities in the renewable energy industry. The Madison property had a measured plus indicated resource of 6 Mt grading 0.306% cobalt, 0.470% nickel, and 0.743% copper using a cobalt equivalent cutoff grade of 0.20% (U.S. Cobalt Inc., 2002a-c).

PolyMet Mining Corp.'s NorthMet project was placed on care-and-maintenance status, while the company concentrated its efforts on identifying potential joint-venture partners or other forms of financing to complete a final feasibility study. The NorthMet polymetallic deposit, which is in the Duluth Complex of northeastern Minnesota, was being considered for development by open pit mining and hydrometallurgical processing. It had an estimated 371 Mt of measured and indicated reserves grading 0.29% copper, 0.08% nickel, 67.2 parts per million cobalt, 0.28 parts per million palladium, 0.08 parts per million platinum, and 0.04 parts per million gold using a copper equivalent cutoff grade of 0.01% (PolyMet Mining Corp., 2002a, p. 9; 2002b).

U.S. processors made cobalt chemicals and cobalt metal powders from refined cobalt materials and/or cobalt-bearing scrap. U.S. Geological Survey (USGS) data on chemical and metal powder production, shipments, and stocks were derived from a monthly voluntary survey of U.S. cobalt processors. Information from this survey was used to prepare the statistics on cobalt consumption and stocks in table 3. Four of the six cobalt processors on this survey provided data. Estimates were made for plants for which data were not provided. Two processors made extra-fine cobalt metal powder in the

United States. Carolmet Cobalt Products (a division of n.v. Umicore s.a.), made cobalt metal powder from cobalt metal at its Laurinburg, NC, plant. Osram Sylvania Inc. produced cobalt metal powder as a byproduct of tungsten recovered from cemented carbide scrap in Towanda, PA. Production and shipments of cobalt metal powder are withheld to avoid disclosing company proprietary data.

Consumption

U.S. apparent consumption for 2002 as calculated from net imports, consumption of purchased scrap, and changes in Government and industry stocks, was 17% lower than that calculated for 2001 (see table 1). The decrease in apparent consumption in 2002 was primarily because cobalt shipments from the NDS were significantly lower than those in 2001.

U.S. reported consumption for 2002 was 17% lower than that for 2001. As compared with 2001, metallurgical industries consumed 19% less cobalt, and the total reported cobalt consumption for chemical uses was 9% lower. Reported consumption was derived by the USGS from voluntary surveys of U.S. operations. Most of the data on cobalt chemical uses were obtained from the cobalt processors survey. A second survey covered a broad range of metal-consuming companies, such as superalloy, magnetic alloy, and cemented carbide producers. For this survey, nearly 90 cobalt consumers were canvassed on a monthly or annual basis. Reported consumption and stocks data in tables 1 and 3 contain estimates to account for nonrespondents.

Prices

U.S. spot prices for cathode (minimum of 99.8% cobalt), as reported by Platts Metals Week, fluctuated between \$6 per pound and \$9 per pound. The highest price, at a range of \$8.60 to \$9.00 per pound, was reported in mid-May and the lowest price, at a range of \$6.00 to \$6.25 per pound, was reported in late October. Platts' annual average U.S. spot cathode price for 2002 was \$6.91 per pound, down by 34% from that of 2001 (table 1). This price has steadily declined since 1995, when it was \$29.21 per pound.

Trends in Platts prices for Zambian cobalt (minimum 99.6% cobalt) and Russian cobalt (minimum 99.3% cobalt) were more or less parallel to those for U.S. spot cathode. The annual average of weekly prices for Zambian cobalt was \$6.71 per pound, 32% lower than that of 2001, and the annual average of weekly prices for Russian cobalt was \$6.63 per pound, 30% lower than that of 2001.

Sales prices for 99.8% cobalt cathode reported by WMC Resources Ltd. (formerly WMC Ltd.) at its Internet Web site provided some market transparency and were considered a benchmark for cobalt prices (Metal Bulletin, 2000; Ryan's Notes, 2000). The trend in these prices was similar to that of Platts' U.S. spot cathode prices. WMC's highest sales price during the year was \$8.85 per pound in early May, and its lowest sales price was \$6.20 per pound for several sales during mid- to late October.

OM Group, Inc. (OMG) sold grade B cobalt briquettes, with a minimum of 99.8% cobalt, on its Internet Web site. Sale prices

during 2002 ranged from a high of \$8.50 per pound for a sale in July to a low of \$6.75 per pound for a sale in September.

Foreign Trade

Net import reliance as a percentage of apparent consumption is used to measure the adequacy of current domestic production to meet U.S. demand. Net import reliance was defined as imports minus exports plus adjustments for Government and industry stock changes. Releases from stocks, including shipments from the NDS, were counted as part of import reliance, regardless of whether they were imported or produced in the United States. In 2002, net import reliance as a percentage of apparent consumption was 72%. Because there was no measurable U.S. primary cobalt production in 2002, this indicates that 72% of U.S. cobalt supply was from imports and stock releases of primary cobalt and 28% was from scrap, which would have been generated domestically or imported.

As shown in tables 4 and 5, in 2002, the United States imported 10% less cobalt than it did in 2001. Nine countries supplied 90% of U.S. imports of unwrought cobalt and cobalt in chemicals. Finland was the leading supplier, followed by Norway, Russia, Canada, Belgium, Zambia, Brazil, the Democratic Republic of the Congo [Congo (Kinshasa)], and South Africa. Compared with those of 2001, cobalt imports from Belgium, Canada, and Norway increased and imports from Congo (Kinshasa), Finland, Russia, South Africa, and Zambia decreased. Cobalt imports from Brazil were approximately equal during the past 2 years.

In 2002, the United States imported 72 t, gross weight, of unwrought cobalt alloys valued at \$1.4 million. Six countries supplied most of these materials—the United Kingdom (33%), Congo (Kinshasa) (28%), Japan (14%), Germany (12%), Belgium (8%), and Canada (3%). The United States imported 224 t, gross weight, of cobalt waste and scrap, valued at \$1.8 million. Seven countries supplied 99% of this material—the United Kingdom (31%), Ireland (21%), Canada (19%), Brazil (10%), Japan (9%), Germany (5%), and France (4%). The United States also imported 230 t, gross weight, of wrought cobalt and cobalt articles valued at \$11.5 million. The leading suppliers of these materials were the United Kingdom (39%), Japan (13%), Belgium (12%), Australia (11%), Canada and France (9% each), and Germany (6%).

U.S. exports of unwrought cobalt and cobalt contained in chemicals decreased by 35% compared with those of 2001. As listed in table 6, 82% of the cobalt metal and chemical exports was shipped to eight countries—Belgium, Canada, China, Germany, Ireland, Japan, the Netherlands, and the United Kingdom. The remainder was shipped to 38 other countries.

Exports also included 923 t, gross weight, of wrought metal and cobalt articles valued at \$26.6 million. More than 85% of these materials was sent to 8 countries—the United Kingdom (26%), France (17%), Germany and Switzerland (10% each), Japan (9%), Belgium (6%), Canada (5%), and the Republic of Korea (4%). The remainder was shipped to 35 other countries.

World Review

World refined cobalt production increased in 2002 as compared with that of 2001. Refinery capacity by country is

listed in table 7. Plants that processed refined cobalt, that used secondary materials (scrap) as their main source of feed, or that produced a cobalt product that required further refining were not included.

Australia.—QNI Pty. Ltd. (a subsidiary of BHP Billiton Ltd.) processed lateritic ore imported from third party mining operations in Indonesia, New Caledonia, and the Philippines at its Yabulu nickel-cobalt refinery in Townsville, Queensland, and produced 1,863 t of cobalt as cobalt oxide hydroxide, a slight increase as compared with the 1,818 t produced in 2001. During the year, QNI continued to study the feasibility of developing an integrated nickel-cobalt mine and front-end acid leaching plant at Ravensthorpe on the southern coast of Western Australia and expanding the Yabulu refinery to accommodate the intermediate nickel-cobalt hydroxide that would be produced from Ravensthorpe. QNI performed trial mining at Ravensthorpe, which generated ore for metallurgical studies. The company planned to complete the studies and make an investment decision by the end of 2003. Late in the year, QNI received environmental approvals from the Federal Government to construct and operate the infrastructure necessary to increase Yabulu's production capacity to approximately 73,500 t/yr of nickel and 3,100 t/yr of cobalt from the current capacity of 29,000 t/yr of nickel and 1,900 t/yr of cobalt. The expansion was scheduled to be completed by the end of 2006 (Cobalt Development Institute, 2003e; QNI Pty. Ltd., 2003; BHP Billiton, undated^{§1}).

