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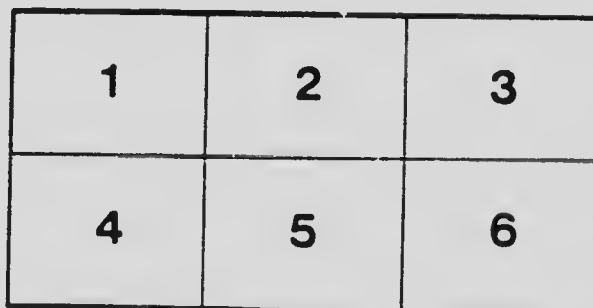
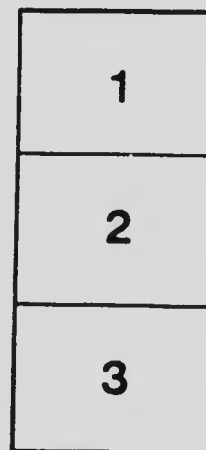
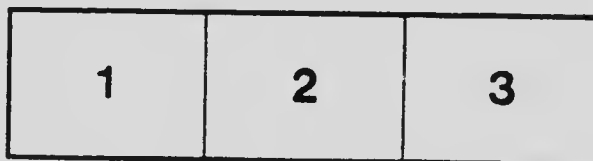
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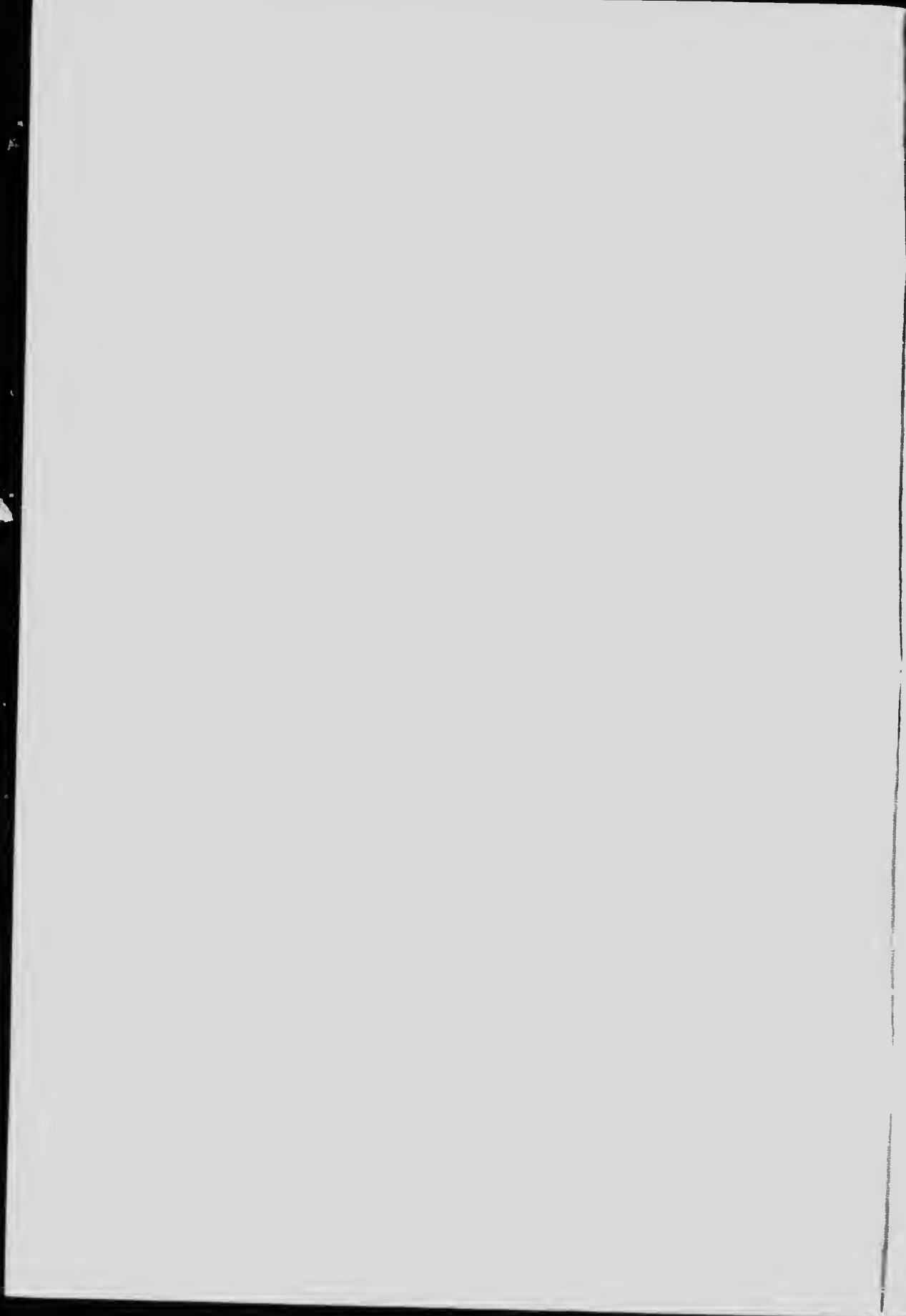


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The Mining and Metallurgical Treatment of Molybdenum Ores in Canada

BY
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THE MINING AND METALLURGICAL TREATMENT OF
MOLYBDENUM ORES IN CANADA.

G. C. MACKENZIE.

By Permission of the Director of Mines Branch.

The opening of the great European war found the British Empire lacking in adequate supplies of certain metals that were urgently required for the manufacture of munitions. We had grown so accustomed to securing many of these metals from foreign reduction works, that, rather than spend money in the exploitation of our own natural resources, we depended upon the foreigner to supply our requirements, because it was easier and cheaper to buy what he had to sell than to go to the trouble and expense of developing our own supplies.

This penny-wise, short-sighted policy of the past, with its foolish disregard of future contingencies, has cost the Empire much lost time in the manufacture of munitions, and, thereby, many valuable lives of its brave soldiers. The experience has been costly, but the lack of these materials has at least brought about an awakening that promises the adoption of a wiser policy in the future. Not the least of these deficiencies has been the lack of the steel hardeners, tungsten and molybdenum, and as these metals are important factors in the manufacture of modern ordnance and ammunition, the curtailment of supplies during the first two years of the war was a serious matter.

