

# Porphyry and Volcanogenic Massive Sulphide Ore Deposit in Canada

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**Abstract.** Canada is one of the leading countries in ore production that involves variety types of ore deposits. Among the significant ore deposits found in the country, porphyry and volcanogenic massive sulphide (VMS) deposits stand out as major contributors to the production of copper, gold, molybdenite, zinc, lead and many other essential minerals. Porphyry deposits are the major copper production in the country that are predominantly located in British Columbia, where subduction processes occur. While the overall mineral grade of porphyry deposits is relatively low, their immense tonnage makes them the largest reservoirs of copper in Canada. Notable porphyry mines such as Copper Mountain and Highland Valley Copper produce millions of tons of ore annually. On the other hand, VMS deposits, associated with volcanic activities, play a significant role in the production of zinc, copper, lead, gold, and silver. These deposits are distributed across Canada, with concentrations found in the Ontario and British Colombia. VMS deposits make up nearly a quarter of the country's copper production with significant mine sites including Kidd Mine and Windy Craggy. The future of the mining industry in Canada and the whole world should be focusing on sustainability. Sustainable mining recognizes the interconnectedness of environmental, social, and economic aspects and seeks to balance them for the benefit of present and future generations.

**Keywords:** Porphyry deposit, volcanogenic massive sulphide deposit, ore genetic model, geology of Canada, mining.

## 1. Introduction

The geology of Canada is remarkably diverse and complex from coast to coast. The country's geological history is shaped by a variety of tectonic processes, including the assembly and breakup of supercontinents, volcanic activity, mountain building, and glaciation. According to its geological history, Canada is divided into the Eastern Continental Margin, Western Canada Sedimentary Basin, Canadian Shield, Appalachian Orogen, Interior Platform, Innuitian Orogen and Cordillera. The geological background has shaped Canada into an ideal place for mineral deposits and thus becoming the world's leading country in mineral production. One of the largest mineral deposit regions in Canada is the Canadian Shield that spans a vast area, covering a significant portion of eastern, central, and northern Canada. Within the Canadian Shield, there are several prominent mining districts that have contributed to Canada's status as a major mining nation including Abitibi greenstone belt, the Sudbury Basin and the Labrador Trough. The Cordillera region in western Canada is known for its rich mineral deposits. The Cordillera Orogen also hosts a variety of mineral deposits especially the porphyry ore deposit. At the same time, Canada ranks among top five countries in producing diamond, gemstones, gold, platinum group metals and so on. In 2021, the value of Canada's mineral production has reached over five billion dollars with gold being on the top of the production with a value of more than one billion dollars.

Ore stands for valuable minerals that can be profited from, while ore deposits refer to the accumulations of those minerals that are formed through various geological processes over long period of time. The importance of ores lies in their fundamental role as a foundation for economic growth, technological progress, resource security, and infrastructure development, ultimately shaping various aspects of human society and global prosperity. The source-transport-trap model is an explanation of how minerals are sourced and traveled underground until it reached a trap site to deposit. Once discovered and assessed for economic viability, mineral deposits can be extracted

through open-pit or underground mining methods. The extracted minerals are then processed to separate and refine the desired elements or compounds for commercial use. Major ore deposits include porphyry, VMS, sedimentary, skarn deposit etc. Due to the specific geological setting Canada is placed in, porphyry and VMS deposits have become the most significant ore deposits in the country providing large amounts of copper, gold, molybdenum, zinc, lead and numerous of other minerals for the whole world. Mining in Canada plays a crucial role in supporting economic growth and development, providing essential raw materials for industries, and contributing to employment and revenue generation.

This essay is aimed to give a general overview of porphyry deposit and VMS deposit including their source-transport-trap model, major metal and tonnage, geological environments and distribution, and corresponding major mine sites in Canada.