WMC produced cobalt in intermediate nickel-cobalt mixed sulfide at its Kwinana nickel refinery in Western Australia. The refinery processed matte produced at WMC's Kalgoorlie smelter from nickel sulfide concentrates produced from ores mined in Western Australia by WMC and other companies. WMC's mixed sulfide was refined in Norway by Falconbridge Ltd. under a tolling agreement and the resulting cobalt cathode was offered for sale by WMC on its Internet Web site. In 2002, WMC sold approximately 848 t of cobalt, 15% more than the 737 t sold in 2001 (WMC Resources Ltd., 2003a, p. Business Performance-6).

Anaconda Nickel Ltd. produced 1,838 t of cobalt as metal powder and briquettes from its Murrin Murrin nickel-cobalt laterite pressure acid leaching operation east of Leonora in Western Australia, 27% more than the 1,452 t produced in 2001. During the year, the company focused on increasing metal production levels, reducing production variability, debt restructuring, and recapitalization. Production problems during the year were attributed to an unstable power supply, lack of availability of autoclaves, a hydrogen flare header blockage, scale buildup in the hydrogen sulfide precipitation circuit, unplanned refinery maintenance, and relatively high employee turnover. Late in the year, Anaconda Nickel reported that based on a strategic review, it had determined that previous production and cost estimates for the Murrin Murrin project were overly optimistic and unlikely ever to be attained (American Metal Market, 2002; Anaconda Nickel Ltd., 2003a, p. 3-4; 2003b; Cobalt Development Institute, 2003e).

OMG shipped intermediate nickel hydroxide produced from its Cawse plant, northwest of Kalgoorlie in Western Australia, to

¹References that include a section mark (§) are found in the Internet References Cited section.

Finland for refining. Output from the plant, which used pressure acid leaching to treat lateritic ore, was expected to supply approximately 8,000 t/yr of nickel to Harjavalta and 800 t/yr of cobalt to Kokkola (OM Group, Inc., 2001; Reuters Ltd., 2002c).

During the first half of 2002, Preston Resources Ltd. produced 220 t of cobalt in intermediate cobalt sulfide from its Bulong nickel-cobalt laterite pressure acid leaching operation east of Kalgoorlie in Western Australia; no cobalt metal was produced during that period and no production data were available for the second half of the year. As a result of financial restructuring that became effective in late August, 95% of Preston's interest in Bulong was acquired by Barclays Bank Plc. and related entities and noteholders (Preston Resources Ltd., 2002a, p. 2, 6, 49-51; b; c).

In addition to the production discussed above, cobalt-bearing nickel sulfide concentrates produced in Australia were exported to OMG in Finland and Inco Ltd. in Canada to be refined.

Titan Resources NL, West Perth, Western Australia, continued development work on a metallurgical process that used bacterial oxidation to recover base metals from sulfide ores. In addition to studying the feasibility of using the heap-leach process on company ores from the Carr Boyd, Mt. Scholl, and Widgiemooltha deposits in Western Australia, Titan was testing the process on ore samples from Inco, Jinchuan Group Ltd., WMC, and other companies (Titan Resources NL, 2002a, 2003).

Sally Malay Mining Ltd. agreed to sell 100% of the nickel-copper-cobalt concentrates from its nickel sulfide mine in the East Kimberly district of Western Australia to Jinchuan Group Ltd. First shipment of concentrates, which were expected to contain an estimated 7,500 t/yr of nickel, 3,600 t/yr of copper, and 370 t/yr of cobalt, was scheduled for early 2004. As part of the agreement, Jinchuan was considering financing a study on the feasibility of producing a nickel-cobalt intermediate (mixed sulfide or carbonate) from the mine's low-grade flotation concentrates (Sally Malay Mining Ltd., 2002a, p. 6, 15, 17; 2002b).

Compass Resources NL continued to study the feasibility of developing its Browns lead-copper-cobalt-nickel sulfide project in the Northern Territory. In June, Compass announced that it had selected a hydrometallurgical process to treat Browns' ores. The process, which was jointly owned by Engitec Technologies S.p.A. and Compass' strategic partner the Doe Run Corp., used ferric fluoborate to leach lead. Compass was considering a project with average metal production levels of 40,000 t/yr of lead, 4,500 t/yr of copper, 1,200 t/yr of cobalt, and 850 t/yr of nickel. Progress on the project was delayed during the second half of the year while Doe Run underwent financial restructuring (Compass Resources NL, 2002; 2003; Engitec Technologies S.p.A., undated§).

Belgium.—Umicore converted cobalt metal, residues, and other cobalt-bearing materials into a wide range of cobalt specialty products including metal powders, oxides, salts, and compounds. According to the Cobalt Development Institute, Umicore's 2002 cobalt refinery production was 1,135 t, 4% more than the 1,090 t produced in 2001 (Cobalt Development Institute, 2003e). This production occurred in plants in Olen, Belgium; south central China; and Roodepoort, South Africa. In addition, Umicore produced specialty cobalt products at processing plants in Arab, AL, and Laurinburg, NC, in the

United States; in Leduc and Fort Saskatchewan, Alberta, Canada; in Shanghai, China; Subic, Philippines; and Cheonan, the Republic of Korea (Gellens, 2002, p. 7-8; n.v. Umicore, s.a., 2003, p. 10).

Brazil.—Cia. Niquel Tocantins produced 960 t of cobalt cathode at its refinery in Sao Miguel Paulista, Sao Paulo State, 8% more than the 889 t produced in 2001 (Cobalt Development Institute, 2003e). The refinery used lateritic nickel-cobalt ore from Niquelandia, Goias State, as feed. Niquel Tocantins proceeded with its plan to complete an expansion of the refinery's cobalt capacity to 1,100 t/yr during 2004. Cobalt output was forecast to steadily increase as the plant was expanded (Metal Bulletin, 2002g).

Cameroon.—In August, the Government of the Republic of Cameroon granted Geovic Cameroon S.A. the exclusive rights to mine and process lateritic ore from Geovic Cameroon's exploration license in the Eastern Province, and to export cobalt-nickel sulfide intermediates produced from the ore. On the basis of exploration and development drilling and trenching undertaken in the area since 1995, Geovic Cameroon estimated that the resource was more than 225 million metric tons (Mt), grading approximately 0.6% nickel and 0.3% cobalt. During the year, Geovic Cameroon began the first phase of a bankable feasibility study on the project, which was financed in part by the U.S. Trade and Development Agency. The study was to include confirmation of ore reserves, refinement of a proprietary heap-leach metal recovery process, and analyses of the cobalt market. Geovic Cameroon is 60.5% owned by Geovic, Ltd., of Grand Junction, CO, and 39.5% owned by the Government of Cameroon and other stakeholders (Embassy of the United States of America, Office of Public Affairs, Yaounde, Cameroon, 2002; Geovic, Ltd., 2002; Sherborne, 2002, p. 3, 6, 9).

Canada.—Falconbridge Ltd. produced 690 t of cobalt in concentrate from its Sudbury, Ontario, mines and 386 t of cobalt in concentrate from its Raglan Mine in Quebec. Nickel-copper matte produced at the Sudbury smelter was refined at the company's Nikkelverk refinery in Norway. In 2002, this matte contained 1,955 t of cobalt; 54% of the cobalt originated from ores produced at company mines, and 46% from custom feed materials, defined as feeds that did not originate from Falconbridge mines. The custom feed was primarily nickel-copper-cobalt secondary materials (scrap), plus some intermediate feedstocks and smaller amounts of concentrates (Falconbridge Ltd., 2003a, p. 20; 2003b, p. 11-16).

