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Cobalt

Cobalt is a silvery grey metal with chemical symbol Co and atomic number 27. It is a technologically important metal; it is magnetic and has a high melting point (1450°C).

Historically cobalt-based superalloys have consumed most of the cobalt produced but over the last 10 years demand has soared on account of its use as a key component in Lithium-ion (Li-ion) rechargeable batteries in consumer electronics such as laptops, tablets and smartphones. This is expected to grow further with increasing consumer demand for Electric Vehicles (EV).

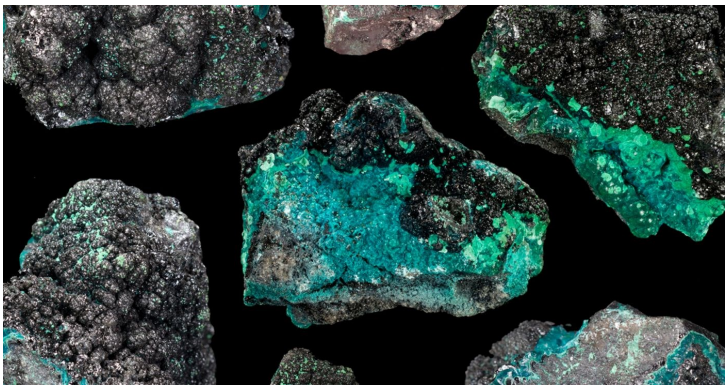
The temperature stability of cobalt in superalloys and the ability to retain its strength and wear resistance at high temperatures makes them suitable in blades for gas turbines and aircraft jet engines. Cobalt alloys are also used for dental prosthetics. Cobalt is also used in cemented carbides for cutting and wear resistant applications such as in diamond tools, in catalysts and blue pigments in ceramic, glasses and glazes. Cobalt is ferromagnetic and is used in industrial applications which require permanent magnets.

Apart from rare occurrences in meteoric iron, pure cobalt in its native form is unknown on Earth. However, the element has medium abundance, primarily within ultramafic rock — rocks characterized by very low silica contents and high iron and magnesium contents — nonetheless cobalt bearing minerals and compounds are numerous and widespread. Small amounts are found in most rocks, soils, plants and animals; it is also a component of vitamin B12 ($C_{63}H_{88}CoN_{12}O_{14}P$). Its ionic radius is like those of Mg2+, Mn4+, Fe2+, Fe3+ and Ni2+; thus, under favourable conditions, cobalt can replace these elements within many minerals.

With few exceptions cobalt is obtained as a by-product of the winning of another metal, mostly copper or nickel, which means supplies have always been largely dependent on nickel or copper production and demand. This has limited the flexibility of the producers to adjust the amount of cobalt production in response to the market of cobalt.

The DR Congo (DRC) is by far the largest producer of cobalt – over 70% of total world production, but the mining of cobalt has been linked to child labour, political controversy, human rights abuses and environmental degradation. Several well-known companies, including miners, suppliers and end users have been named in lawsuits filed by International Rights Advocates. With its supply largely dependent on the DRC, cobalt is classified as a Critical Mineral.

Cobalt compounds impart rich blue colours and their use in glass can be traced back to about 2600BC in Egypt. However, it was only in 1735 that cobalt was isolated as a metal, by the Swedish



Heterogenite (cobalt oxyhydroxide) from the DRC 來自剛果民主共和國的水氧鈷礦石
PHOTO ILLUSTRATION BY 731: PHOTOS: COURTESY THE ARKENSTONE

鈷

鈷是一種銀灰色金屬，化學符號為 Co，原子序數為 27。具有磁性，熔點高（1450°C）。

歷史上鈷基超級合金消耗了大部分的鈷，但是在過去的十年中，由於將其用作筆記本電腦、平板電腦和智能手機等消費電子產品中鋰離子可充電電池的關鍵組件，需求激增。隨著消費者對電動汽車的需求不斷增加，這種情況有望進一步增長。

鈷在高溫合金中的溫度穩定性以及在高溫下保持其強度和耐磨性的能力使其適合用於燃氣輪機和飛機噴氣發動機的葉片。 鈷合金也用於假牙。 鈷亦用於硬質合金中（用於切削和耐磨應用，如金剛石工具）、催化劑和藍色顏料（用於陶瓷、玻璃和釉料中）。 鈷是磁鐵性的，並用於需要永磁體的工業應用中。