The story of the production of tungsten is in itself sufficient material for a long article, and cannot be dealt with at the moment, and as the subject of this address is molybdenum, I will confine myself to a description of its occurrence as a mineral and its use as a metal.

The name Molybdena, now applied only to the metal Molybdenum and its compounds, really means lead, and has come to us from the early Greeks who used the term to describe all of the dark metallic sulphides. The resemblance between lead, molybdenite and "black lead" or graphite especially, is best evidenced by lack of discrimination between them and our retention of the ancient confused term black lead and lead pencil. No doubt when better means of determination arose, the easiest one to identify, lead, was eliminated, but the difference, superficially slight, did not permit classification until late in the phlogiston

period. The name molybdenum for many centuries, therefore, pertained to graphite and molybdenite which were considered identical.

It is interesting to note how these two were finally distinguished. By the action of nitric acid upon molybdenite, Scheele, in 1778, three years before his work on tungsten, showed that there were formed sulphuric acid and a white acidic earthy substance which we term molybdic acid to-day. In 1779, Scheele firmly established the difference between the two minerals, theretofore confused, in another treaty on plumbago. In the Phlogiston way, the earth was considered the calx of a metal, and on this theory, in 1790, facts were made known regarding the first preparation of the metal by Hjelm, who, prompted by the current belief that carbon was rich in phlogiston, ignited the acid oxide of Scheele in a graphite crucible with carbon. The resulting gray metal must have contained considerable carbon. That process is commercially used to-day.

Until recent years, the metal was in little demand for industrial purposes, and very little search was made for the ores of molybdenum. At the present time, however, owing to its introduction into metallurgy, in the form of iron molybdenum alloys, there is a considerable demand for such ores. They are produced, however, very irregularly and in small quantities. If a larger and more regular ore supply were assured, there is no doubt that new uses would be found for the metal, its alloys and salts, and the demand for the ores would increase.

PROPERTIES AND USES.

Physical and Chemical Properties of Molybdenum: Pure molybdenum is a white metal, which is malleable, ductile, and soft enough to be filed and polished with ease. However, it is seldom produced in the pure state, and its appearance depends largely upon the method of production. Reduction of the oxides or sulphides of molybdenum with hydrogen yields molybdenum as a grey powder, which, under heat and pressure, may be compacted into a metallic bar that is brittle and even fragile. Molybdenum produced by the Alumino Thermic methods or by reduction in the electric furnace is a compact metal, but that produced in the electric furnace contains carbon, and its physical properties differ from those of carbon-free metal. The melting point of molybdenum is still in question. The United States Bureau of Standards has placed it at about $2,500^{\circ}$ C., or $4,500^{\circ}$ F. This is about $1,400^{\circ}$ C., above the melting point of copper, and 740° C., above that of platinum. Osmium, tantalum and tungsten are the only three metals listed by the Bureau of Standards as having higher melting points. The specific gravity of molybdenum is increased appreciably by drawing or hammer-



ing the metal, as is that of many other metals, such as copper and tungsten. The Research Laboratory of the General Electric Company has determined the specific gravity of ductile molybdenum before drawing as 10.02, whereas, after drawing, it ranges from 10.04 to 10.32. Molybdenum wire has a tensile strength approximately one-half that of hard-drawn steel piano wire or tungsten wire of corresponding size, and this tensile strength increases very appreciably with the fineness of the wire. In other words, the more the metal is worked the stronger it becomes. The electrical resistance of ductile molybdenum is 5.6 microhms per cubic centimeter of hard-drawn wire, and 4.8 for annealed wire, the resistivity being measured at 25° C.

Metallic molybdenum containing carbon is grey and brittle; it is also very hard and scratches steel and quartz, and even the hardest file will not cut molybdenum alloyed with a certain proportion of carbon. The melting point of the grey metal is much lower than that of pure molybdenum, and its specific gravity is also lower, ranging from 8.6 to 8.9, according to the amount of carbon present. Pure molybdenum surrounded with carbon and heated to about 1,500° C., absorbs carbon and becomes hard; conversely, carbon-bearing molybdenum melted with molybdenum-dioxide is refined by the oxidation of the carbon in the metal.

Pure molybdenum undergoes oxidation to an appreciable extent at the ordinary temperature, but it is superficially attacked at a dull red heat, and rapidly at 600° F., molybdenum trioxide subliming. Dilute acids have no effect upon it. Strong nitric acid oxidizes it, so does concentrated sulphuric acid, and at the same time there are formed lower oxides, which are soluble in the acid with the formation of a deep blue colour. The halogens attack it with a formation of more or less volatile, variously coloured halogen and oxy-halogen compounds.

The massive metal, on account of its less surface exposure, is less active toward reagents than the powder molybdenum.

The trioxide is volatile at high temperature.

Uses: Molybdenum is used in the form of oxides, ammonium salt and metal. Several tons a year are used in North America in the form of ammonium molybdate for the determination of phosphorus in iron ores, pig irons and steels, and also in the determination of phosphorus in fertilizers. The salt finds further use in fire-proofing certain fabrics. The metal is used in self-hardening steel; from five to ten per cent. is introduced, and the resulting steel is raised in elastic limit and tensile strength and possesses greater toughness in addition to the former property.

Ferro-Molybdenum is found to be of value as a constituent in the manufacture of large castings, gun barrels, in which it is prized for its resistance to corrosive gas action, armour plate, armour-piercing shells, car steel, and magnets.

Equal parts of molybdenum and chromium introduced into steel are claimed to be more preferable for many of the above uses, especially self-hardening steel. Two to five per cent. of molybdenum and ten per cent. chromium with little or no carbon will make steel acid resisting to a great degree. Nickel steels alloyed with molybdenum are found to possess desirable qualities. The tensile strength of molybdenum wire is given at from 200,000 to 270,000 pounds per square inch, as compared to tungsten with 480,000 to 580,000 pounds per square inch.