Inco Ltd. produced cobalt cathode at its Port Colborne, Ontario, refinery, and cobalt oxide at its Thompson, Manitoba, refinery. Approximately 63% of the cobalt produced was from nickel sulfide ores from company mines in Sudbury, Ontario; 24% was from nickel sulfide ores from company mines in Thompson, Manitoba; and 13% was from purchased feedstocks, including nickel sulfide concentrates from the Jubilee Mines NL's Cosmos nickel project and Lionore Mining International Ltd.'s Emily Ann Mine in Western Australia. In 2002, Inco produced 1,480 t of refined cobalt, a slight increase from the 1,450 t produced in 2001. Approximately 80% of this production was cathode and 20% was oxide (Jubilee Mines NL, 2002, p. 41; Cobalt Development Institute, 2003e; Inco Ltd., 2003, p. 17, 19-21; Lionore Mining International Ltd., 2003, p. 17-21).

During the year, Inco reached agreements with the Government of Newfoundland and Labrador, the Labrador Inuit Association, and the Innu Nation that enabled it to proceed with the commercial development of the Voisey's Bay nickel-copper-cobalt-sulfide deposits in northeastern Labrador. Inco's agreement with the Provincial Government included the development of a mine and concentrator at Voisey's Bay, a research and development program focusing on hydrometallurgical processing technologies, an industrial and employment benefits program, a timetable for the start and completion of principal stages of the project, and other items related to the overall development of the project. Inco began infrastructure and site development work for the first phase of the project in July. This stage included construction of the mine and concentrator at Voisey's Bay and construction of a demonstration plant in Argentia, Newfoundland, to test hydrometallurgical processing technologies on Voisey's Bay concentrates. Once the demonstration plant was operational, Inco would be allowed to ship Voisey's Bay concentrates to its Ontario and Manitoba operations for refining, which would generate early cash flow for the project. The company expected initial concentrate production to begin in 2006.

In the second stage of the project, Inco was to build and begin operating a commercial processing facility in the Province by the end of 2011. Once the commercial facility was operational, it would treat all of the concentrates from Voisey's Bay and produce finished nickel and cobalt products by using hydrometallurgical processing technologies, or if hydrometallurgical processing did not prove to be technically or economically feasible, by using conventional technologies. In return for permission to process Voisey's Bay concentrates in Ontario and Manitoba during the first phase of the project, Inco was required to bring in and process intermediate products at the Voisey's Bay commercial facility, which originated outside of the Province of Newfoundland and Labrador and contained total quantities of nickel and cobalt equal to those of the concentrates shipped from Voisey's Bay to Ontario and Manitoba. The hydrometallurgical plant was expected to produce approximately 50,000 t/yr of nickel, 2,300 t/yr of cobalt, as much as 7,000 t/yr of copper intermediates, and 32,000 t/yr of copper concentrates. The third phase of the project was to be the development of underground deposits at Voisey's Bay to extend the life of the project (Inco Ltd., 2003, p. 2, 34-38).

The Sherritt International Corp.-General Nickel Co. S.A. joint venture's refinery in Fort Saskatchewan, Alberta, produced 3,065 t of cobalt in 2002, which was a 4% increase from the 2,943 t of cobalt in 2001 and record-breaking production for the seventh consecutive year. The increase in production in 2002 was attributed to a reduction in process variability and a higher concentration of metals within the refinery (Sherritt International Corp., 2003b, p. 7-8). Most of the feed was in the form of nickel-cobalt mixed sulfides from the joint venture's operations at Moa Bay, Cuba. As a result of a U.S. embargo on imports of products originating from Cuba, nickel and cobalt produced by Sherritt cannot be sold to U.S. customers.

In late March, Canmine Resources Corp. began the initial processing of cobalt-nickel feedstock at its newly modified hydrometallurgical refinery in Cobalt, Ontario. By August, the refinery had been successfully commissioned and the first batch

of good quality product had been produced. Shortly thereafter, Canmine placed the refinery on care-and-maintenance status, while it worked on restructuring its financial obligations to acquire adequate working capital for continuing operations (Canmine Resources Corp., 2002a, b).

China.—According to the Cobalt Development Institute, 1,842 t of refined cobalt was produced in China from domestic and imported raw materials, a 25% increase from the 1,470 t estimated for 2001 (Cobalt Development Institute, 2003e). This cobalt would have been in the form of metal, metal powders, and compounds. The number of Chinese cobalt refiners and processors was reported to be approximately 50. The largest refiners were Jinchuan Group Ltd. (formerly called Jinchuan Non-Ferrous Metals Corp.) and Ganzhou Cobalt & Tungsten Co., Ltd. (Aidong, 2002).

Most of Jinchuan's production of cobalt cathode and other cobalt products was from domestic nickel-copper-cobalt sulfide ores mined and refined at Jinchuan, Gansu Province. Jinchuan has been steadily increasing its refinery capacity for nickel, copper, cobalt, and platinum-group metals. Cobalt refinery capacity was expected to reach 2,000 t/yr by 2005. Production is limited, however, by the amount of ore that can be produced from Jinchuan's mines. As a result, Jinchuan has been investigating new sources of feed materials. In late 2001, Jinchuan reportedly signed an agreement with Empresa Cubana Exportadora de Minerales y Metales (also known as Cubaniquel) to purchase 300 t/yr of cobalt "concentrate" from Cuba. In 2002, Jinchuan signed a life-of-mine concentrate offtake agreement with Sally Malay Mining Ltd. in Western Australia, signed an agreement with WMC to purchase nickel matte from the Kalgoorlie Smelter beginning in 2005, and began discussions with Heron Resources Ltd. regarding its North Kalgoorlie nickel laterite project in Western Australia. Jinchuan also negotiated with Titan Resources on the formation of a joint venture for the commercial use of Titan's BioHeap bacterial heap-leaching technology on Jinchuan's ores. As proposed, the joint venture would begin by mining ores, and then construct and operate a trial heap-leaching operation (China Metal Market, 2001a, p. 13-14; 2001b, p. 12-13; Song, 2001, p. 3-16; Sally Malay Mining Ltd., 2002b; Titan Resources NL, 2002b, 2003; Heron Resources Ltd., 2003; WMC Resources Ltd., 2003b, p. 38).

Ganzhou, which produced cobalt metal powders and compounds at Ganzhou, Jiangxi Province, and several of the smaller refiners, also planned to expand their cobalt refining capacities in the near term. To lessen their dependence on imported raw materials, an increasing number of these smaller refiners worked on developing local cobalt resources (Song, 2001, p. 3-16; Aidong, 2002).

Hainan Iron & Steel Co. produced cobalt and copper concentrates as byproducts of iron ore mined on Hainan Island. In 2002, Hainan reportedly secured financial backing from the Provincial Government for the construction of a copper-cobalt refinery. The refinery would be built in Changjiang County on Hainan Island and would have the capacity to produce 330 t/yr of cobalt metal and 1,000 t/yr of copper cathode (Metal Bulletin, 2002c; Hainan Steel Co., undated\$).

In May, Umicore announced that it had commissioned a cobalt refinery in south central China during 2001. The refinery

had the capacity to produce 2,000 t/yr of cobalt from low-grade primary and secondary materials. Some of the cobalt from the new refinery would be processed into cobalt metal powders at Umicore's metal powder plant in Shanghai. Umicore also planned to produce cobalt compounds for sale in China and for export to other markets (Gellens, 2002, p. 7-8).

Congo (Kinshasa).—Kababankola Mining Co. S.P.R.L. (KMC) mined copper-cobalt ores from open pit operations in La Générale des Carrières et des Mines' (Gécamines) Central Group and processed the ores at the nearby Kakanda concentrator, which it operated under lease from Gécamines. During part of the year, ores and concentrates from KMC's mining operations were toll-treated at Gécamines' Shituru refinery in Likasi. Late in the year, KMC reportedly was considering other options for refining its concentrates, because of problems at the Shituru refinery. KMC was a joint venture between Tremalt Ltd., a private company based in the British Virgin Islands (80%), and Gécamines (20%) (Metal Bulletin, 2002d; Kababankola Mining Co. S.P.R.L., undated a§, b§).

Gécamines and L'Enterprise Générale Malta Forrest S.P.R.L. produced copper-cobalt concentrates from the Luiswishi Mine, which were exported under a long-term supply contract to OMG's Kokkola refinery in Finland. In November, Forrest announced that the mine would close for an indefinite period of time to perform a complete refurbishment and to make improvements to the flotation plant, which had been in continuous operation for 5 years. The Luiswishi Mine was estimated to have a production capacity of approximately 4,500 t/yr of cobalt in concentrates (Reuters Ltd., 2002f; OM Group, Inc., 2003, p. 42).