除了稀有的隕鐵外，地球上沒有已知以天然形式存在的純鈷。然而該元素具有中等豐度，主要在超鎂鐵質岩中 – 特徵在於二氧化矽含量極低、鐵和鎂含量極高的岩石 – 而且含鈷的礦物和化合物種類繁多且分佈廣泛。在大多數岩石、土壤、植物和動物中發現少量；它也是維生素 B12（$C_{63}H_{88}CoN_{12}O_{14}P$）的成分。其離子半徑類似於 Mg^{2+}、Mn^{4+}、Fe^{2+}、Fe^{3+}和 Ni^{2+}；因此在有利的條件下 鈷可以替代許多礦物中的這些元素。

除少數例外，鈷主要是來自另一種金屬礦（主要是銅或鎳）的副產品，這意味著供應一直主要取決於鎳或銅的生產和需求。這限制了生產者根據鈷市場調整鈷產量的靈活性。

剛果民主共和國是迄今為止最大的鈷生產國 – 佔世界總產量的 70%以上，但鈷的開採與童工、政治爭議、侵犯人權和環境惡化有關。 在國際權利倡導者提起的訴訟中，包括礦工、供應商和最終用戶在內的幾家知名公司等。由於鈷的供應主要依賴於剛果民主共和國，因此鈷被歸類為關鍵礦物。

鈷化合物賦予豐富的藍色，其在玻璃中的使用可追溯到大約 2600BC 的埃及。 但是直到 1735 年，瑞典化學家 George Brandt 才將鈷分離為金屬，到 20 世紀初才被用於冶金應用。 唐朝（618AD-907AD）的釉料和陶瓷含有鈷化合物。

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chemist George Brandt, and then not until the early twentieth century that it was used in metallurgical applications. Glazes and ceramics from the Tang Dynasty (618AD - 907AD) contain cobalt compounds.

Geological Deposition

Cobalt has low crustal abundance, but is concentrated locally by various geological processes to provide potentially workable deposits. These deposits generally contain 0.1% to 0.4% cobalt, equivalent to a tenfold increase in concentration relative to ultramafic rocks (average 110ppm). Principal deposit types include:

* Stratiform sediment-hosted Cu-Co deposits — most of the world's cobalt derives from such deposits, hosted in tabular bodies within shales and sandstones. The most commercially important deposits are located in the copper belt of the DRC and Zambia. Since the 1970s these deposits have contributed between 25% and 50% of annual world mine production. The cobalt content varies between 0.17% to 0.25% and the principal ore minerals are carrollite ($Cu(Co,Ni)_2S_4$) and linnaeite (Co_3S_4).
* Ni-Co laterite deposits — laterites are red soil which develop in humid tropical climates due to deep tropical weathering of the bedrock where certain elements are removed and others enriched by the supergene process. Such laterites may be up to 20m thick and typically contain 0.10% to 0.15% cobalt. The Kalgoorlie and the Murrin Murrin deposits in Western Australia and the Goro deposit in New Caledonia are examples of Ni-Co laterites.
* Magmatic Ni-Cu(-Co-PGE) sulfide deposits — are concentrations of nickel, copper and minor cobalt sulphides produced by high temperature magmatic processes in certain mafic or ultramafic intrusions or volcanic flows. Examples of this deposit are found in Voisey's Bay in Newfoundland and Labrador, Canada, Sudbury district in Ontario, Canada, and the Norilsk-Talnakh district in Siberia, Russia.
* Hydrothermal and volcanogenic deposits — it is also known that there are substantial cobalt resources on the sea floor deposited from metal rich fluids discharging from vents at plate boundaries. However, there are technological barriers to economically extract them from as deep as 6,000m.

Mining and Processing

Most mines extracting cobalt use conventional open pit mining as the predominant mining method. This is because high grades of ore are found close to the surface. Underground methods are only used for magmatic ore deposits but supply from these is minimal in terms of global supply.

Approximately 90% of cobalt mine supply is either from stratiform copper deposits (55%), or from nickel laterites deposits (35%), both as a byproduct. There are only two operating cobalt mines where cobalt is the main product; Mukondo in the DRC (up to 1.5% cobalt) and Bou Azzer in Morocco (up to 1.2% cobalt). These are the highest grades of mined ore.

The supply of cobalt comes from mined ore, refined cobalt and recycling. In 2017 total supply was estimated at 270,000t — from mined cobalt (130,000t), refined cobalt (120,000t) and recycling (15,000t). In 2019 global mine production was estimated by the USGS at 140,000t of which the DRC supplied 100,000t (over 70% of global supply) where 10% to 25% came from artisanal mining.