Molybdenum wire-wound electric furnaces have special claims made for them. A thermocouple which uses the metal has been described recently. The lower oxides of molybdenum are highly coloured. Their use is recorded in colouring leather, rubber and porcelain. A soluble variety is used as a substitute for indigo.

In some form not disclosed, molybdenum is added as a preservative to certain smokeless powders.

The principal use of molybdenum, however, is in the manufacture of special steels to which, particularly in conjunction with chromium, manganese, nickel, cobalt, tungsten and vanadium, it imparts many desirable properties. These steels are used for a large variety of purposes, such as for crank and shaft forgings, high pressure boiler plate, ordnance, armour-plate, armour-piercing projectiles, permanent magnets, wire, and self-hardening and high speed machine tools. In a general way, molybdenum acts like tungsten in steel, but it is more active, and less is needed to produce a given result. Absolute figures as to the relative effect of the two elements cannot be given, as the effects are not exactly similar. The effective ratio of molybdenum to tungsten seems to be between one to two and one to three.

Metallic molybdenum is used in various electrical contact making and breaking devices, X-ray tubes and voltage rectifiers, and in the form of wire for filament supports in incandescent electrical lamps, for winding electric resistance furnaces, and in dentistry, as a molybdenum tungsten alloy.

CANADIAN MOLYBDENUM PRODUCTS.

The only molybdenum products manufactured at present in Canada are C.P. molybdic acid, C.P. ammonium molybdate, and ferro molybdenum. The International Molybdenum Company manufacture all three of the above at their Orillia, Ontario, works, this Company being

the first Canadian operator to establish the molybdenum business on a commercial basis, therefore being the pioneer of this new industry.

The Tivani Electric Steel Company of Belleville, Ontario, have commenced the manufacture of ferro-molybdenum quite recently, but so far have made no attempt to produce molybdic acid or ammonium molybdate.

The manufacture of metallic molybdenum, ingot, molybdenum wire, molybdenum steels, etc., is not carried out in this country, but it is well within the range of possibility, and, providing the mines are able to produce sufficient minerals to meet the demands of the market, all of these various lines of manufacturing will be entered into within the Dominion.

I am unable at this time to give particulars of the manufacture of these molybdenum products, but it may be stated that Canadian ferro-molybdenum, molybdic acid and ammonium molybdate are now being marketed satisfactorily, and that the production of ferro-molybdenum up to the end of 1916 was in the neighbourhood of thirty tons. The value of the molybdic acid and ammonium molybdate manufactured at Orillia during 1916 is stated by the management of the International Company to be \$18,867.35.

ECONOMIC MOLYBDENUM MINERALS.

Only two molybdenum minerals—molybdenite and wulfenite—are common enough to form molybdenum ores.

Molybdenite: Molybdenite, the disulphide of molybdenum (MoS_2), contains 59.95% molybdenum, and 40.05% sulphur. It is opaque, lead-grey, and has a metallic lustre and a greasy luster. It is so soft (hardness 1 to 1.5) that it soils the fingers readily, and leaves a bluish-grey trace on paper. On porcelain its streak is slightly greenish. The specific gravity ranges from 4.7 to 4.8. Molybdenite commonly occurs in flakes or scales, resembling those of some micas in the way that they may be split into thin leaves. Finely, granular and massive forms are also common. Molybdenite crystallizes in hexagonal form, with crystals being tabular, or short and slightly tapering prisms.

Molybdenite is often confused with graphite, but may be easily distinguished because graphite is much lighter (specific gravity 2.09 to 2.23). Heating a fragment of the mineral in an open tube will conclusively settle any question as to its identity, for molybdenite gives strong sulphurous fumes, whereas graphite gives none.

Molybdenite, on weathering, commonly forms molybdite, a hydrous ferric molybdate ($\text{Fe}_2\text{O}_3 \cdot 3\text{MoO}_3 \cdot 7\frac{1}{2}\text{H}_2\text{O}$), which theoretically contains 39.63% molybdenum. In colour, molybdite is a lemon-yellow to pale

yellow, and occurs as an earthy powder, in crustations, fibrous masses, or capillary crystals in radiating groups. For many years molybdate was thought to agree in composition with the artificial molybdic trioxide obtained by oxidizing molybdenite, and most of the present text-books on mineralogy persist in this error, giving its composition as MoO_3 . Iron, however, is an essential part of the mineral. Molybdate by its colour often calls attention to deposits of molybdenite which otherwise might be unnoticed.

Tests: Heated in an open tube, molybdenite gives off sulphurous fumes, and a pale yellow crystalline sublimate of molybdenum trioxide (MoO_3) is formed. Before the blow-pipe molybdenite is infusible, but imparts a yellowish-green colour to the flame. On charcoal in the oxidizing flame, pulverized molybdenite gives a strong odour of sulphur dioxide, and the charcoal is coated with crystals of molybdic acid, which appear yellow when hot and white when cold. Near the assay the coating is copper-red, and if the white coating be touched with an intermittent reducing flame it assumes a beautiful azure-blue colour. Molybdenite is decomposed by nitric acid, leaving a white or greyish residue (molybdic oxide).

Occurrences and Accompanying Minerals: Probably three-quarters of the reported occurrences and practically all of the commercial deposits of molybdenite so far discovered are in acid rocks, such as granite, pegmatite, and syenite, the mineral being notably at home in rocks of this type. Outside of the gangue-forming minerals, such as quartz, felspar, mica, garnet, calcite, fluor spar, etc., the minerals with which molybdenite is most frequently associated are molybdate (its alteration product), pyrite, pyrrhotite, chalcopyrite, malachite, chrysocolla. Other accompanying minerals are native copper, cuprite, chalcocite, bornite, tetrahedrite, azurite, galena, sphalerite, arsenopyrite, magnetite, limonite, wolframite, hübnerite, scheelite, cassiterite, and bismuthenite.

Wulfenite: Wulfenite is a molybdate of lead (PbMoO_4), and theoretically contains 26.15% molybdenum, and 56.42% lead. It is heavy and brittle, sub-transparent and sub-translucent, and has a resinous or adamantine lustre, and generally a wax or orange-yellow colour. It may, however, be green, grey, brown, nearly colourless, or orange to bright red. The streak is white. The hardness is 2.75 to 3 and the specific gravity is 6.7 to 7. Wulfenite crystallizes in the tetragonal system, the crystals commonly being square and tabular and sometimes extremely thin. The mineral generally occurs in well crystallized forms, but also in coarse or fine-grained masses.