## **2. Porphyry Deposit**

A porphyry deposit is a type of mineral deposit that is characterized by the presence of disseminated ore minerals within a large volume of igneous rock known as a porphyry. Porphyry refers to the texture of the rock, which consists of large phenocrysts embedded in a fine-grained matrix. Porphyry ore deposits are major resources for metals like copper (Cu), molybdenum (Mo) and gold (Au) that are found in bornite, chalcopyrite, galena, molybdenite, pyrite, sphalerite [1]. They typically form at 2-4km depth with some extremes that can reach 8 km depth.

Formation involves the exsolution of metalliferous and sulfur-rich saline hydrothermal fluids from silicate melt. Porphyry deposits are typically formed in association with subduction zones, where oceanic crust is subducted under the continental crust [2]. The process begins with the intrusion of a large magma body called a pluton into the crust. As the magma cools and solidifies underground, it forms a porphyritic texture due to the different rates of cooling between the larger crystals and the surrounding groundmass. Tonnage of the deposit size varies from tens of millions to billions according to different mines and mineral grades vary within the average of 1% [2].

### **2.1. Source-Transport-Trap Model**

The source of hydrothermal fluid that porphyry deposits form from is from the magma that is mostly intermediate to felsic. Metals the form the deposits and the energy driving the system are also derived from the magma. As the subducting plate descends into the Earth's mantle, it experiences increasing pressure and temperature, causing it to partially melt and generate magma. The surrounding rocks are denser than the magma and this difference in density will force magma to rise towards the surface.

Metals then are carried by the magma to trap site by hydrothermal fluid that exsolved from the magma. The fluid that rises under lithostatic fluid pressure will undergo a variety of physiochemical changes at rise, for instance, cooling, disproportionation, depressurization and drop to hydrostatic fluid pressure.

The mineralization in porphyry deposits occurs during the magmatic and hydrothermal processes that includes a variety of different alteration zones, for example, propylitic and potassic alteration [3]. There are 3 main reasons for metals to precipitate: cooling, fluid-rock interaction and sulfide solubility drop. As the magma cools, volatile-rich fluids separate from the crystallizing magma and rise to higher levels within the Earth's crust. Hydrothermal fluids that are rich in metals such as copper, gold and molybdenum interact with the surrounding rocks and deposit ore minerals in fractures and pore spaces.

### **2.2. Major Metal and Grade**

Porphyry deposits are the world's largest sources for copper. The main economic minerals found in porphyry deposits are typically copper and gold, although they may also contain other metals such as molybdenum, silver, and rhenium. As seen from the Fig.1, the deposits are usually low-grade,

meaning that the concentration of valuable minerals is relatively low, but the large size of the deposit makes it economically viable for mining operations [4]. Island Copper is a porphyry deposit in Vancouver Island, British Columbia, Canada. The major metals that are mined in this site are Cu, Mo and Au that are within minerals like bornite, chalcocopyrite, galena, molybdenite, pyrite and sphalerite. According to the U.S. Geological Survey (USGS), this mine site has a tonnage of 377 Mt with a Cu grade of 0.41%, an Mo grade of 0.017%, an Au grade of 0.19 g/t, and an Ag grade of 1.4g/t [5]. The overall contained copper reaches 1,500,000 tons.