Glencore is the world's largest cobalt mining company achieving a total production of 27,400t in 2017, nearly one quarter of global production. China Molybdenum Co. Ltd. is the second largest (16,419t in 2017).

There are three stages in the cobalt supply chain,

i. production at mine - representing recoverable cobalt which is concentrated at the mine site ready for shipping

地理分佈

鈷在地殼的濃度低，但通過了各種地質過程富集提供可能利用的礦床。這些礦床通常含有 0.1%至 0.4%的鈷，相當於相對於超鎂鐵質岩石（平均 110ppm）濃度增加了十倍。 主要礦床類型包括：

* 層狀沉積物蘊藏的Cu-Co礦床 – 世界上大多數鈷均來自此類礦床，這些礦床蘊藏在頁岩和砂岩中的板狀體中。 商業上最重要的礦床位於剛果民主共和國和讚比亞的銅帶。 自1970年代以來，這些礦床貢獻了世界年度礦山產量的25%至50%。 鈷含量在0.17%到0.25%之間變化，主要的礦石礦物是卡洛特石（$Cu(Co,Ni)_2S_4$）和硫鈷礦石（Co_3S_4）。
* Ni-Co紅土礦床 – 紅土是在潮濕的熱帶氣候中形成的紅色土壤，這是由於基岩的熱帶熱帶風化所致，其中某些元素被去除，而其他元素則通過超基因過程而富集。 這樣的紅土可能厚達20m，通常含有0.10%至0.15%的鈷。 西澳大利亞州的Kalgoorlie和Murrin Murrin礦床以及新喀裡多尼亞的Goro礦床是鎳鈷紅土的例子。
* 岩漿性 Ni-Cu(-Co-PGE) 硫化物礦床 – 是由某些岩漿或超鎂鐵質侵入岩或火山岩流中的高溫導致鎳、銅和次要鈷硫化物的富集。 在加拿大紐芬蘭和拉布拉多的Voisey's Bay，加拿大安大略省的薩德伯里地區和俄羅斯西伯利亞的Norilsk-Talnakh地區都可以找到這種礦床的例子。
* 熱液和火山成因礦床 – 海床還存在大量鈷資源，這些鈷資源是從板塊邊界處的海底火山口排放的富金屬流體沉積而來的。 但是要從6000m深度開採，存在經濟效率和技術上的困難。

開採與加工

大多數開採鈷的礦山都採用常規的露天開採作為主要開採方法。這是因為發現高品位礦石的地方一般都靠近地面。 地下開採僅用於岩漿礦床，但就全球供應量而言地下開採的供應量很小。

大約 90%的鈷礦供應來自層狀銅礦床（55%）或鎳紅土礦床（35%），兩者都是副產品。只有兩個營運中的鈷礦是以鈷作為主要產品。剛果民主共和國的 Mukondo（鈷含量最高為 1.5%）和摩洛哥的 Bou Azzer（鈷含量最高為 1.2%）。 這些是最高品位的開採礦石。

鈷的供應來自礦山、精煉鈷和回收利用。 2017 年估計總產量為 270,000 噸 – 來自礦山的鈷（130,000 噸）、精煉鈷（120,000 噸）和回收利用（15,000 噸）。據美國地質調查局估計 2019 年全球礦山產量為 140,000 噸，其中剛果民主共和國佔了 100,000 噸（佔全球供應的 70%以上），其中 10%至 25%來自手工採礦。

嘉能可公司是全球最大的鈷礦開採公司，2017 年總產量為 27,400 噸，接近全球產量的四分之一。洛陽欒川鉬業集團股份有限公司是第二大鉬業公司（2017 年產量為 16,419 噸）。

鈷供應鏈分為三個階段，

i. 礦山生產 – 代表可回收的鈷，在礦山現場濃縮然後準備運輸
ii. 中間產品 – 精礦經火法冶金或濕法冶金工藝，以生產消光粉、粗金屬化合物和 Co-Cu-Fe 合金
iii. 精煉 – 將鈷與其他存在的金屬分離以生產鈷金屬、金屬粉末、氧化物和其他簡單化合物。中國擁有全球精煉產能的 60%。

ii. intermediate – which is the pyrometallurgical or hydrometallurgical processing of concentrates to produce mattes, crude metal compounds and Co-Cu-Fe alloys

iii. refining – which separates the cobalt from the other metals present to produce cobalt metal, metal powders, oxides and other simple compounds. China has 60% of global refining production capacity.