Tests: Before the blow-pipe wulfenite decrepitates and fuses below 2. With borax in the oxidizing flame it gives a colourless glass, which in the reducing flame becomes an opaque black or dirty green with black flecks. With salt of phosphorus in the oxidizing flame it gives a yellowish-green glass, which becomes dark green in the reducing flame. Heated with soda on charcoal, the powdered mineral yields metallic lead. On evaporation in hydrochloric acid it decomposes, forming lead chloride and molybdic oxide. Moistening the residue with water and adding metallic zinc gives an intense blue colour, which persists after dilution.

Occurrences and Accompanying Minerals: Deposits of wulfenite are found almost wholly in veins, where it is associated with other lead minerals such as galena, cerussite, pyromorphite, anglesite and desclozite. Gold and silver minerals also occur with it, and native gold is sometimes contained directly in the wulfenite crystals.

Up to the present time, however, the mineral molybdenite has constituted the only economic ore of the metal in Canada.

PRICES AND MARKETS.

Molybdenite ores and concentrates are marketed on their content of MoS_2 , and are paid for as so much per unit of contained molybdenum sulphide. In Canada and the United States, the short ton of 2,000 pounds and the unit (1% of a ton) twenty pounds, are used, whereas, in Great Britain and Australia, the long ton of 2,240 pounds and the unit of 22.4 pounds always apply.

Under existing abnormal market conditions, brought about by the war, the prices being paid at the present time for molybdenite concentrate are from 100 to 200% greater than pre-war quotations. In 1908, high grade concentrates containing 90 to 95% MoS_2 were sold for \$6.50 to \$7.60 per unit, and in 1909 the price was as low as \$5.65 per unit.

In the Fall of 1915 the Imperial Government fixed a price of 105 shillings per unit (long ton) for molybdenite concentrates containing not less than 85% MoS_2 , f.o.b., London and Liverpool, and as the mineral was under embargo which prohibited its export to any country outside of the British Empire, this price naturally became the official standard quotation for all ores and concentrates produced within the Empire. Since that date, however, licenses have been granted for the export of the mineral to France and Russia at the official quotations given above.

The quotation, it should be noted, means 105 shillings per unit, 22.4 pounds of molybdenite (MoS_2), not 85% concentrates as many have imagined. This price corresponds to \$1.09 per pound of MoS_2 contained in 85% concentrates, f.o.b., Ottawa, Ontario, at which point

the Canadian production is purchased for the Allied Governments by the Imperial Munitions Board.

Canadian molybdenum purchased by the Imperial Munitions Board at Ottawa in the form of molybdenite concentrate, is, at the moment, being converted to ferro-molybdenum in Canada before being exported to Europe, and as it is possible to manufacture the ferro-alloy from concentrates containing less than 85% MoS_2 , the following sliding scale of payment has been adopted by the Board:

(a) For concentrates containing not less than 85% molybdenite, \$1.09 per pound of contained MoS_2 .

(b) For concentrates containing not less than 80% molybdenite, \$1.05 per pound of contained MoS_2 .

(c) For concentrates containing not less than 75% molybdenite, \$1.02 per pound of contained MoS_2 .

(d) For concentrates containing not less than 70% molybdenite, \$1.00 per pound of contained MoS_2 .

It is difficult to forecast with any accuracy the future conditions of the industry, but it is reasonable to assume that with increased production and a more normal market, the present prices will decline. It is possible that with the end of the war consumption may keep pace with production as the metal has a multitude of useful applications in the peaceful arts; however that may be, producers would do well to assume that a drop in price is inevitable with the end of the war and to prepare themselves accordingly.

CANADIAN PRODUCTION.

The mining and metallurgical treatment of Canadian molybdenum ores has up to 1916 played a very small part in the world's production. This has been due to various factors, chief of which have been the limited demand for the mineral and at unattractive prices, together with the fact that no Canadian mine had until 1916 been developed to the point of a steady producer.

In 1911, the Mines Branch of the Department of Mines published a monograph entitled "Report on the Molybdenum Ores of Canada" by Dr. T. L. Walker, of Toronto University; and while this report contained considerable detailed information regarding the various localities throughout the country in which ores of molybdenum occurred, it was at that time impossible to foretell with any degree of accuracy, the probabilities of Canadian production, or to describe commercial methods of preparing the ore for the market.

In 1915, the Mines Branch, in response to a circular issued by the Colonial Institute of Great Britain, commenced a detailed examination

of the molybdenum ores of Canada; and as the Department at this later date were fully equipped to experiment on the problem of concentration, the investigation consisted for the most part in looking for a solution of the problems involved in preparing the ore for market.

The Department secured large samples in carload lots which were shipped to the Testing Laboratories of the Mines Branch in Ottawa. After much patient research work with the more common specific gravity types of ore concentrating machinery, the conclusion was reached that concentration methods based upon specific gravity would not yield commercial results and therefore a solution of the problem would have to be looked for in other directions.

After coming to the conclusion that the older processes of concentrating minerals would not apply, the possibilities of separation by flotation were carefully looked into and for a time it was considered that the modern Oil Flotation Process would probably be adopted. However, during a laborious and detailed examination of this method, there were encountered certain difficulties in the application of the Oil Process which indicated the desirability of continuing the investigation for an easier method of working. This method was eventually found in what has been called the Water Film Flotation Process, and although commercial results were not immediately attained the process lent itself readily to adjustment, and as the factors governing the separation of molybdenite from its gangue by this method were more completely understood, a type of apparatus was gradually evolved which is at the present time in successful operation at the Ore Testing Laboratories of the Department.

The principle upon which this method is based is the surface tension of water, advantage being taken of the fact that molybdenite resists wetting, while its associated minerals are more or less easily wetted and submerged.

The method of separating molybdenite from other minerals by means of projecting the ore upon a sheet of flowing water has been known for many years, but the first commercial application of the process on a large scale was made by Henry E. Wood, of Denver, Colorado, who patented the Wood Water Film Flotation Machine in the United States and Canada.

