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THE ORIGIN OF ORE DEPOSITS AND THEIR RELATION TO
THE SULLIVAN MINE

An essay submitted during the Third
Year of the Course in Applied Science
at the University of British Columbia

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September 18, 1958

Fort Camp,
University of British Columbia,
Vancouver 8, British Columbia.
September 18, 1958.

Dr. H. C. Gunning, Dean,
Faculty of Applied Science,
University of British Columbia,
Vancouver 8, British Columbia.

Dear Sir:

In compliance with calendar regulations concerning the course in Geological Engineering, I hereby submit the accompanying report, The Origin of Ore Deposits and Their Relation to the Sullivan Mine, as partial fulfillment of requirements for students entering their Third Year of Applied Science at the University of British Columbia. The report also completes Course Number Geology 398.

Yours truly,

D. F. Irving

D. F. Irving

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PREFACE

The material for this essay is based partially on personal experience acquired during the summer of 1958 while I was employed at the Sullivan Mine Geology Department as an assistant mine geologist for the Consolidated Mining and Smelting Company of Canada, Limited. The remainder of the essay is based upon a study of ore genesis which I became interested in while studying the ore at the Sullivan Mine.

I wish to thank the geologists at the Sullivan Mine for the knowledge about geology and mining gained through them that enabled me to write on the subject of ore genesis. I must also ask the reader of this report to regard all material concerning the Sullivan Mine as confidential and not reproducible without full permission from the Consolidated Mining and Smelting Company of Canada, Limited.

D. F. Irving

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THE ORIGIN OF ORE DEPOSITS AND THEIR RELATION TO
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Introduction

The study of mineral deposits has become increasingly important during the last one hundred years. This essay endeavors to give a brief description of the many ways in which economic mineral deposits can be formed. The latter part of the essay involves a discussion of the origin of the enormous lead, zinc, silver ore body at the Sullivan Mine near Kimberley, British Columbia. The essay is primarily a discussion of factual material and does not tend to draw any specific conclusions.

The Formation of Mineral Deposits

Fundamentally, mineral deposits have been classified as either syngenetic or epigenetic. Syngenetic

deposits are those which were formed concurrently with the country rock while epigenetic deposits are those which were formed later than the country rock. Deposits formed by magnetic concentration and sedimentation are the commonest syngenetic type while most others are epigenetic.

Magmatic Concentration

The ore deposits of this group show a close relationship with deep-seated igneous intrusives. They result from simple crystallization or accumulation caused by differentiation in magmas. Simple crystallization results in a granular igneous rock which may contain disseminated mineralization of economic importance. Differentiation is caused by the forces of gravity acting on the denser particles. Heavy minerals like chromite will tend to accumulate in a single mass. The crystallization and separation of any one mineral however, will depend upon the temperature and pressure to which it is subjected.

There is some dispute as to the validity of the theory of crystallization differentiation mentioned above. A process known as "filter pressing" has been introduced in its place. Essentially, it implies that a residual liquid contained in a mush of crystals was squeezed out into the surrounding rock by pressure thus leaving the mass of crystals as a single unit. If conditions were favorable, the mass of crystals left behind could form an ore deposit.

A suggestion concerning sulphide deposits states that they may be a direct result of their immiscibility in solution. The dissolved sulphides separated as immiscible droplets with a lowering of the temperature and settled out as a molten fraction which crystallized as the melt cooled. This process however, is limited, as many minerals are miscible in one another.

The deposits which have so far been mentioned are termed as early magmatic. Late magmatic deposits include groups of pyrogenic minerals that crystallized towards the end of the magmatic period. The ore minerals are actually later than the enclosing rock but were formed before the entire igneous body consolidated.

In certain types of basic magmas, residual liquids become iron enriched and in time may separate from the crystal interstices in the magma chamber where they will then cool. In other cases the residual liquid may be squeezed into the surrounding rocks where it then crystallizes. Deposits of this type are late magmatic.