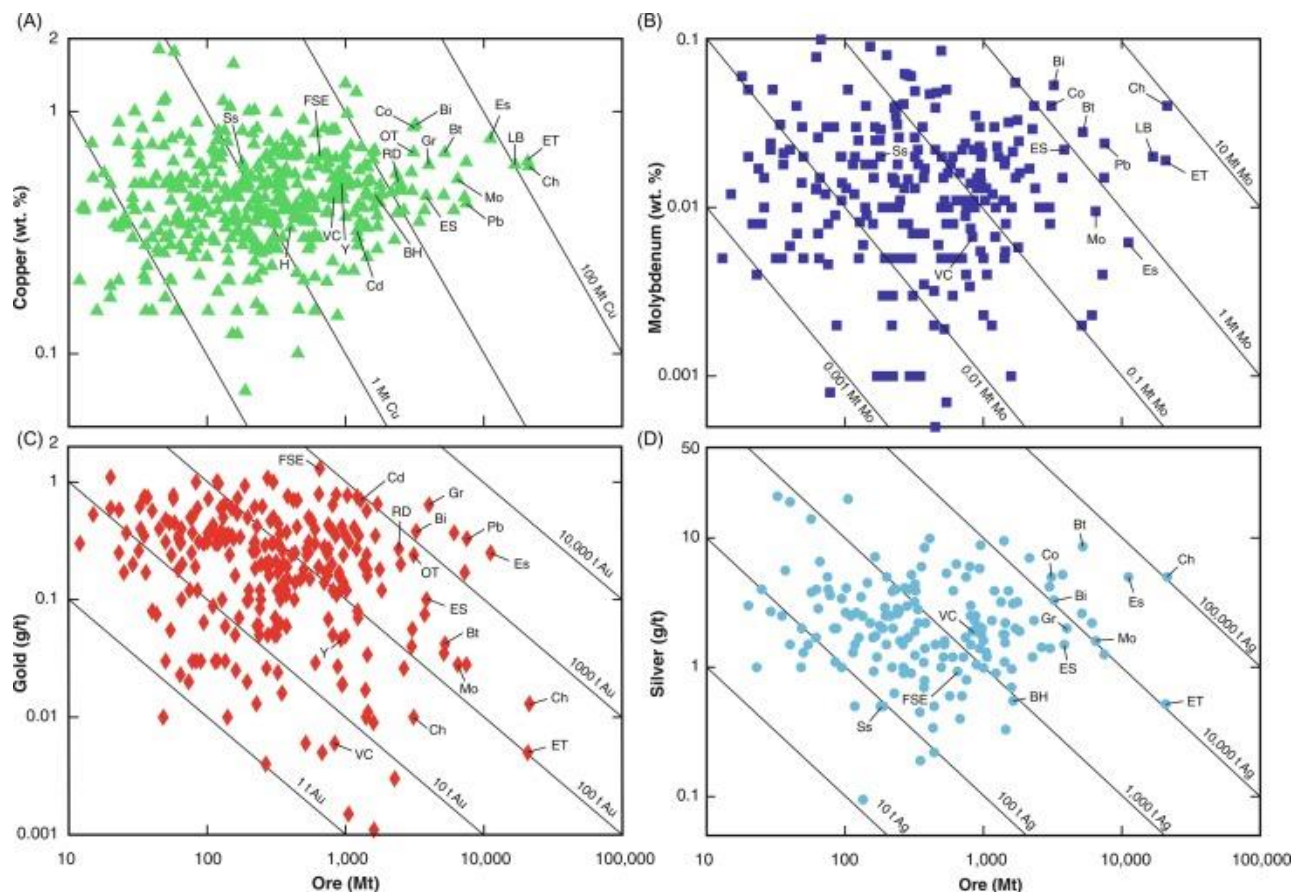


**Fig. 1** Mineral grades and tonnages of porphyry deposits. (photo source: <https://doi.org/10.1016/B978-0-08-102908-4.00005-9>)

### 2.3. Geological Environments and Distribution

On the west coast of Canada, along the Cascadia Trench, Juan de Fuca plate is subducting under the North America plate. Since porphyry deposits are mostly formed where subduction is happening, it makes west Canada a great location for exploring this type of deposits. Porphyry deposits often form in association with large-scale plutonic intrusions. Canada has a rich history of magmatic events that have produced extensive granite and granodiorite intrusions. These intrusions serve as the heat source and reservoir for the hydrothermal fluids responsible for the deposition of metals in porphyry systems. Major porphyry deposits are located in British Columbia and Northwest Territory (Fig. 2) [6].