During January through mid-March, the Big Hill smelter at Lubumbashi was shut down for scheduled maintenance and improvements to its cooling system. In May, the smelter ran at an improved production rate equivalent to 70% to 80% of its design capacity of 5,000 t/yr of contained cobalt. Big Hill, which was operated by Le Société pour le Traitement de la Terril de Lubumbashi (a joint venture between Gécamines, OMG, and S.A. Groupe George Forrest), processed stockpiled slag to produce a cobalt-copper alloy, which was shipped to OMG's Kokkola refinery (Metal Bulletin, 2002b).

Preminco Ltd. of London, United Kingdom, built a hydrometallurgical plant in Lubumbashi for refining rich copper-cobalt ores. The Chemaf S.P.R.L. plant had the capacity to produce 600 t/yr of cobalt as carbonate and 1,200 t/yr of copper as carbonate by direct leaching of the ores with sulfuric acid, followed by carbonation with soda ash (Cobalt Development Institute, 2002b; Chemaf S.P.R.L., undated§).

America Mineral Fields Inc. (AMF) acquired full ownership of Congo Mineral Developments Ltd. (CMD), a company it established in 1998 with Anglo American Corp. of South Africa Ltd. to develop the Kolwezi project. The Kolwezi project was to be a 60-40 joint venture between CMD and Gécamines to recover cobalt and copper from the Kingamyambo Musonoi tailings stockpiled near Kolwezi. CMD completed much of the work for the feasibility study, including establishing the resource and process flowsheet for the project, and in 2002, the company began the first stage of the environmental and social impact assessment. During the year, the Government of Congo (Kinshasa) established a new mining code. AMF received acknowledgement from the Government of its and Gécamines'

exploitation rights for the project, but expected that it would need to renegotiate the financial terms with Gécamines in 2003 (America Mineral Fields Inc., 2003, p. 3, 12-13).

Tenke Mining Corp. held discussions with the Government of Congo (Kinshasa) and Gécamines on developing the copper-cobalt deposits at Tenke and Fungurume on a smaller scale than the 100,000 t/yr of copper and 8,000 t/yr of cobalt originally planned in the base case study of the deposits. In August, Phelps Dodge Corp. replaced BHP Billiton in its option to acquire a controlling interest in and to act as the primary operator of the project. Although Tenke Mining was optimistic about progress towards sustainable peace and government stability in Congo (Kinshasa), the project remained under force majeure during the year (Tenke Mining Corp., 2002).

Gold City Industries Ltd. of Vancouver, British Columbia, Canada, announced that it had decided not to continue funding the Costamin International Joint Venture, which was set up to bring the Congo Stars copper-cobalt mine near Lubumbashi back into production (Gold City Industries Ltd., 2002).

Melkior Resources Inc. decided to end its involvement in exploration projects in Congo (Kinshasa). Melkior held a 60% interest in Société Minière de Kabolela et de Kipese, which was a joint venture created with Gécamines to mine the Kabolela copper-cobalt and Kipese cobalt-gold-platinum deposits near the city of Likasi (Melkior Resources Inc., 2001, 2002).

Kumba Resources Ltd. had an agreement with Gécamines and held a presidential decree to rehabilitate and manage the Kamoto Mine. The mine, which is a large underground copper-cobalt mine, has had only limited production since it suffered a major collapse in 1990. Kumba completed a feasibility study on rehabilitating the mine, but planned to wait for sustained political and economic stability before seeking financing and starting work on the project (Kumba Resources Ltd., 2002a, p. 35; 2002b; undated§).

Undeveloped projects for which Gécamines reportedly was seeking partners included the Kamwale deposit north of Kolwezi, which would produce concentrates that might yield up to 3,000 t of cobalt during 3 years of production and the Tilwezembe project, which would produce a cobalt alloy intermediate (Metal Bulletin, 2002e).

Cuba.—Moa Nickel S.A., which was part of the joint venture between Sherritt (50%) and General Nickel Co., S.A. (50%), mined nickel-cobalt laterites at Moa Bay in Holguín Province and produced mixed sulfides containing 33,382 t of nickel and cobalt, a 3% increase from the 32,360 t produced in 2001. This record production was attributed to higher ore grades, continued debottlenecking initiatives, and capital investments targeted at maintaining plant reliability (Sherritt International Corp., 2003b, p. 7-8). The mixed sulfides produced at Moa were sent to the joint venture's refinery in Fort Saskatchewan, Alberta, Canada.

Unión del Níquel S.A. also mined and refined nickel-cobalt laterites in Holguín Province. Nickel-cobalt mixed sulfides produced at the Ernesto Che Guevara Mining and Metallurgical Combine at Punta Gorda were exported to Canada and China (McCutcheon, 2002, p. 38.32). Nickel and cobalt of Cuban origin cannot be imported into the United States because of a U.S. embargo on imports from Cuba.

QNI performed geological and initial metallurgical studies for the San Felipe project in the Camaguey Province. The San Felipe project was being investigated as a joint venture with

Unión Geológica Minera S.A., also known as Geominera (BHP Billiton Ltd., 2002, p. 59).

Finland.—OMG produced 8,200 t of cobalt in cobalt metal powders, briquettes, oxides, and compounds, slightly more than the 8,100 t produced in 2001 (Cobalt Development Institute, 2003e). The company's Kokkola Chemicals Oy refinery processed cobalt-bearing materials from Australia, the Big Hill smelter and Luiswishi Mine in Congo (Kinshasa), and elsewhere. During the fourth quarter, OMG announced that it would reduce its production by 20%. The decision was driven in part by the closure of the Luiswishi Mine (as discussed in the Congo (Kinshasa) section of this report) and in part by OMG's decision to liquidate cobalt inventories to generate cash as part of a restructuring program. OMG reportedly held 6,800 t of cobalt in inventories in October, which it drew down to 5,700 t by yearend (OM Group, Inc., 2002, p. 2, 4; 2003, p. 3; Ryan's Notes, 2003).

France.—The Eramet Group produced cobalt chloride at its refinery at Sandouville, near Le Havre. Feed for the refinery was nickel matte imported from Eramet subsidiary Le Nickel-SLN's Doniambo smelter in New Caledonia.

India.—According to the Cobalt Development Institute, 270 t of cobalt was produced in India in 2002, 8% more than the 250 t produced in 2001. Three companies refined cobalt from imported raw materials. Nicomet Industries Ltd. produced cobalt cathode and various compounds at its plant in Cuncolim, Goa State; Rubamin Ltd. produced cobalt cathode and various compounds at its plant in Vadodara, Gujarat State; and Conic Metals Ltd. produced cobalt sulfate and carbonate at its plant in Mumbai, Maharashtra State. In addition to this refinery production, cobalt metal powder was recovered from cemented carbide scrap by Sandvik Asia Ltd. at a pilot plant in Pune, Maharashtra State, and spent catalysts from plants producing dimethyl terephthalate, terephthalic acid, and OXO alcohols were reprocessed by more than a dozen small cobalt chemical processors (Cobalt Development Institute, 2001; 2003e).

Indonesia.—State-owned P.T. Aneka Tambang (Antam) exported lateritic nickel-cobalt ore to QNI's Yabulu refinery in Queensland, Australia. Several companies, including QNI, worked on projects to explore and develop Indonesia's nickel-cobalt laterite resources.

Weda Bay Minerals Inc. studied various options for processing ore from nickel-cobalt laterite deposits on Halmahera Island, east Indonesia. The company was considering an integrated plant, which would use pressure acid leaching in conjunction with atmospheric leaching and saprolite neutralization, to produce up to 40,000 t/yr of nickel and 3,000 t/yr of cobalt as a mixed sulfide intermediate product. OMG was a major shareholder in Weda Bay Minerals and provided funding for the engineering and feasibility studies. In November, as a part of its restructuring program, OMG informed Weda Bay Minerals that it would no longer provide funding to the Halmahera project. Weda Bay Minerals planned to bring in additional joint-venture partners to develop the project. The Jinchuan Group was interested in obtaining the mixed sulfide for feed for its refinery in China. Jinchuan and Weda Bay Minerals discussed ways that Jinchuan could participate in the development of the project (OM Group, Inc., 2003, p. 42; Weda Bay Minerals Inc., 2003, p. 1-7).