A suggestion concerning the origin of some iron-nickel-copper sulphide deposits points out that since they are partially soluble in basic magmas they may separate out as immiscible droplets which accumulate at the bottom of the magma chamber. These sulphides result in disseminated

mineralization. If the deposit was subjected to pressure it could be squeezed out into the country rock to form ore deposits there.

Sublimation

Igneous activity involves very large quantities of heat which invariably causes volatilization of some substance. These substances may later be deposited as sublimates. Such deposits are found around fumaroles and other volcanic vents. Sulphur is perhaps the commonest ~~of all~~ deposits of this nature.

Contact Metamorphism

Contact metamorphism gives rise to the formation of mineral deposits at or near the contact of a magmatic intrusion when suitable rocks have been intruded. These deposits are characterized by high temperature minerals resulting from the interaction of highly heated emanations and calcareous rocks.

The initial stages of this process require large quantities of heat which causes baking and recrystallization of the rocks and finally a recombination of minerals to form various silicates. The formation of sulphides sometimes occurs after the silicates have been formed. The temperatures involved in the process range from five hundred to eleven hundred degrees Centigrade.

No definite conclusions have been formed as to how the minerals have been transferred. They may be brought in by magmatic liquids or gaseous emanations. Silicic intrusions like granodiorite are usually the ones that give rise to mineral deposits. The reason for this may be that since the silicic rocks, which carry more water than the basic rocks, supply the magmatic water which acts as the chief collector and transporter of materials.

The rocks which are most susceptible to metamorphism are impure calcareous sediments. As a direct result of heat, limestones recrystallize to form marble. The ore minerals usually found in contact metamorphic deposits include the native elements, some oxides, and the base metal sulphides.

Metasomatic Replacement

The majority of epigenetic ore deposits are a result of replacement. The process is essentially one of simultaneous capillary solution and deposition by which a new mineral of partly or wholly differing chemical composition may grow in the body of an old mineral or mineral aggregate. When mineralizing solutions encounter minerals that are unstable in their presence, substitution may occur. The replacing minerals are brought in by solutions and the replaced ones carried away in solution. The exchange is simultaneous and volume for volume. The original features are often preserved as in the case of petrified wood.

Replacement cannot be described by the use of chemical equations as it is volume for volume replacement and not molecule for molecule. Equations can only show the trend of the process.

The process of replacement demands a continuous supply of new materials and removal of dissolved material. The simultaneous interchange must be accomplished by infinitesimal particles of atomic size. The growing mineral must be in sharp contact with the vanishing substance and lying between them there must be a thin film of a super-saturated supplier solution which brings in the replacing materials and carries away the replaced substances. A continuous supply of solution will cause the volume of replaced material to grow.

When crystals are replaced from the outside ^{Towards the centre,} ~~in,~~ diffusion ~~of the liquid~~ is probably the only way in which ^{the liquid} ~~it~~ can enter the previously replaced material. Diffusion involves the movement of molecules through materials in which a body of solution could not flow. It is however, only possible over short distances ^{such} as those encountered in crystal replacement.

In order that a constant supply of materials be maintained at the replacing front, suitable channelways and permeable beds must serve as main routes while fractures, cleavage planes, and pore spaces serve as a means of farther

distribution. Water is the main agency of replacement and is usually magmatic in origin but is often diluted by meteoric waters. The generally alkaline waters carry materials in from magmas and dissolved country rock. Gaseous solutions, which in time condense, also carry some material.

Replacement also occurs from meteoric waters but ^{in this case it} is confined to soluble rocks like limestone. However, replacement is much more effective by hot magmatic waters since dissolution of minerals is better. Replacement of any one rock depends upon the temperature of the surroundings. At very high temperatures almost any rock can be replaced.

Replacement deposits can be of three types: massive, lode-fissure, and disseminated. The copper ores at Bingham, Utah are of the disseminated type and the pure pyrite at Noranda is of the massive type.