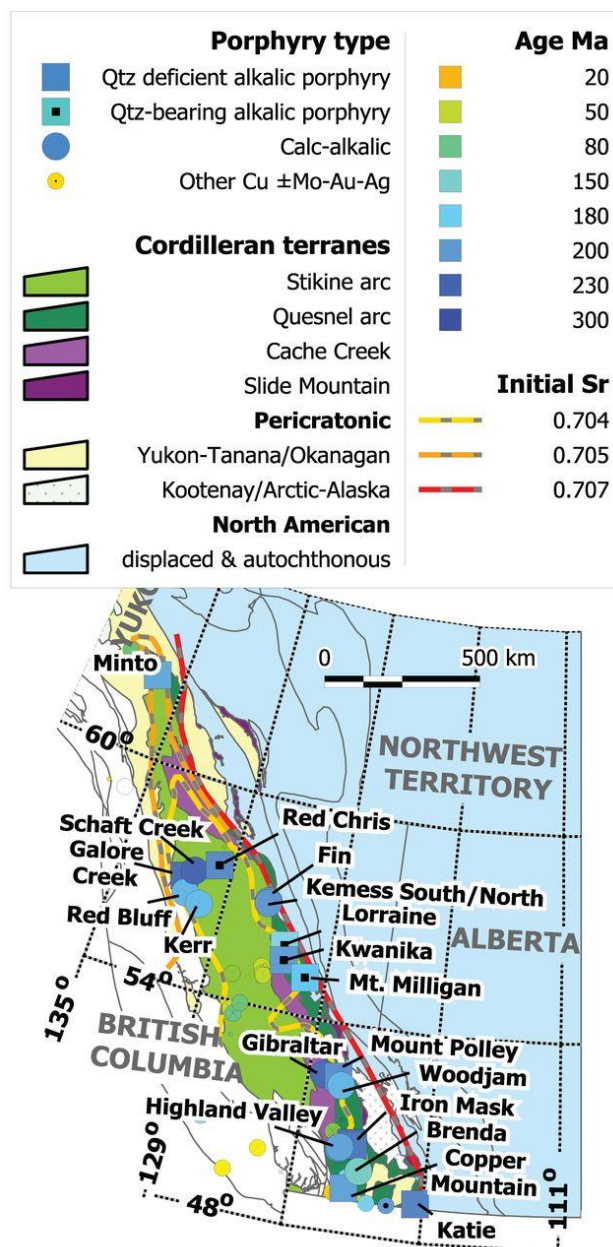


**Fig. 2** Location of porphyry deposits within the Canadian Cordillera. (photo source: <https://doi.org/10.2113/econgeo.109.4.827>)

### 2.3.1 Copper Mountain

The Copper Mountain area in south-central British Columbia hosts a porphyry-style Cu-Au-Ag mineralization. The mineralization is concentrated at the margins of the Copper Mountain stock and the Lost Horse intrusion, with the majority occurring in the surrounding country rocks [6]. The area exhibits intense hydrothermal alteration, including biotite flooding, albite-epidote metasomatism, and late-stage veining. The most widespread alteration occurs along fractures in biotite-flooded volcanic rocks, resulting in bleaching. Veins of biotite-K-feldspar and sulfides follow these fractures, particularly near the Copper Mountain stock contact. Ore grade is controlled by the intensity of veining, with thickened veins reaching significant widths. The ages of the Copper Mountain stock and the titanite in chalcopyrite-biotite veins indicate a connection between intrusion crystallization and mineralization. Copper Mountain Mining Corporation has been actively mining the area since 2011, with reported copper production [6]. A substantial resource has been identified adjacent to and beneath the proposed "super-pit," adding to the historical production of copper, gold, and silver. There are also unexplored targets at greater depths.

### 2.3.2 Highland Valley Copper

The Highland Valley Copper deposit is located at southern British Columbia, approximately in between two major cities, Vancouver and Kamloops [6]. It has been in operation since 1962 and is one of Canada's largest base metal mines. Recorded metal production from the Highland Valley deposits until 2005 includes over 3.33 Mt of copper, 0.044 Mt of molybdenum, 1,000 t of silver, and 7 t of gold [6]. Annual production from 2005 to 2009 averaged 0.1372 Mt of copper and 0.0023 Mt of molybdenum. The deposit consists of five major deposits known as Valley, Lornex, Highmont, Bethlehem, and JA.