The Gag Island nickel-cobalt laterite project was placed on care-and-maintenance status, while Antam sought a new joint-venture partner for the project. Falconbridge withdrew from the project in late 2001 after extensive deliberations with the Government did not resolve an issue related to open pit mining in areas designated as protected forest. In early 2002, BHP Billiton announced that it had suspended work on the project (BHP Billiton Ltd., 2002, p. 59; Falconbridge Ltd., 2002b, p. 3; Cobalt Development Institute, 2003a; PT Antam Tbk, 2003).

Japan.—Sumitomo Metal Mining Co., Ltd., produced electrolytic cobalt, cobalt oxide, and cobalt compounds as a byproduct of nickel at its Niihama nickel refinery in Ehime Prefecture. In July, a consortium led by Sumitomo reached an agreement in principle to acquire a 25% interest in Inco's Goro nickel-cobalt laterite project in New Caledonia. Sumitomo was also the largest shareholder in Coral Bay Nickel Corp., which was a joint venture formed to build a plant in the Philippines that would use pressure acid leaching technology to process lateritic ores (also discussed under the Philippines section below). The mixed sulfide produced at the new plant, containing approximately 10,000 t/yr of nickel and 700 t/yr of cobalt, would be refined at Niihama. Sumitomo planned to increase the capacity of the Niihama plant by March 2004 to approximately 45,000 t/yr of nickel and 1,100 t/yr of cobalt to accommodate the output from Coral Bay Nickel (Metal Bulletin, 2002f; Reuters Ltd., 2002b).

Morocco.—Cie. de Tifnout Tiranimine (CTT) mined cobalt arsenic deposits at Bou Azzer and produced concentrates. CTT refined the concentrates and tailings generated by past mining at Bou Azzer to produce cobalt cathode. In December, CTT began operating a pilot-scale unit to investigate the production of cobalt chemicals, such as oxides (Cie. de Tifnout Tiranimine, 2001; Groupe ONA, 2002, p. 37; 2003, p. 46).

New Caledonia.—Lateritic nickel-cobalt ore was exported to QNI's Yabulu refinery for processing. Nickel matte from Le Nickel-SLN's Doniambo smelter was sent to Eramet's refinery in Sandouville, France, where it was refined into nickel cathode and chloride and byproduct cobalt chloride.

Inco proceeded with the commercial development of its Goro nickel-cobalt laterite project in southern New Caledonia. The project consisted of an integrated mining and pressure acid leaching-solvent extraction processing facility with a planned capacity of approximately 55,000 t/yr of nickel as oxide and 4,500 t/yr of cobalt as carbonate. In September, temporary labor disruptions resulted in a decision by Inco to curtail certain onsite activities while procedures were developed to avoid future disruptions. During this period, Inco began an update of several key aspects of the project. By yearend, the company decided that a more comprehensive review of the project was necessary to evaluate information that suggested a possible 30% to 45% increase in Goro's capital cost estimate. The review was to include a determination of changes that could be made to the project to maintain its economic feasibility. During the year, Inco reached an agreement with Bureau de Recherches Géologiques et Minières (BRGM), a French Government agency, to acquire BRGM's 15% interest in the Goro project. Further negotiations on this matter were suspended pending completion of the project's review (Inco Ltd., 2003, p. 1, 31-33).

Argosy Minerals Inc. decided to end its involvement in the Nakety-Bogota nickel-cobalt laterite project on the east coast

of New Caledonia after receiving notice that Russia's Norilsk Nickel planned to withdraw from the project (Argosy Minerals Inc., 2002).

Norway.—Falconbridge produced 3,994 t of cobalt at its Nikkelverk refinery, a 21% increase from the 3,314 t produced in 2001. Record production levels during the fourth quarter confirmed the refinery's capacity levels of 85,000 t/yr of nickel, 38,000 t/yr of copper, and 4,500 t/yr of cobalt. During 2002, 24% of the cobalt produced at Nikkelverk originated from Falconbridge's mines in Canada and 76% originated from custom feeds, defined as feeds that did not originate at Falconbridge's mines. The custom feeds included matte from BCL Ltd. in Botswana, scrap, and intermediate materials (Falconbridge Ltd., 2003a, p. 19-20; 2003b, p. 15-16).

Papua New Guinea.—The Ramu nickel-cobalt laterite project was placed on care-and-maintenance status. Highlands Pacific Ltd. suspended its efforts to bring an additional equity partner into the project while it resolved a legal dispute with joint-venture partner Orogen Minerals Ltd. (Highlands Pacific Ltd., 2002a, p. 8; 2002b, p. 4). On the basis of a feasibility study completed in 1998, the project was to use pressure acid leaching technology to produce 33,000 t/yr of nickel metal and 3,200 t/yr of cobalt as cobalt sulfate.

Philippines.—Lateritic nickel-cobalt ore from the Philippines was exported to QNI's Yabulu refinery for processing.

Sumitomo announced that it had established a joint-venture company (Coral Bay Nickel Corp.) to construct and manage a plant that would use pressure acid leaching technology to process low-grade lateritic ores stockpiled at the Rio Tuba nickel mine on Palawan Island. The plant, which would be built adjacent to the mine, would produce a mixed nickel-cobalt sulfide intermediate product, which would be refined at Sumitomo's Niihama Nickel Refinery in Japan. Enough stockpiled ore was available to produce mixed sulfide containing 10,000 t/yr of nickel and 700 t/yr of cobalt for approximately 20 years. In July, the Philippine government granted an environmental compliance certificate for the project and in November, Coral Bay Nickel began construction. Initial production of mixed sulfide was scheduled to begin during the summer of 2004. Sumitomo's partners in the joint venture were Rio Tuba Nickel Mining Corp., Nissho Iwai Corp., and Mitsui & Co., Ltd. (Platts Metals Week, 2002b; Reuters Ltd., 2002d).

Russia.—Nickel and cobalt production in Russia involved a complex flow of ores, flotation concentrates, precipitates, and mattes between various production sites. The main feed materials were domestic nickel-copper sulfide and nickel-cobalt laterite ores and imported nickel- and cobalt-bearing secondary materials. Russia had the capacity to produce refined cobalt at four locations—Norilsk Nickel's refineries at Monchegorsk on the Kola Peninsula and Norilsk in Siberia, the Ufaleynickel Joint Stock Co. refinery at Verkhniy Ufaley in the Ural Mountains, and the Yuzhuralnickel Joint Stock Co. refinery at Orsk, also in the Ural Mountains (Roskill Information Services Ltd., 1995, p. 11-15).

Russian cobalt production was 1.6% higher than that of 2001 (Interfax International Ltd., 2003). Norilsk Nickel remained the largest cobalt producer in Russia. In 2002, the company received permission from the Russian Government to disclose information on its cobalt and nickel production for the first time

since 1996. Norilsk Nickel's cobalt production during the past 3 years was as follows: 4,200 t in 2002, 4,600 t in 2001, and 4,100 t in 2000. In 2002, 4,100 t of Norilsk Nickel's production was exported (Reuters Ltd., 2002g; OJSC MMC Norilsk Nickel, 2003b).

South Africa.—Cobalt was produced as a byproduct from six platinum-group metal mines and one nickel mine (Harding, 2002). Two South African companies produced refined cobalt as a byproduct of domestic platinum mining and refining. Rustenburg Base Metal Refiners Pty. Ltd. (a subsidiary of Anglo American plc) produced cobalt sulfate at its refinery near Rustenburg, Northwest Province, and Impala Platinum Ltd. produced cobalt metal powder at its base-metals refinery near Springs, Gauteng Province.

The Nkomati nickel sulfide mine in Mpumalanga Province was a joint venture between Anglovaal Mining Ltd. (Avmin) and Anglo American plc. In recent years, sales of cobalt in nickel concentrates produced from Nkomati have been approximately 50 t/yr. In 2002, Avmin completed a feasibility study on expanding production from the mine. The study included combined open pit and underground mining and the construction of a new concentrator and a processing plant, which would use the "Activox" low-pressure leach process. Production rates following expansion were estimated at 16,000 t/yr of refined nickel, 9,000 t/yr of refined copper, 900 t/yr of cobalt oxides, and 80,000 ounces of platinum group metals for toll refining (Anglovaal Mining Ltd., 2002, undated§).