Cavity Filling

Cavity filling consists of the deposition of minerals from aqueous solutions in rock openings. These solutions may be dilute or concentrated, hot or cold, juvenile or meteoric. The process is often associated with replacement of the wall rocks.

Cavity filling involves two different processes: the formation of the openings to start with, and ^{finally} ~~the~~ the

deposition of the minerals. Both of these processes may be simultaneous but are generally quite distinct.

Direct deposition may result from mineralizing solutions coming in contact with solids or ~~by~~ changing from acidic to alkaline by contact with the wall rock. Deposition begins at the walls and proceeds outwards until both sides meet. Cavities known as vulgs and druses, which contain well developed crystals, are left where the two wall deposits join.

Fissure veins are formed by the filling of pre-mineral openings resulting from stresses in the earth's crust. Filling is often accompanied by wall replacement, depending upon the nature of the rocks and the mineralizing solutions.

Shear zones are another type of fracture which can become filled. They are areas of many closely spaced parallel fractures. Other deposits resulting from filling are stockworks, solution cavities, and permeable beds like sandstone. Stockworks are an interlaced network of tiny fractures. Permeable beds like sandstone often contain oil and natural gas.

Sedimentary Deposits

Sedimentary deposits are syngenetic in origin. Their formation depends upon an adequate supply of new materials, a method of gathering by solution or some other source, a means of transportation, and a mode of deposition.

When these conditions occur for long periods of time, very large bodies of ore can be formed. Some geologists have recently been theorizing on what are now replacement deposits and believe that they may be syngenetic in origin.

The best known deposits of sedimentary origin are perhaps certain iron ores. The source of the iron is from iron bearing igneous minerals like hornblende and mica and also from sedimentary and metamorphic rocks. Upon weathering, these minerals and rocks supply both ferrous and ferric iron. The ferrous group is directly soluble while the ferric must be changed to ferrous iron by the action of various salts in solution.

The iron remains in solution until the waters undergo some physical or chemical change. Deposition will occur in a number of instances. When iron solutions contact carbonate rocks, iron carbonate or iron oxides may be deposited. Other ways in which iron deposits may be formed are by evaporation when solutions come to rest, by contact with organic substances, and by the decrease of the carbon dioxide content in the solution. If these methods fail, perhaps the solutions will be transported to bogs and lakes where, ^{their mineral content} they may be deposited by the action of various iron bacteria.

Manganese is also a sedimentary deposit formed very similarly to iron. Other deposits resulting from sedimentation are coal, sulphur, and dolomite.

Evaporation

The formation of mineral deposits by evaporation is relatively simple. Formation occurs quite rapidly in warm, arid climates. Deposits of this nature are typically saline and occur only when a solution becomes saturated with respect to some particular salt. The least soluble salts precipitate first but again their solubility depends upon the presence of other salts and the temperature of the solution. Formation of complex salts will depend upon the rate of evaporation. Typical deposits of this type are gypsum and sodium carbonate.

Mechanical Concentration

The formation of mineral deposits by mechanical means involves two distinct processes: 1) the disintegration of rocks, and 2) the transportation and concentration by water and air. Concentrations by mechanical processes requires that the minerals have high specific gravities, chemical stability, and durability.

Minerals are prepared for transportation by mechanical and chemical weathering and transported by wind and water. Placer concentrations occur when stream velocities are suddenly reduced, the lighter particles being carried away and the heavier ones being left behind. Concentration is also dependent on particle size, the coarse particles being left near the origin.

There are a number of types of placers. Fluvial placers are those formed by stream action and are by far the most common. ^{Aeolian} ~~Eolian~~ deposits are those formed by wind action. Eluvial placers are formed by the creep of material down hillsides. There are also beach placers.

Residual Concentration

Residual concentration is a result of chemical weathering whence certain minerals are removed and others left to form a deposit. Concentration is due largely to a volume decrease.