### 3. Volcanogenic Massive Sulfide Deposit

VMS deposits are a specific type of mineral deposit characterized by the presence of polymetallic massive sulfide lenses (Fig. 3) [6]. These deposits are formed either at or approximately close to the seafloor within submarine volcanic environments. VMS deposits originate from fluids that are enriched with metals. The host rocks of VMS deposits can be either volcanic or sedimentary in nature [7]. They are significant sources of several valuable metals, including zinc, copper, silver, lead and gold. Major ore minerals include sphalerite for zinc, chalcopyrite for copper and galena for lead.

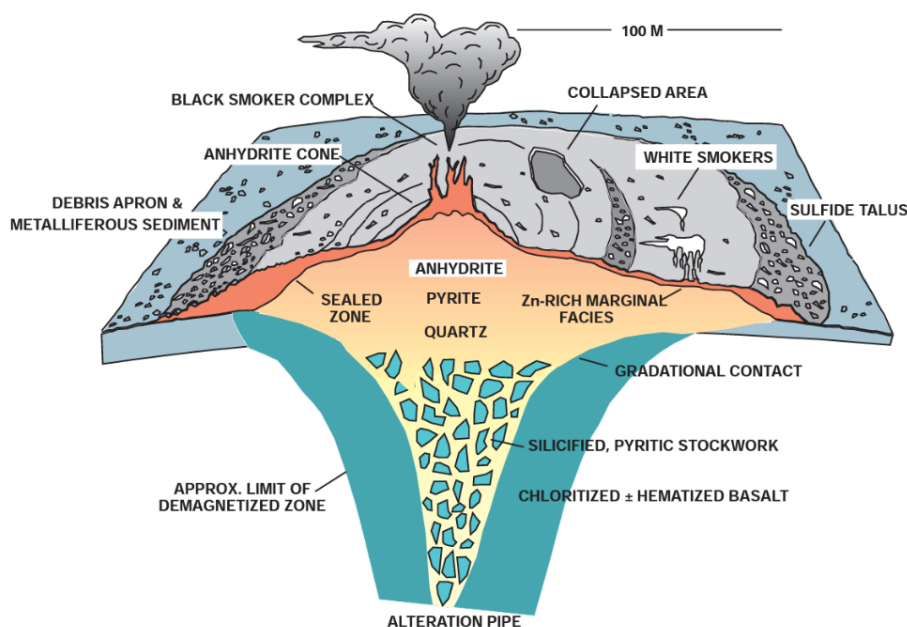


**Fig. 3** Schematic diagram of VMS. (photo source: <https://doi.org/10.2113/econgeo.109.4.827>)

VMS deposits are normally found at ancient back-arc basins or island arcs. These types of geological conditions are due to volcanic activities that are related to subduction events [8]. They are frequently discovered within greenstone belts, geological regions that comprise diverse volcanic and sedimentary rocks and are connected to past volcanic arcs. “Black smoker” is a submarine event that reveal the location of VMS deposits that is caused by the release of hot fluids filled with metals

### 3.1. Source-Transport-Trap Model

Since VMS deposits are mostly associated with submarine volcanism, the source of the sulfide in VMS deposits is mostly seawater sulphate, while the source of most of the metals is the host rocks that lie under [7]. The transport phase involves the movement of metal-bearing fluids from their source to the site of deposit formation. This transport system can occur through various mechanisms, including hydrothermal circulation and fluid flow along permeable pathways within the crust. These fluids that carry the metals and sulfur will eventually reach the seafloor. Trap represents the specific conditions or geological features that promote the deposition and accumulation of sulfide minerals. VMS deposits' trap is the vent on the seafloor or water-saturated zone just below the seafloor. When

the hot hydrothermal fluids interact with cold seawater, the metals and sulfur precipitate, forming sulfide minerals that accumulate in and around the vent structures (Fig. 3).