Umicore South Africa Pty. (a subsidiary of Umicore) produced cobalt compounds from low-grade cobalt-containing residues in Roodepoort, near Johannesburg.

Uganda.—Early in the year, Newmont Mining Corp., of Denver, CO, acquired control of Normandy Mining Ltd., the parent company of Banff Resources Ltd. In August, Newmont sold its interest in Banff to MFC Bancorp Ltd., an international merchant banking company with offices in Vienna and Berlin. Banff's sole operation was the Kasese cobalt refinery in southwestern Uganda. Soon after acquiring Kasese, MFC Bancorp decided to suspend production and place the plant on care-and-maintenance status until cobalt prices improved. Late in the year, it was reported that Kasese would not resume production unless the price of cobalt increased to \$10 to \$11 per pound. From January through August 2002, Kasese produced an estimated 450 t of cobalt cathode as compared with 634 t produced during the full year of 2001 (Banff Resources Ltd., 2002; Newmont Mining Corp., 2002; Reuters Ltd., 2002e; Cobalt Development Institute, 2003e).

Zambia.—Mopani Copper Mines Plc [owned by Glencore International AG (73%), First Quantum (17%), and Zambia Consolidated Copper Mines Ltd. (ZCCM) (10%)] produced 1,800 t of cobalt metal at its Nkana cobalt refinery, a 4% decrease from the 1,876 t produced in 2001. The refinery processed concentrates from Mopani's Nkana Mine, Metorex Ltd.'s Chibuluma West Mine, and Konkola Copper Mines PLC (KCM) operations (Metal Bulletin, 2002h; Metorex Ltd., 2002, p. 12; Cobalt Development Institute, 2003e).

Chambishi Metals plc (a subsidiary of Avmin) produced 4,344 t of cobalt metal at its Chambishi cobalt refinery, a 56% increase from the 2,789 t produced in 2001. The refinery's main feed materials were metal-bearing solutions from the company's

COSAC smelter and matte leach facility, and concentrates from Mopani's Nkana Mine and KCM operations, which it toll refined. The COSAC plant was built to recover cobalt and copper from slag stockpiled at Nkana. Early in the year, the plant was shut down to reline the furnace; a second shutdown was necessary during July and August to install a redesigned cooling system. Avmin hoped to have the plant running at full production by yearend (Metal Bulletin, 2002a; Platts Metals Week, 2002a; Reuters Ltd., 2002a; Cobalt Development Institute, 2003e).

KCM mined copper ores from the Nchanga open pit and underground mines and the Konkola Mine. Cobalt in concentrates produced by KCM was toll refined at the Chambishi and Nkana refineries. In January, Anglo American plc announced that because of the substantial losses suffered by KCM, the poor outlook for copper and cobalt prices, and the lack of project financing to develop the Konkola Deep project, it could not justify further investment in KCM beyond that committed at the time of acquisition (March 2000). After a long period of negotiation, Anglo American announced that it had reached an agreement with the Government of the Republic of Zambia and other KCM shareholders regarding the restructuring of KCM and the withdrawal of Anglo American, CDC Group plc, and the International Finance Corp. as direct or indirect shareholders of KCM. Following a series of transactions, ownership of KCM was transferred to Zambia Copper Investments Ltd. (58%) and ZCCM Investments Holdings plc (42%). KCM was substantially debt-free and would own and operate the Konkola Mine, the Nchanga underground and open pit mines, the Nampundwe pyrite mine, and the Nkana smelter and copper refinery. By yearend, KCM had begun a review of potential strategic equity partners (Anglo American plc, 2002; Metal Bulletin, 2002h; Zambia Copper Investments Ltd., 2003, p. 1-3).

Roan Antelope Mining Corp.'s assets, which included the Baluba and Luanshya mines, the Muliashi deposit, and approximately 10 Mt of smelter slag, were not sold during the year. The assets have been for sale since Roan Antelope was put under receivership in late 2000. Mining operations ceased in early 2001 as a result of flooding following heavy rains (Platts Metals Week, 2001; Reuters Ltd., 2001).

Approximately 100 t of refined cobalt was produced from copper-cobalt ore from the Chibuluma West Mine. During most of the year, the ore was toll-refined at Mopani's Nkana operations. The Chibuluma operations are 85% owned by Metorex Ltd. and 15% owned by ZCCM (Metorex Ltd., 2002, p. 2, 12; undated§).

Outlook

World production of refined cobalt has steadily increased since 1993 and is expected to continue to increase. Production increases to date were the result of capacity expansions at existing refineries, plus production from new refineries that began operating in the late 1990s. Future production is expected to come from Formation Capital, which planned to begin producing primary cobalt in Idaho in late 2004, and from various new nickel operations, which were being developed to satisfy projected increases in nickel demand during the next

decade. Cobalt from these new nickel operations was not expected to enter the market before 2005 or 2006 (Bending, 2002, p. 2; Cobalt Development Institute, 2003d; Inco Ltd., 2003, p. 18). In addition to production, inventory releases and recycled cobalt will continue to contribute to supply. Offers of NDS cobalt are expected to continue at the rate set each year under the AMP until the amount authorized for disposal has been sold. If the current fiscal year 2003 AMP level of 2,720 t (6 million pounds) is maintained, and the amount of cobalt sold each year is close to the AMP level, then the NDS cobalt sales program would extend into the fiscal year that begins October 1, 2004. Lower annual sales volumes would result in extending the sales program farther into the future.

World demand for cobalt has also increased during the past decade. Until 2001, strong demand for cobalt to make rechargeable batteries and growth in cobalt consumption in Asia resulted in total annual growth rates for cobalt demand that were above the average annual growth rates for the metals industry as a whole (Searle, 2002). Beginning during the second half of 2001, world demand for cobalt weakened because of poor global economic conditions; a worldwide downturn in the cellular telephone market, which impacted the demand for cobalt in rechargeable batteries; reduced demand from the electronics industry, which, like the battery industry, was drawing down excess inventories; and reduced demand from the aerospace and energy-generating industries, which use cobalt-bearing superalloy gas turbine engine parts (Cobalt Development Institute, 2002a, 2003d; Falconbridge Ltd., 2002a, p. 32; Inco Ltd., 2003, p. 18; Searle, 2002). In 2002, world demand for cobalt increased, despite continued weak demand from the superalloys industry (Cobalt Development Institute, 2003d; Falconbridge Ltd., 2003a, p. 30). In the future, industries expected to show significant increases in cobalt demand include superalloys for civil aviation, catalysts for gas-to-liquid production of synthetic liquid fuels, and rechargeable batteries for hybrid electric vehicles (Cobalt Development Institute, 2003d).

From 1995 to 2002, the general trend in cobalt prices was downward, because supply was growing at a faster rate than demand (Inco Ltd., 2003, p. 18). Cobalt prices increased sharply during the first quarter of 2003, and by midyear average prices for cobalt cathode were more than \$10 per pound. The increase in prices was attributed to reduced production and concerns over tightness in global supply (Cobalt Development Institute, 2003b, 2003c; Sherritt International Corp., 2003a, p. 10).

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TABLE 1
 SALIENT COBALT STATISTICS¹

(Metric tons, cobalt content, unless otherwise specified)

	1998	1999	2000	2001	2002
United States:					
Consumption:					
Reported	9,380	8,660	8,980	9,540 ^r	7,930
Apparent	11,500	10,700	11,600	11,800	9,860
Imports for consumption	7,670	8,150	8,770	9,410	8,450
Exports	1,680	1,550	2,630	3,210	2,080
Stocks, December 31:					
Industry ²	751	738	820	852 ^r	917
U.S. Government ³	14,700	13,200	10,200	7,200 ^e	6,680
Price, metal ⁴ dollars per pound	21.43	17.02	15.16	10.55	6.91
World, production:					
Mine	35,300 ^r	31,600 ^r	37,200 ^r	45,800 ^r	47,600
Refinery	31,400 ^r	33,100 ^r	35,000 ^r	38,600 ^r	40,300

^eEstimated. ^rRevised.