The formation of economic residual deposits demands a rock which contains minerals of economic importance and in which the undesirable minerals are chemically weatherable and the desired ones are not. Climatic conditions must favor chemical decomposition and relief must not be too great otherwise the deposit will be washed away. The earth's crust must also be stable for a long period of time so that formation of the deposit is not disturbed. Under these conditions iron bearing limestones will be dissolved leaving a concentration of iron. Similarly, feldspars decay to form bauxite, the common source of aluminum.

Oxidation and Supergene Enrichment

As ore deposits become exposed to weathering by erosion they are acted upon by air and water which results

in oxidation. The deposit eventually becomes leached and the minerals carried down into the earth's crust. As the solutions seep downward they will lose part of or all of their metallic content which results in an oxidized ore deposit. If the solutions penetrate the water table the metals may precipitate to form a deposit of secondary or supergene enrichment. Some sulphide deposits are formed by supergene sulphide enrichment.

Supergene oxidation and enrichment go hand in hand. The process consists of 1) oxidation and solution in the zone of oxidation, 2) deposition in the zone of oxidation, and 3) supergene enrichment.

Metamorphism

Metamorphic processes, excluding contact metamorphism, alter pre-existing mineral deposits to form new ones. Heat, pressure, and water are the main agencies involved in the process. They react on the rocks and minerals and cause recrystallization and recombination.

Summary

The basic constituents of mineral deposits are derived chiefly from magmas. In the initial stages of crystallization various components become segregated and as cooling continues residual liquids are left behind which may or may not be injected into fractures and joints in the

country rock. Secondary processes now take over.

Weathering of all kinds releases valuable minerals from the rocks and redeposits them elsewhere. Metamorphism alters pre-existing deposits and organic processes result in coal and oil. Thus, it is evident that the types of economic mineral deposits are varied, complex, and often unrelated.

The Sullivan Ore Body

The Sullivan Mine is situated in the south eastern corner of British Columbia, one half mile west of the City of Kimberley. This mine, which is the world's largest single producer of lead, zinc and silver, is owned and operated by the Consolidated Mining and Smelting Company of Canada, Limited.

The senior company geologists believe that the ore is a hydrothermal replacement deposit. However, a few of the junior members have lately been discussing the possibilities that the ore is syngenetic or sedimentary in origin. The ore in different parts of the mine supports evidence in favor of both theories. The syngenetic theory has not yet been accepted by the senior geologists.

The Hydrothermal or Replacement Theory

In the south and north sections¹ of the mine there

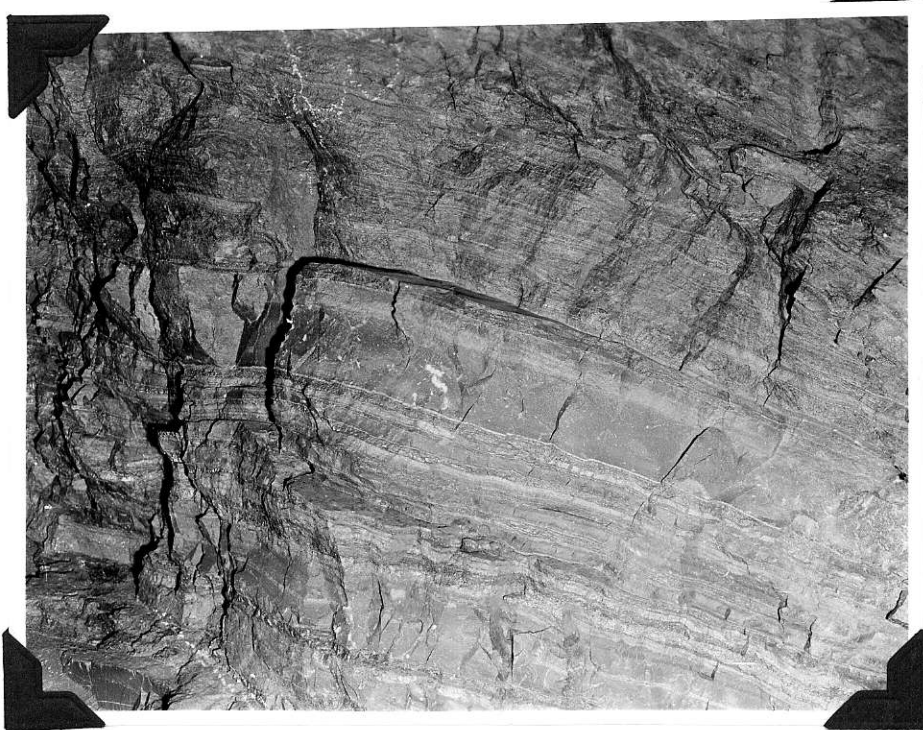
¹ The mine consists of four sections: North, South, Center and below 3900 feet.