About the time the officials of the Department had satisfied themselves that water film flotation was the most desirable process for the separation of the majority of Canadian ores, attention was directed to the Wood type of apparatus, and after consultation with Mr. Wood it was decided to install one of his machines at the Testing Laboratories in Ottawa. Subsequently, certain weaknesses in the Wood machine

developed in the treatment of some of our Canadian ores and the Department in endeavouring to correct these weaknesses and to improve upon the general adaptability of the machine, have evolved a type of apparatus which has been found to work very satisfactorily under almost all conditions.

While the Department were experimenting for a solution of the separation problem, the search for molybdenite deposits of economic value continued throughout the country. Old deposits were re-opened and developed with more vigour than heretofore and many new discoveries were made, but it was not until the spring of 1916 that the industry as a whole was strengthened by the development of the "Moss Mine" of the Canadian Wood Molybdenite Company, near Quyon, Pontiac County, Province of Quebec. The occurrence of a mineral resembling graphite had been known in this locality for many years, but it was not until January, 1916, that the identity of this mineral was definitely established as molybdenite.

The Canadian miner of molybdenum ores while encouraged by the reported prices for the mineral during 1915 had no definite guarantee that his product when ready for market would be accepted by the Imperial authorities; and as the great majority of these miners were men of small means it was difficult for them to raise the necessary capital for development without such assurances or contracts from the Imperial authorities. In June of 1916, the Imperial Munitions Board at Ottawa announced that they were in a position to purchase a considerable tonnage of molybdenite concentrates in Canada to be delivered before June 30th, 1917. At this time the Laboratories of the Department of Mines at Ottawa possessed not only the best concentration equipment, but were also in possession of a staff that had considerable experience with the problem of concentration. It was, therefore, natural that the Imperial Munitions Board should turn to the Department of Mines for assistance in the securing of a part of the tonnage of concentrates above mentioned, and an arrangement was entered into between the Imperial Munitions Board and the Mines Branch of the Department of Mines whereby the latter became the millers and assayers for the Board in all matters pertaining to the supply of metallic ores and minerals.

The Moss Mine of the Canadian Wood Molybdenite Company having at that time developed sufficiently to make shipments, an agreement was drawn up with that Company whereby they were to supply the Mines Branch of the Department of Mines with 100 tons of molybdenite ore weekly, the concentrates produced therefrom being purchased by the Imperial Munitions Board. At the same time, the Mines Branch

advertised their willingness to treat small parcels of ore originating from other localities and while no other mines of the magnitude of the "Moss" have been encountered to date, the Department received during the year about 217 tons from other sources.

The method first adopted for the purchase and settlement of these ores was as follows:

The miner was required to deliver his ore carriage paid to the Testing Laboratories of the Department, and after the ore had been milled he was to receive the proceeds from the sale of his molybdenite at approximately \$1.09 per pound of MoS_2 f.o.b., Ottawa, less the cost of concentration—between \$5.00 and \$6.00 a ton. No definite recovery was guaranteed. In December, 1916, it was found possible to standardize milling operations and to fix a definite cost per ton for the ore treated together with definite schedule of guaranteed recovery of molybdenite. This schedule is as follows:

Terms of Purchase of Molybdenite Ores, Department of Mines, Ottawa.

- (1) On assay returns from samples dried at 212° F.
- (2) For dry ores—moisture to be deducted.
- (3) The cost of concentration to be \$5.65 per net ton.
- (4) The value of Molybdenite (MoS_2) to be \$1.00 per pound, Ottawa.
- (5) Payment to be calculated as follows per ton of 2,000 lbs. dry ore delivered or siding at Mines Branch Testing Laboratories, Ottawa:

Molybdenite Ores containing:

- | | | | |
|-----|---------------------|---------|------------------------------------------------------|
| (a) | Between 0.5% and 1% | for 70% | of the total Molybdenite (MoS_2) Content. |
| (b) | " 1.1% and 1.5% | for 78% | " " " " " |
| (c) | " 1.51% and 2.0% | for 84% | " " " " " |
| (d) | " 2.1% and 2.5% | for 87% | " " " " " |
| (e) | " 2.51% and 3.0% | for 90% | " " " " " |
| (f) | " 3% and .. | for 92% | " " " " " |

- (6) Net returns to the miner will be the value of the ore calculated as indicated above less \$5.65 per net ton concentration charges.

The Departmental Plant has operated since June, 1916, and up to the first of February, 1917, has treated 2,097 tons of crude ore and picked flake with the production of 34.85 tons of pure molybdenite in the form of a concentrate averaging 80% MoS_2 . The ore treated contained 1.84% molybdenite and the actual molybdenite shipped has been 79.09% of the total amount received. The total recovery would be slightly over 80% as no account has been taken in this calculation of the several tons of middling product in process of milling.

THE INTERNATIONAL MOLYBDENUM COMPANY OF ORILLIA.

The International Molybdenum Company of Orillia, Ontario, with concentrating mill at Renfrew and smelter at Orillia, have been in opera-

tion since 1915. During the past year this company have milled approximately 2,419 tons of molybdenite ores of which approximately 26 tons were derived from the United States. According to figures supplied by the management of the company, the average content of the ore milled was 1.23% MoS_2 with a production of approximately 60,000 pounds of molybdenite. The recovery has been estimated to be 80% of the total amount of molybdenite received.

This company are under contract with the Imperial Munitions Board for 50 tons of ferro-molybdenum of which they have already delivered in the neighbourhood of 30 tons. The ferro-molybdenum must comply with the following specification:

Molybdenum.....	70% minimum.
Carbon.....	4% maximum.
Sulphur.....	0.4% maximum.

The alloy must be arsenic and copper-free.