¹Data are rounded to no more than three significant digits, except prices.

²Stocks held by cobalt processors and consumers.

³Defense National Stockpile Center. Includes material committed for sale pending shipment.

⁴Annual average U.S. spot price for minimum 99.8% cobalt cathode reported by Platts Metals Week.

TABLE 2
 U.S. GOVERNMENT NATIONAL DEFENSE STOCKPILE
 SALES AND SHIPMENTS¹

(Metric tons, cobalt content)

	2001	2002
Sales:		
Fiscal year ²	2,210	1,210
Calendar year	1,770	1,320
Shipments: ³		
Fiscal year ²	2,930	1,330
Calendar year	3,050 ^e	524

^eEstimated.

¹Data are rounded to no more than three significant digits.

²Twelve-month period ending September 30 of year stated.

³Calculated from yearend inventory levels.

Source: Defense National Stockpile Center.

TABLE 3
U.S. REPORTED CONSUMPTION AND STOCKS OF COBALT^{1,2}

(Metric tons, cobalt content)

	2001	2002
Consumption by end use:		
Steels	624	555
Superalloys	4,850	3,700
Alloys (excludes steels and superalloys):		
Magnetic alloys	472	416
Other alloys ³	661	634
Cemented carbides ⁴	720	617
Chemical and ceramic uses	2,150 ^r	1,950
Miscellaneous and unspecified	63	63
Total	9,540 ^r	7,930
Consumption by form:		
Chemical compounds (organic and inorganic) ⁵	1,510	1,270
Metal	5,240	3,870
Purchased scrap	2,780 ^r	2,800
Total	9,540 ^r	7,930
Stocks, December 31: ⁶		
Chemical compounds (organic and inorganic) ⁵	242	242
Metal	427	486
Purchased scrap	182 ^r	189
Total	852 ^r	917

^rRevised.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Includes estimates.

³Includes nonferrous alloys, welding materials, and wear-resistant alloys.

⁴Includes diamond tool matrices, cemented and sintered carbides, and cast carbide dies or parts.

⁵Includes oxides.

⁶Stocks held by cobalt processors and consumers.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY FORM¹

(Metric tons unless otherwise specified)

	2001	2002
Metal:²		
Gross weight	7,910	6,800
Cobalt content ³	7,910	6,800
Value thousands	\$183,000	\$114,000
Oxides and hydroxides:		
Gross weight	1,280	1,300
Cobalt content ³	921	936
Value thousands	\$25,700	\$20,000
Other forms:		
Acetates:		
Gross weight	398	349
Cobalt content ³	95	84
Value thousands	\$2,410	\$1,790
Carbonates:		
Gross weight	49	131
Cobalt content ³	23	60
Value thousands	\$649	\$1,120
Chlorides:		
Gross weight	53	86
Cobalt content ³	13	22
Value thousands	\$419	\$799
Sulfates:		
Gross weight	1,650	2,020
Cobalt content ³	445	545
Value thousands	\$7,500	\$6,780
Total:		
Gross weight	11,300	10,700
Cobalt content ³	9,410	8,450
Value thousands	\$219,000	\$144,000

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Unwrought cobalt, excluding alloys and waste and scrap.

³Estimated from gross weights.

Source: U.S. Census Bureau, minor adjustments by the U.S. Geological Survey.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY COUNTRY¹

Country of origin	Metal ²			Oxides and hydroxides			Other forms ³			Total		
	Gross weight (metric tons)	Cobalt content ⁴ (metric tons)	Value (thou- sands)	Gross weight (metric tons)	Cobalt content ⁴ (metric tons)	Value (thou- sands)	Gross weight (metric tons)	Cobalt content ⁴ (metric tons)	Value (thou- sands)	Gross weight (metric tons)	Cobalt content ⁴ (metric tons)	Value (thou- sands)
2001:												
Australia	168	168	\$3,240	--	--	--	--	--	--	168	168	\$3,240
Belgium	256	256	7,870	406	292	\$9,480	9	3	\$79	671	551	17,400
Brazil	286	286	6,270	--	--	--	(⁵)	(⁵)	5	286	286	6,270
Canada	818	818	21,900	--	--	--	--	--	--	818	818	21,900
China	62	62	981	1	1	24	17	4	125	80	67	1,130
Congo (Kinshasa)	682	682	13,500	--	--	--	--	--	--	682	682	13,500
Finland	1,040	1,040	27,200	721	519	12,200	1,940	523	9,490	3,700	2,080	48,900
France	8	8	484	45	32	1,800	--	--	--	52	40	2,290
Germany	30	30	1,200	9	6	226	--	--	--	39	36	1,430
Japan	34	34	1,130	1	1	77	8	2	102	43	36	1,310
Morocco	210	210	4,570	--	--	--	1	(⁵)	6	211	210	4,580
Norway	1,440	1,440	29,700	--	--	--	--	--	--	1,440	1,440	29,700
Philippines	--	--	--	--	--	--	10	4	106	10	4	106
Russia	1,610	1,610	38,500	--	--	--	--	--	--	1,610	1,610	38,500
South Africa	661	661	13,300	--	--	--	--	--	--	661	661	13,300
Uganda	60	60	1,370	--	--	--	--	--	--	60	60	1,370
United Kingdom	45	45	687	88	64	1,930	139	34	911	272	142	3,520
Zambia	497	497	10,500	--	--	--	--	--	--	497	497	10,500
Other	5	5	168	9	6	31	25 ^r	6 ^r	162 ^r	39 ^r	18 ^r	360 ^r
Total	7,910	7,910	183,000	1,280	921	25,700	2,150	577	11,000	11,300	9,410	219,000
2002:												
Australia	177	177	2,490	--	--	--	--	--	--	177	177	2,490
Belgium	437	437	9,090	528	380	8,550	8	2	52	973	819	17,700
Brazil	289	289	4,480	--	--	--	6	3	70	295	292	4,550
Canada	888	888	15,700	--	--	--	--	--	--	888	888	15,700
China	41	41	990	1	(⁵)	18	6	2	36	47	43	1,040
Congo (Kinshasa)	271	271	3,570	--	--	--	(⁵)	(⁵)	4	271	271	3,570
Finland	1,000	1,000	18,900	560	403	6,740	2,190	594	7,900	3,750	2,000	33,500
France	31	31	1,620	46	33	1,700	--	--	--	77	64	3,320
Germany	27	27	683	12	9	224	54	18	271	93	54	1,180
Japan	93	93	2,380	(⁵)	(⁵)	33	57	14	623	150	107	3,040
Morocco	57	57	842	--	--	--	--	--	--	57	57	842
Norway	1,710	1,710	25,800	--	--	--	--	--	--	1,710	1,710	25,800
Philippines	--	--	--	--	--	--	85	34	601	85	34	601
Russia	1,040	1,040	16,600	--	--	--	--	--	--	1,040	1,040	16,600
South Africa	231	231	3,070	52	37	527	--	--	--	283	269	3,600
Uganda	44	44	650	--	--	--	--	--	--	44	44	650
United Kingdom	45	45	365	101	73	2,170	180	44	927	326	162	3,460
Zambia	316	316	4,680	--	--	--	--	--	--	316	316	4,680
Other	102	102	1,880	(⁵)	(⁵)	8	--	--	--	102	102	1,880
Total	6,800	6,800	114,000	1,300	936	20,000	2,580	710	10,500	10,700	8,450	144,000

^rRevised. -- Zero.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Unwrought cobalt, excluding alloys and waste and scrap.

³Includes cobalt acetates, cobalt carbonates, cobalt chlorides, and cobalt sulfates.

⁴Estimated from gross weights.

⁵Less than 1/2 unit.

Source: U.S. Census Bureau, minor adjustments by the U.S. Geological Survey.