### 3.2. Mineral and Tonnage

The major minerals formed in VMS deposits are iron sulfides like pyrite and chalcopyrite, with sphalerite and galena being major constituents. There are approximately 850 known VMS deposits over the world with a tonnage of 200,000 tonnes each. They have supplied more than 5 billion tonnes of ore to the whole world with a proportion of at least 22% of the world's zinc production and 6% of the world's copper production [7]. In Canada, 27% of copper production, 49% of zinc production, 20% of lead production, 3% of gold production and 40% of silver production are originated from VMS deposits [7].

### 3.3. Geological Environments and Distribution

Canada is located at a geologically active region, particularly in areas associated with ancient volcanic arcs, island arcs, and back-arc basins. These tectonic settings have experienced intense volcanic activity, subduction-related volcanism, and hydrothermal systems, creating favorable conditions for the formation of VMS deposits. The extensive Precambrian terranes are consisted with numerous types of volcanic and sedimentary rocks, providing the necessary host environments for VMS deposits to form. On the other hand, Canada's extensive coastline and offshore regions provide opportunities for hydrothermal circulation systems to develop. The Cordilleran Orogen and Canadian Shield are concentrated mining area especially in Ontario and British Columbia. VMS deposits involve the circulation of hot fluids through the seafloor, carrying metals and sulfur from deep within the crust to the surface and leading to the formation of VMS deposit. Canada holds two supergiant VMS deposits (Fig. 4) which are Windy Craggy and Brunswick No. 12, as well as two giant VMS deposits which are Kidd Creek and Horne [7, 9, 10]. In terms of total original reserves, the four deposits are ranked top 1% among the worldwide VMS deposits.

#### 3.3.1 Kidd mine

The Kidd Mine is situated in the prolific mining region of Timmins, Ontario, which has a rich history of gold and base metal mining [9]. The Kidd Mine contains substantial reserves of copper, zinc, and other base metals. It is estimated to have a resource base of approximately 138.7 million Mt with 6.18 % Zn, 2.31% Cu, 0. 22% Pb and 87 g/t Ag [7]. The Kidd Mine plays a significant role in the local and regional economy, providing employment opportunities and contributing to the socio-economic development of Timmins and the surrounding communities. The mine adheres to environmental and safety regulations, focusing on sustainable mining practices and responsible resource management.

#### 3.3.2 Windy craggy

The Windy Craggy deposit, located in British Columbia, is the largest known VMS deposit in Canada. While its overall size is considerable at 297 million Mt, its metal content is relatively lower, with 4.1 Mt of ore [11]. The remote location and ecological sensitivity of the Windy Craggy Mountains present unique challenges for any potential mining development. Environmental impact assessments and regulatory considerations would be crucial in determining the feasibility and sustainability of any mining activities in the area. The remote location and ecological sensitivity of the Windy Craggy Mountains present unique challenges for any potential mining development. Thus, since September 2021, Windy Craggy had stopped any mining operations on the site.

## 4. Conclusion

Mineral production plays a crucial part in Canada's economy and the global supply of essential resources. Porphyry ore deposit is one of the major ore deposits in the country that produce copper, gold and molybdenite. Most of the porphyry deposits in Canada is in British Columbia where

subduction is taken place. The overall mineral grade is relatively low with a large tonnage thus making porphyry deposits the largest copper reservoir. Copper Mountain and Highland Valley Copper are two of the major porphyry mine in Canada that produce millions of tons of ore. VMS deposits are formed with association of volcanic activities that are significant sources of zinc, copper, lead, gold, and silver. The copper production takes nearly a quarter of the country's total copper output. The distribution of the deposits in Canada is fairly spread out but mainly concentrated in Cordilleran Orogen and Canadian Shield area. Standout VMS mine sites are Kidd Mine and Windy Craggy that are located at Ontario and British Columbia respectively. However, mining activities can have significant environmental impacts including soil erosion, land degradation, water contamination, deforestation, and many other consequences. As a result, sustainable mining, also known as green mining, should be the fundamental aspects for mining worldwide. It refers to the adoption of practices and strategies that minimize the environmental, social, and economic impacts of mining operations. It involves integrating environmental stewardship, social responsibility, and economic viability into mining practices to ensure long-term sustainability.

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