The International Company manufacture their ferro at Orillia from commercial molybdic acid produced in their chemical plant. The concentrate required as raw material is supplied partly from their own concentrator at Renfrew and partly by the Imperial Munitions Board at Ottawa. The ferro alloy produced by the International Company has been found entirely satisfactory as regards analyses, and is sold to the Imperial Munitions Board at a price of \$3.25 per ton of contained molybdenum, delivered f.o.b., Montreal. Therefore, a ton of 2,000 pounds of ferro-molybdenum containing exactly 70% Mo., is worth \$4,550. The ferro-molybdenum is shipped to the Testing Laboratories of the Department of Mines at Ottawa where it is crushed, sampled, assayed and repacked for shipment to Europe by the Mines Branch officials; and it may be of interest to note that the weighing and analytical work of the Mines Branch has to date proved so satisfactory that the weights and assays determined by the Department are final and binding on both parties to the contract. The International Company control two molybdenite mines, the O'Brien, situated on Mount St. Patrick, Renfrew County, Ontario, and the "Molly" mine at Salmo, Sheep Creek, B.C. These two properties, however, are insufficiently developed to meet the capacity of the concentrating mill at Renfrew and the Company have treated a considerable tonnage of customs ore during the year.

The method of concentration adopted by the International Molybdenum Company is water film flotation, but the machine developed by the Company staff is somewhat differently constructed than either the Wood Machine or the apparatus developed by the Department of Mines. The principles involved are, however, exactly similar, and

while the International Molybdenum Company have not produced concentrate of as high grade as the Department of Mines, the recovery of molybdenite is said to be equally as good and the product sufficiently high in molybdenite to meet the requirements of their refinery at Orillia.

THE CANADIAN WOOD MOLYBDENITE COMPANY.

The Canadian Wood Molybdenite Company, Ottawa, with mines at Quyon, Que., and mills at Quyon and Hull, Que., are unquestionably the foremost producers of molybdenite ore and concentrates in North America. Since the mine started operations in March, 1916, this Company has mined approximately 5,000 tons of ore, and from assay returns supplied by the Canadian Wood Company together with figures arrived at by the Department of Mines, it is estimated that the ore averaged 1.7% MoS_2 with a total content of 85 tons of pure molybdenite. Assuming that 80% of the total amount has been recovered at least 68 tons of pure molybdenite have been recovered from this property during 1916.

Early in the fall of 1916, the Canadian Wood Company commenced the installation of a water film flotation mill at their property at Quyon. This mill with a capacity of 50 tons of crude daily was not completed until some time in December owing to difficulties encountered in securing machinery and supplies. The Company have also made an arrangement with the Canada Cement Company whereby the latter crush and pulverize the ore as it is delivered to them at Hull, Que., and transport it to a 100 ton water film concentrator mill erected by the Canadian Wood Company on the Cement Company's grounds.

The Canadian Wood Molybdenite Company have a contract at the present time with the Imperial Munitions Board at Ottawa for the total output from their mills at Quyon and Hull in addition to the 100 tons of ore which they have contracted to deliver weekly to the Department of Mines.

SMALLER PRODUCERS.

In addition to the foregoing may be mentioned the molybdenite mine of Wm. J. Spain, situated in the Township of Griffith, in the County of Renfrew, and also the property of the Renfrew Molybdenum Mines, Limited, Mount St. Patrick, County of Renfrew, together with a prospect being developed by A. M. Chisholm in the Township of Sheffield, County of Addington, all in the Province of Ontario.

The Spain mine was active for about the half of 1916, and shipped to the Department of Mines, in Ottawa, $3\frac{1}{2}$ tons of molybdenite in the form of flake and ore. During the early spring a 50 ton mill was erected on the property, but has not yet been operated to capacity, as the mine

has been insufficiently developed to supply the necessary tonnage. The mill consists, essentially, of a rock crusher, rolls, picking belts and screens, and has produced several tons of medium grade concentrate which it is understood are held at the property for future concentration.

The Chisholm mine opened up as a rather promising prospect and was so considered until the property of the Canadian Wood Company at Quyon completely overshadowed it in the matter of quick production. The Chisholm mine is being operated by open cut and the management have installed a small roll and screen cobbing plant of sufficient capacity to treat 15 tons of ore in 10 hours. This cobbing plant was installed with a view of cobbing the run of mine which is in the neighbourhood of 1% up to a shipping product of 15% molybdenite or better; the intention being to send the cobbled mill product to the Testing Laboratories at Ottawa, where it will be milled to a commercial grade.

The Renfrew Molybdenum Mines, Limited, are working a property on Mount St. Patrick about 11 miles from Ashdod Station on the Kingston and Pembroke railway. This mine is probably in a more advanced stage of development than any other molybdenite mine in Ontario. Some years ago the mine was opened up by an adit tunnel driven to intersect a hillside vein. The tunnel encountered the vein about 80 feet on the incline below the surface and proved the ore to exist at that depth and to contain about 1% molybdenite. In 1916, active work was commenced and we are informed that a shaft has been sunk on the vein to a depth of 75 feet at which point the vein has been found to persist in both width and molybdenite content. During the fall of 1916, a single unit Elmore Vacuum Flotation plant was installed at the property and milling operations were commenced some time in December. The management state that with the Elmore plant they are treating from 30 to 40 tons daily and producing therefore 500 to 1,000 pounds of 80% concentrate.

So far, the entire production of the Renfrew Molybdenum Mines, Limited, has been exported to France where this Company have a contract to fill with one of the Metallurgical Departments of the French Government.

BRITISH COLUMBIA.

While we have records of several promising Molybdenite prospects in British Columbia this Province has not—up to the present time—produced any merchantable concentrate, the western miner having contented himself with making shipments of crude ore.

In the fall of 1916 the Canadian Muniting Resources Commission engaged J. C. Gwilli, Professor of Mining Engineering, Queen's

University, to investigate and report upon the possibilities of securing supplies of certain minerals in British Columbia; and while Professor Gwillim investigated or actually inspected some 45 different occurrences of molybdenite his report indicates that there are but a half-dozen localities from which a tonnage of Molybdenite ore may be expected within the near future.

The following notes have been compiled very largely from Professor Gwillim's report together with such other information as is readily accessible through Government reports, etc.

The *Molly Mine*, situated on Lost Creek, about 15 miles from Salmo, in Kootenay, has shipped at various times during 1914 and 1915 approximately 50 tons of high grade ore to the Henry E. Wood Testing Plant at Denver, Colorado. In 1916 this property, under the management of the International Company of Orillia, Ont., has produced about 74½ tons of cobbed ore which has been shipped to the concentrator of the International Molybdenum Company at Renfrew, Ontario. It is understood that the Molly mine may be looked upon as a small producer of high grade ore for some little time to come.