TABLE 6
U.S. EXPORTS OF COBALT IN 2002, BY COUNTRY^{1,2}

Country of destination	Metal ³		Oxides and hydroxides		Acetates		Chlorides		Total	
	Gross weight (metric tons)	Value ⁴ (thousands)	Gross weight (metric tons)	Value ⁴ (thousands)	Gross weight (metric tons)	Value ⁴ (thousands)	Gross weight (metric tons)	Value ⁴ (thousands)	Cobalt content ⁵ (metric tons)	Value ⁴ (thousands)
Argentina	22	\$480	18	\$198	--	--	--	--	35	\$679
Belgium	628	15,000	--	--	48	\$196	--	--	639	15,200
Brazil	12	315	9	138	10	53	--	--	21	506
Canada	126	2,440	9	254	13	94	18	\$191	140	2,980
China	47	898	65	914	--	--	--	--	94	1,810
Colombia	10	156	7	100	4	21	--	--	16	277
France	55	786	--	--	--	--	--	--	55	786
Germany	75	2,390	⁽⁶⁾	17	--	--	--	--	76	2,410
Hong Kong	15	375	32	607	--	--	--	--	38	982
Ireland	226	3,420	--	--	--	--	--	--	226	3,420
Japan	82	2,280	98	1,340	⁽⁶⁾	6	--	--	152	3,620
Mexico	18	576	2	103	135	542	4	66	53	1,290
Netherlands	140	1,230	229	2,220	5	37	--	--	307	3,490
Spain	1	76	--	--	79	168	--	--	20	243
Sweden	62	806	--	--	--	--	--	--	62	806
Taiwan	2	73	11	170	3	18	--	--	11	262
United Kingdom	60	2,430	28	406	--	--	--	--	80	2,840
Other	20	1,080	50	575	9	37	--	--	59	1,690
Total	1,600	34,800	558	7,040	306	1,170	23	257	2,080	43,200

-- Zero.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²In addition to the materials listed, the United States exports cobalt ores and concentrates and wrought cobalt and cobalt articles.

³Includes unwrought cobalt, powders, waste and scrap, and mattes and other intermediate products of cobalt metallurgy.

⁴Free alongside ship value.

⁵Estimated from gross weights.

⁶Less than 1/2 unit.

Source: U.S. Census Bureau, minor adjustments by the U.S. Geological Survey.

TABLE 7
WORLD ANNUAL COBALT REFINERY CAPACITY, DECEMBER 31, 2002^{1,2}

(Metric tons, cobalt content)

Country	Capacity
Australia ^c	4,350
Belgium	1,200
Brazil	1,000
Canada	5,200
China ^c	4,400
Congo (Kinshasa)	17,600
Finland	10,000
France	300
India	370
Japan	480
Morocco	1,200
Norway	4,500
Russia ^c	8,000
South Africa ^c	1,000
Uganda ^c	650
Zambia	9,000
Total	69,300

^cEstimated.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Refinery products include cobalt metal, metal powder, oxides, and/or salts.

TABLE 8
COBALT: WORLD MINE PRODUCTION, BY COUNTRY^{1,2}

(Metric tons, cobalt content)

Country ³	1998	1999	2000	2001	2002 ^e
Australia ^{e,4}	3,300	4,100	5,600	6,200	6,700
Botswana ⁵	335	331	308	325	269 ⁶
Brazil ^e	400	700	900	1,100	1,200
Canada ⁷	5,861	5,323	5,298	5,326 ^r	5,093 ⁶
China ^e	40	250	90	150	200
Congo (Kinshasa) ^{e,8}	5,000	6,000	10,000 ^r	13,000 ^r	12,500
Cuba ⁹	2,665	2,537	2,943	3,411	3,400
Kazakhstan ^{e,10}	300	300	300	300	300
Morocco ¹¹	287	863	1,305	1,300	1,300
New Caledonia ^{e,12}	1,000	1,100	1,200	1,400	1,400
Russia ^e	3,600 ^r	3,900 ^r	4,000 ^r	4,600 ^r	4,600
South Africa ^e	435	450	580	550	540
Zambia ¹³	11,900	5,640	4,600	8,000	10,000
Zimbabwe ¹⁴	138	121	79	95	87 ⁶
Total	35,300 ^r	31,600 ^r	37,200 ^r	45,800 ^r	47,600

^eEstimated. ^rRevised.

¹World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

²Table includes data available through June 18, 2003. Figures represent recoverable cobalt content of ores, concentrates, or intermediate products from copper, nickel, platinum, or zinc operations. Morocco was the only country where cobalt was mined as a primary product.

³In addition to the countries listed, Bulgaria, Indonesia, Philippines, and Poland are known to produce ores that contain cobalt, but information is inadequate for reliable estimates of output levels. Other copper-, nickel-, platinum-, or zinc-producing nations may also produce ores containing cobalt as a byproduct component, but recovery is small or nil.

⁴Quantities of cobalt contained in intermediate or refined metallurgical products produced from Australian and imported ores. Cobalt content of lateritic nickel ore, nickel concentrate, and zinc concentrate originating in Australia was estimated as follows, in metric tons: 1998--4,000; 1999--7,000; 2000--5,100; 2001--6,100; and 2002--6,400.

⁵Reported cobalt content of pelletized nickel-copper matte.

⁶Reported figure.

⁷Assay content of cobalt in concentrates produced. The cobalt content of all products derived from ores of Canadian origins, including cobalt oxide shipped to the United Kingdom for further processing and nickel-copper matte shipped to Norway for refining, was reported as follows, in metric tons: 1998--2,262; 1999--2,014; 2000--2,022; 2001--2,112 (revised); and 2002--2,027.

⁸Cobalt content of concentrates, tailings, and slags.

⁹Determined from reported nickel-cobalt content of sulfide production.

¹⁰Estimated cobalt content of only those ores from which it is assumed cobalt is recovered. Cobalt content of total ores mined is assumed to be as follows, in metric tons: 1998-2002--1,400.

¹¹Cobalt content of concentrates.

¹²Quantities of cobalt contained in intermediate or refined metallurgical products (cobalt chloride, cobalt oxide-hydroxide, and cobalt sulfide) produced from New Caledonian ores exported to Australia and France. Cobalt content of total ores mined is estimated as follows, in metric tons: 1998--12,500; 1999--11,000; 2000-2002--12,000.

¹³Cobalt content of concentrates and slags. 1998 is fiscal year beginning April 1; 1999-2002 are calendar years.

¹⁴Cobalt content of intermediate products produced in Zimbabwe from ores originating in Botswana and Zimbabwe.

TABLE 9
COBALT: WORLD REFINERY PRODUCTION, BY COUNTRY^{1,2}

(Metric tons, cobalt content)

Country ³	1998	1999	2000	2001	2002
Australia, metal (including metal powder) and oxide hydroxide ^e	1,395 ⁴	1,700	2,610	3,470	3,700
Belgium, metal powder, oxide, hydroxide ⁵	1,200	950	1,110	1,090	1,135
Brazil, metal	364	651	792	889	960
Canada, metal (including metal powder) and oxide	4,415	4,196	4,364	4,378	4,625
China, metal ^e	410	300	410	450	500
Congo (Kinshasa), metal ⁶	4,490	5,180	4,320	4,071	3,000 ^e
Finland, metal powder and salts ⁷	5,250	6,200	7,700	8,100	8,200
France, chloride	172	181	204	199	175
India, metal and salts ^c	120	120	206	250	270
Japan, metal	329	247	311	350	354
Morocco, metal	242	472	967 ^r	1,337 ^r	1,300 ^e
Norway, metal	3,851	4,009	3,433	3,314	3,994
Russia, unspecified ^c	4,000 ^r	4,300 ^r	4,400	5,000	5,100
South Africa, metal powder and sulfate	296	306	397	373 ^r	366
Uganda, metal	--	77	420	634	450 ^e
Zambia, metal ⁸	4,837	4,236	3,342	4,657	6,144
Total	31,400 ^r	33,100 ^r	35,000 ^r	38,600 ^r	40,300

^eEstimated. ^rRevised. -- Zero.

¹World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

²Table includes data available through June 18, 2003. Figures represent cobalt refined from ores, concentrates, or intermediate products and do not include production of downstream products from refined cobalt.

³In addition to the countries listed, Germany and Slovakia may produce cobalt, but information is inadequate to make reliable estimates of production.

⁴Reported figure.

⁵Production reported by n.v. Umicore s.a.; includes production from China and South Africa that is not otherwise included in this table.

⁶Excludes production of cobalt in white alloy, matte, and slag that would require further refining.

⁷Production reported by OM Group, Inc.; may include production from outside Finland that is not otherwise included in this table.

⁸1998 is fiscal year beginning April 1; 1999-2002 are calendar years.