In the case of Ni-Co laterite deposits little beneficiation is required and the ore can be directly shipped. In the case of other deposits conventional crushing and screening is the first stage to concentrate the cobalt and after this several methods exist to separate cobalt from copper and nickel, depending on the concentration of the cobalt and the exact composition of the used ore. One method is froth flotation, in which surfactants bind to ore components, leading to the enrichment of cobalt ores. For cobalt mine material data calculated from the HS trade code assumes 7% cobalt.

At the intermediate stage the cobalt content is enhanced to around 25%. Here roasting converts the ores to cobalt sulphate and the copper and nickel are oxidized into oxide. Further processing takes place finally with cobalt compounds leached from the slag of copper smelting. The resulting products are then transformed into cobalt oxide (Co_3O_4) which is then refined and transformed into metal by aluminothermic reaction or reduction with carbon, in a blast furnace.

Market

Today China, followed by Japan and the USA are the world's leading consumers of cobalt. Largely driven by the increasing demand in the manufacture of Li-ion batteries China share of global refinery capacity rose from 3% in 2000 to approximately 60% by 2018. More than 80% of China's consumption is in the rechargeable battery industry.

Globally the rechargeable battery industry accounts for over 50% of end uses where lithium cobalt oxide ($LiCoO_2$) is a major component of Li-ion battery cathodes. The advent of EVs and their success with consumers has been the important factor in the growth of cobalt demand. In 2016 demand was 50,000t rising to an estimated demand of 80,000t in 2020. By 2030 cobalt miner, Glencore, estimate there will be worldwide production of 30 million EVs which will require 314,000t of cobalt.

Batteries contain 5% - 30% cobalt depending on the ratios of constituent metals which include nickel, aluminium and manganese. Cobalt with the other metals, is needed to produce the preferred balance between performance, energy density, charge time, charge life, safety, and cost. Cobalt outperforms tungsten, aluminium and copper in critical electronics functions.

The Li-ion battery market is predicted to increase to US$75Bn by 2024, from US$30Bn in 2015. Panasonic forecasts the demand to reach 310,000t by 2027 of which 240,000t will come from batteries.

Cobalt metal 鈷金屬

鎳鈷紅土礦床幾乎不需要進行選礦就可以直接運輸礦石。其他礦床的情況，濃縮鈷的第一步是壓碎和篩分，之後根據鈷的濃度和礦石的確切組成，有幾種從銅和鎳中分離鈷的方法。一種方法是泡沫浮選，表面活性劑結合到礦石成分導致鈷礦石的富集。根據 HS 貿易代碼估算出鈷精礦的鈷含量為 7%。

中間產品的鈷含量提高到約 25%。 在此階段，焙燒將礦石轉化為硫酸鈷，而銅和鎳則被氧化成氧化物。最後從銅熔煉爐渣中進一步加工浸出鈷化合物。再將所得產物轉化為氧化鈷（Co_3O_4），最後通過鋁熱反應或在高爐中用碳還原將其轉化為金屬。

市場

如今中國已成為世界領先的鈷消費國，其次是日本和美國。鋰離子電池製造需求的增長在很大程度上推動了中國在全球精煉產能中的份額從 2000 年的 3%上升至 2018 年的約 60%。中 國 80%以上的消費量來自可充電電池行業。

在全球範圍內，可充電電池行業佔最終用途的 50%以上。 鈷酸鋰（$LiCoO_2$）是鋰離子電池陰極的主要成分。電動汽車的出現及成功一直是鈷需求增長的重要因素。 2016 年需求量為 50,000 噸，到 2020 年估計需求量為 80,000 噸。到 2030 年，鈷礦開採商 Glencore 估計全球將生產 3000 萬輛電動汽車，將需要 31.4 萬噸鈷。

電池包含 5% - 30%的鈷，具體取決於構成金屬的比例，包括鎳、鋁和錳。需要鈷與其他金屬在性能、能量密度、充電時間、充電壽命、安全性和成本之間取得最佳平衡。在關鍵的電子功能方面，鈷的性能優於鎢、鋁和銅。

鋰離子電池市場預計將從 2015 年的 300 億美元增長到 2024 年的 750 億美元。松下預測，到 2027 年，鋰離子電池的需求將達到 31 萬噸，其中 24 萬噸將來自電池。

Rockhound is a HK based company set up to serve the minerals industry in the Region. The company offers technical valuations and services in the natural resources sector.

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Jinchuan Group International Resources Co. Ltd.
金川集團國際資源有限公司 (2362.HK)

The Company is engaged in mining exploration, mining development and ore mining business. It has a total of five projects all located in the copper belt of DRC and Zambia. Three of them are in production while one is in development and the other one is in exploration.