The Molybdenum Mining and Reduction Company of Vancouver, who control a molybdenite mine on the Alice Arm of Observatory Inlet, 14 miles above Granby Bay, have expended a considerable amount of capital in the development of their property and may eventually become one of the more important producers in British Columbia. The molybdenite in the ore from this mine is in the so-called amorphous condition, that is to say, the crystallization is so fine that it cannot be distinguished by the naked eye and this ore, therefore, presents some peculiar problems in concentration. The ore is essentially a mixture of Molybdenite and quartz, very little Pyrite or other accessory sulphide being present and mica is almost entirely absent. The problem of concentration, therefore, is more particularly that of grinding the ore to a fineness at which the maximum amount of molybdenite is freed from the quartz and the subsequent separation of the finely divided molybdenite from the gangue. Such finely ground material is difficult to concentrate with any degree of efficiency by water film flotation methods and the probabilities are that one of the Oil Flotation processes will have to be adopted. The management have so far been unable to produce a merchantable concentrate on a commercial scale and the property is for the present inactive pending arrangements which will permit the installation of a suitable milling plant.

A shipment of 350 tons of ore from this property, said to be the average run-of-mine, was made to the concentrator of the International Molybdenum Co. of Orillia, Ontario, late in the fall of 1916. It is

understood that the ore contained on the average 1.25% of molybdenite, but unfortunately owing to the extremely fine crystallization of the molybdenite the International Company have been unable up to the present time to attempt the milling of this shipment.

A third property which may develop into a producer is a prospect called the *Index* mine situated between Cayuse and Cottonwood Creeks, Lillooet Mining Division. This property was worked for a short time during the fall of 1916 by Mr. Newton W. Emmens, of Vancouver, who made a shipment of 8 tons of high grade ore to the concentrator of the International Molybdenum Co. at Renfrew, Ontario.

Other properties mentioned by Professor Gwillim as being worthy of some attention are as follows:

Stave La —7 miles north of Stave Lake on Stump River, owned by Moses Bouchier, Mission, B.C.

Pitt River—10 miles from the north end of Pitt Lake, owned by A. Hewitt, Vancouver.

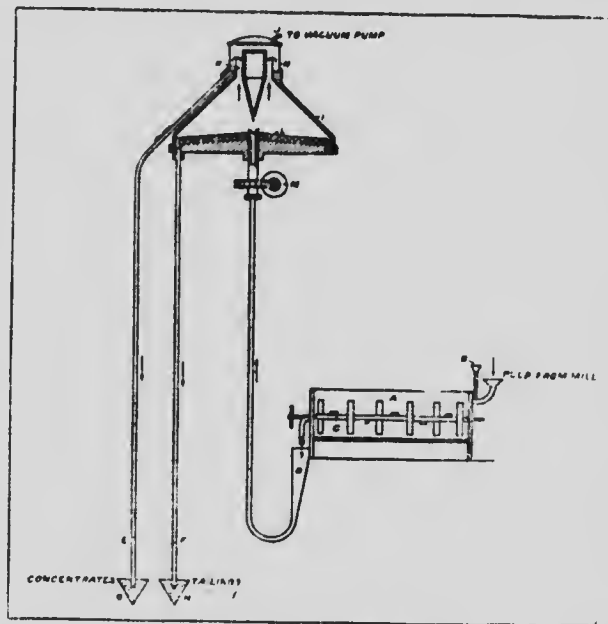
Grande Prairie—20 miles south of Ducks, owned by C. A. Mackay, Adelphi, Post Office.

THE ELMORE VACUUM FLOTATION PROCESS.

The apparatus is illustrated diagrammatically in Figure 1, and its operation may be briefly described as follows: The crushed ore from the pulverizing mill flows continuously into the mixer "A", into which are introduced small quantities of oil (in the separation of molybdenite the oil used is preferably kerosene) and if required, of acid also, at point "B". The pulp with its addition of oil is beaten to an emulsion in the mixer by the rotation of the agitator "C". The emulsion then flows from "A" into the funnel "D". The concentrate and tailing discharge pipes "E" and "F" are both sealed with water in the tanks "G" and "H", respectively. The feed pipe from "D" enters the centre of the vacuum or separating chamber "I". By regulating the flow of pulp down tailing pipe "F" so as to be less the up flow through feed-pipe "D", a small quantity of liquid is induced to overflow the annular lip "K" and to carry with it the floating concentrate down the concentrate pipe "E" into tank "G". The series of rakes "L" are rotated by means of the gear drive at "M", and these rake blades are set at sufficient angle to cause the gangue in the pulp to move from the centre of the chamber "I" toward its periphery and to discharge continuously down the tailing pipe "F" into tank "H". The feed pipe "D" is usually 25 to 30 feet long with the concentrate and tailing pipes "E" and "F" made a few feet longer so that the pulp is syphoned from the mixer

"I" through the machine into tanks "G" and "H". Provided that a continuous flow of pulp is supplied, a continuous and entirely automatic discharge of tailing and concentrate is secured. The annular space "K" is provided with a thick glass window through which the operation of the machine may be observed.

The apparatus is supplied in single units that are said to have a capacity of from 25 to 50 tons of crude per 24 hours, depending upon the nature of the ore.



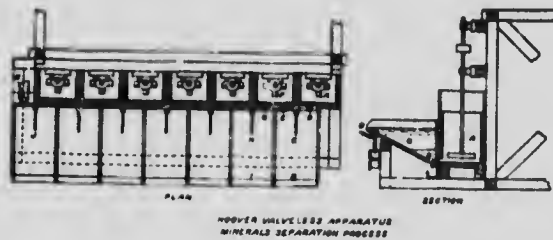
Section of Elmore Vacuum Concentrator

MINERALS SEPARATOR PROCESS—HOOVER VALVELESS APPARATUS.