Ruashi Mine, located in the DRC, is one of the operating mines. It consists of 3 open-pit deposits and 1 processing plant, producing copper cathode and cobalt hydroxide for direct sales to international market; copper and cobalt output reached 33.8kt and 5,070t, respectively, in 2019. The property has a 10 years life of mine with resources of 678kt Cu and 92kt Co and reserves of 268kt Cu and 29kt Co.

China Molybdenum Co. Ltd.
洛陽欒川鉬集團股份有限公司 (3993.HK)

The Company engages in non-ferrous metal industry, mainly the mining, beneficiation, smelting, refining and trading of base and rare metals. With its main business located in five continents: Asia, Africa, South America, Oceania and Europe, the Company is the largest tungsten producers, the second largest cobalt and niobium producer, one of the top five molybdenum producers and a leading copper producer in the world. It is also the second largest producer of phosphatic fertilizers in Brazil. In terms of trading business, the Company is among the third biggest base metals merchants in the world.

The Company is the second largest producer of mined cobalt in the world. 2019 saw the back end of a large downside correction in the cobalt price from USD20/lb down to USD12.6/lb in August, where the market finally found a floor. The downward adjustment was primarily driven by a combination of two factors, firstly the demand side story, EV market not playing out rapidly as anticipated and secondly the build-up of high cost inventories largely due to significantly increased artisanal supplies in DRC that profited on skyrocketing cobalt price in the past two years and pushed the market into a surplus, and brought much pressure to the operation of smelting industry. However the lower price in the second half of 2019 did cause some cobalt supply to switch-off, most notably, Glencore announced to reduce 25,000t annual cobalt production, while part of the artisanal supply also suspended due to the low cobalt prices. As the cobalt market gradually balanced itself, the cobalt price in the second half of 2019 finally found a support with the Metal Bulletin ended the year increasing to just over USD15/lb for standard grade.

Russia ready to increase domestic cobalt production even under the Pacific Ocean (excerpt)

5 June 2020 <Resource World Magazine>

Russia plans to significantly increase the volume of domestic cobalt production within the next several years despite the decrease in global prices for the metal, according to recent statements made by representatives of some senior state officials and local producers.

While the official Russian cobalt reserves are classified, according to some estimates by analysts of the Russian Expert business magazine, they currently vary ranging between 630,000 and 650,000 tonnes, of which 200,000 tonnes are proven.

As part of state plans, by 2022, cobalt production in Russia should increase up to 8,000-10,000 tonnes, compared to 5,000-6,000 tonnes at present. That will allow Russia to increase the share in the global cobalt output from the current 5% to 8%.

In addition to traditional fields, part of Russia's plan is to start cobalt production at the Magellan Mountains in the Western Pacific Ocean. The 3,000 km2 undersea property was granted to Russia by the International Seabed Authority in 2010 for geological exploration and industrial production of cobalt.

Potential resources are estimated to be 270 million tonnes of ore. Of these, 0.9 million tonnes account for nickel, 39 million tonnes for manganese, and 1 million tonnes for cobalt. Russian geologists have already completed exploratory drilling on the site where drill cores of cobalt-rich manganese crusts were recovered for analysis.

Tesla wins green light in China to use cobalt-free batteries (excerpt) 12 June 2020 <Nikkei Asian Review>

Tesla has received approval from China to assemble electric cars with batteries that contain an alternative to cobalt, an expensive metal whose production is linked to child labor.

The cobalt-free batteries will be used in the U.S. automaker's Model 3 vehicles, China's Ministry of Industry and Information Technology said in a notice published Thursday.

Though the document did not name the supplier, the batteries will be made by China's Contemporary Amperex Technology Co. Ltd., the global industry leader known as CATL, a person with knowledge of the matter said.

Tesla to buy cobalt from Glencore for new car plants (excerpt) 16 June 2020 <Financial Times>

Glencore will supply Tesla's new Shanghai Gigafactory and its planned Berlin facility with the metal used in lithium-ion batteries, according to people familiar with the matter.

The deal, which increases Tesla's reliance on supplies from the Democratic Republic of Congo, is a boost for Glencore's cobalt business after a two-thirds slide in the metal's price over the past two years to about $30,000 a tonne.

China's top cobalt producer halts buying from Congo miners (excerpt) 28 May 2020 <Financial Times>

Huayou Cobalt bows to pressure over use of child labour in DRC's informal mining sector.