This machine is illustrated in Figure 2 which shows a plan and section of the apparatus. The ore with its additions of oil and acid is fed into "A" where it is agitated for a time and emerges at the opening "B" into box "C". Any sulphide that floats in box "C" is removed at its lip "D". The bulk of the pulp is then drawn through port "E" into the mixer "F", whence, after further agitation, it is discharged from port "G" into box "H" where more floaty sulphide is removed at lip "I" and so on continuously throughout the series, alternately agitating and delivering sulphide froth until the last frothing-box "J", where

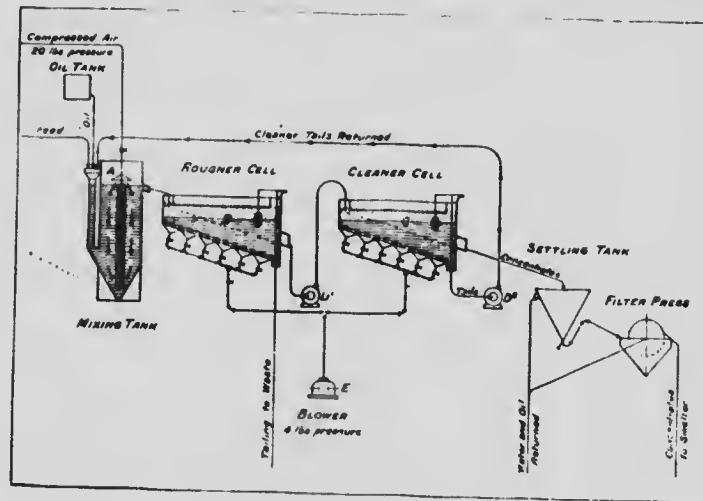
the tailing now depleted of valuable sulphide is allowed to escape through valve "K". The agitators in the mixing compartments are driven at a peripheral speed of 1,500 linear feet per minute.

The machine may be constructed with six, eight, or more agitators and may have a capacity anywhere from 50 to 100 tons of ore per 24 hours.



CALLOW PNEUMATIC FLOTATION PROCESS.

This process of flotation is illustrated in Figure 3 and may be easily followed by the following description: The preparation of the pulp by violent agitation is not essential for this process; the ore from the pulver-



Callow Pneumatic Flotation Process

izing machine passes into the mixing tank "A" along with the necessary oil and acid, while compressed air is blown through the pulp in the

mixer in order to keep the solid matter in suspension. From the mixer, the pulp flows to the rougher cell "B" into which air is blown and atomized through a porous cloth material on the bottom of the cell. Tailings are discharged from "B" through a bottom port controlled by a float valve, while the valuable sulphide, a rough concentrate, proceeds to a cleaner cell "C" where it undergoes a cleaning retreatment. The cleaner cell discharges tailing still containing valuable mineral to the mixer tank "A" and a finished concentrate which is delivered to a filler press. A Standard unit is said to treat from 35 to 75 tons per 24 hours depending upon the nature of the ore.

MOLYBDENITE PRODUCTION.

AUSTRALIA—NORWAY—CANADA.

Ton—2,000 lbs.

From 1900 to 1916. There are no authentic records for the United States.

YEAR	AUSTRALIA		NORWAY		CANADA	
	TONS	VALUE	TONS	VALUE	TONS	VALUE
1900	C 11	\$2.730		\$		
1901	C 26	7.830	C 4.40	1.890		
1902	C 53	34.407	C 22.04	16.200		
1903	C 40	28.124	C 34.16	21.600	M 3.40	1.275
1904	C 46.25	24.304	C 33.06	17.550		
1905			C 50.69	16.470		
1906	C 145?	82.898	C 28.63	14.310		
1907	C 72	58.429	C 32.06	12.960		
1908	C 98	49.893	C 38.57	13.500		
1909	C 121	60.935	C 33.06	12.150		
1910	C 153	86.222				
1911	C 121	77.229	C 2.20	740		
1912	C 159	102.200	C 12.12	3.510		
1913	C 145	125.564	C 3.86	3.240		
1914	M 139?	241.586?	M 59.51	119.732?		
1915	M 129?	281.220?	M 82.65	180.177	M 12.75	27.795
1916	M 132?	287.760	M 100.00?	218.000?	M 83.69	183.434
Totals	1590.25	1,551.331	538.01	652.029	99.84	212.504 B

Explanation.—C = Concentrate, M = Molybdenite (MoS₂), ? = doubtful accuracy.

Summary	Tons	%
Australia produced	1590.25	71.3
Norway produced	538.01	24.1
Canada produced	99.84	4.5
	2228.10	99.9

STATEMENT.
MOLYBDENITE ORES TREATED AND CONCENTRATE PRODUCED DURING 1916 AND TO FEBRUARY 1ST, 1917.
Ore Testing Laboratories, Mines Branch, Department of Mines, Ottawa.

SHIPPED BY	CRUDE ORE AND FLAKE, RECEIVED				PRODUCT MADE			
	WEIGHT LBS.	% MoS ₂	CONTENT LBS. MoS ₂		CONCENTRATE MADE LBS.	% MoS ₂	MoS ₂ RECOVERED LBS.	% OF RECOVERY.
Canadian Wood Co.	4,360,749	1.74	76,303.2034					
Co. of Pontiac, Que.								
Harcroft, T.	72,664	1.38	1,004.910					
Co. of Victoria, Ont.	915	15.31	140.09					
Offer, William C.								
South Porcupine, Ont.								
O'Brien, M. J.	50,324	1.45	732.15					
Co. of Renfrew, Ont.								
Padwell, George	111,280	1.40	1,560.2368					
Co. of Haliburton, Ont.								
Renfrew Molybdenum Co.	109,558	1.29	1,410.40					
Co. of Renfrew, Ont.								
Ross, C. G.	19,784	0.45	88.6					
Co. of Renfrew, Ont.								
Spain, W. J.	69,482	9.89	6,868.72					
Co. of Renfrew, Ont.								
Urquhart, W. J.	35	35.25	12.34					
Toronto, Ont.								
Total	4,794,791 lbs. 2,397 4 Tons	1.84%	88,120 6502 lbs. 43.58 Tons		87,179.51 lbs. 43.58 Tons	79.95%	69,696.7625 lbs. 34.85 Tons	79.09%