is considerable evidence of^a hydrothermal origin. The pure sulphide ores show exceptionally good bedding planes in spite of the fact that they are highly contorted by folding. Disseminated mineralization extends for several feet into the highly altered footwall and hanging-wall rocks of the ore body. Originally the rocks were argillites but due to hydrothermal reaction, faulting, folding, and shearing, they have been altered to chlorites and "cherts".² The so called "cherts" are actually fine tourmaline and quartz which resemble chert in appearance.

The majority of the alteration in the south end is chloritic and contains a fair amount of disseminated mineralization in the form of individual pyrite crystals. In the north section, considerable quantities of tourmalized alteration is present. The disseminated mineralization in the chert consists of pyrrhotite in several forms. These include pyrrhotite laminations, which identify the original bedding, and conglomerates, partially or wholly replaced by pyrrhotite and sometimes containing a pyrrhotite halo around the pebble. Another alteration product, which is found in the hangingwall, is albite. In general, the cherts which occur mainly in the footwall, have retained nearly all of the original structures. The albite however, contains very little disseminated mineralization

² The word "chert" is a misnomer as the rocks are not true cherts.

and replacement seems to have been accompanied by a great deal of fracturing which has obliterated many of the original structures.



Banded Ore From Below 3900 Feet Section

The ore consists of lead-zinc-iron sulphides with some silver. The ores are mainly banded and are controlled stratigraphically.³ The photograph shows well banded ore in the below 3900 feet section of the mine. Note the relatively large thickness of the two waste bands, one at the bottom and the other across the centre. The other bands are lead-zinc-iron sulphides.

³ Refer to Appendix I.

The replacement theory is used to explain the large massive iron sulphide zone in the central part of the mine. It seems improbable that this large body of pyrite could be sedimentary in origin.

In some parts of the mine, what appears to be definite stages of replacement are often noticed. One instance was noticed where the sulphides appeared to be replacing dolomitized limestone. Observations of this nature ^{however,} cannot be conclusive since they are not common in occurrence.

The Syngenetic or Sedimentary Theory

The section of the mine below 3900 feet displays the most evidence of a sedimentary origin. The ore is well banded and shows very distinctly the individual bands of sulphide and unaltered silty argillites.⁴ There is very little alteration of the country rock in this section of the mine but there is disseminated mineralization extending to considerable depths in the footwall. Disseminated sulphide mineralization is also found in the same rock types as found in the mine but occurring many miles away from the mine or any known concentration of ore. However, the fact that the interbedded argillites are unaltered supports a sedimentary origin. Research to date on this theory is not extensive and few conclusions can be drawn.

4 Refer to photograph.

Summary

The presence of disseminated mineralization near the ore and the large amounts of alteration in the upper parts of the mine exemplify the theory of replacement. In the lower section of the mine however, one would think that the interbedded argillites would be highly altered and partly replaced if the ore was hydrothermal. The hydrothermal theory also requires that enormous volumes of sulphide bearing solutions would be necessary to replace the rocks. Such a requirement seems very unlikely. In spite of any new data, the ore deposit is still considered to be a replacement deposit.

Conclusion

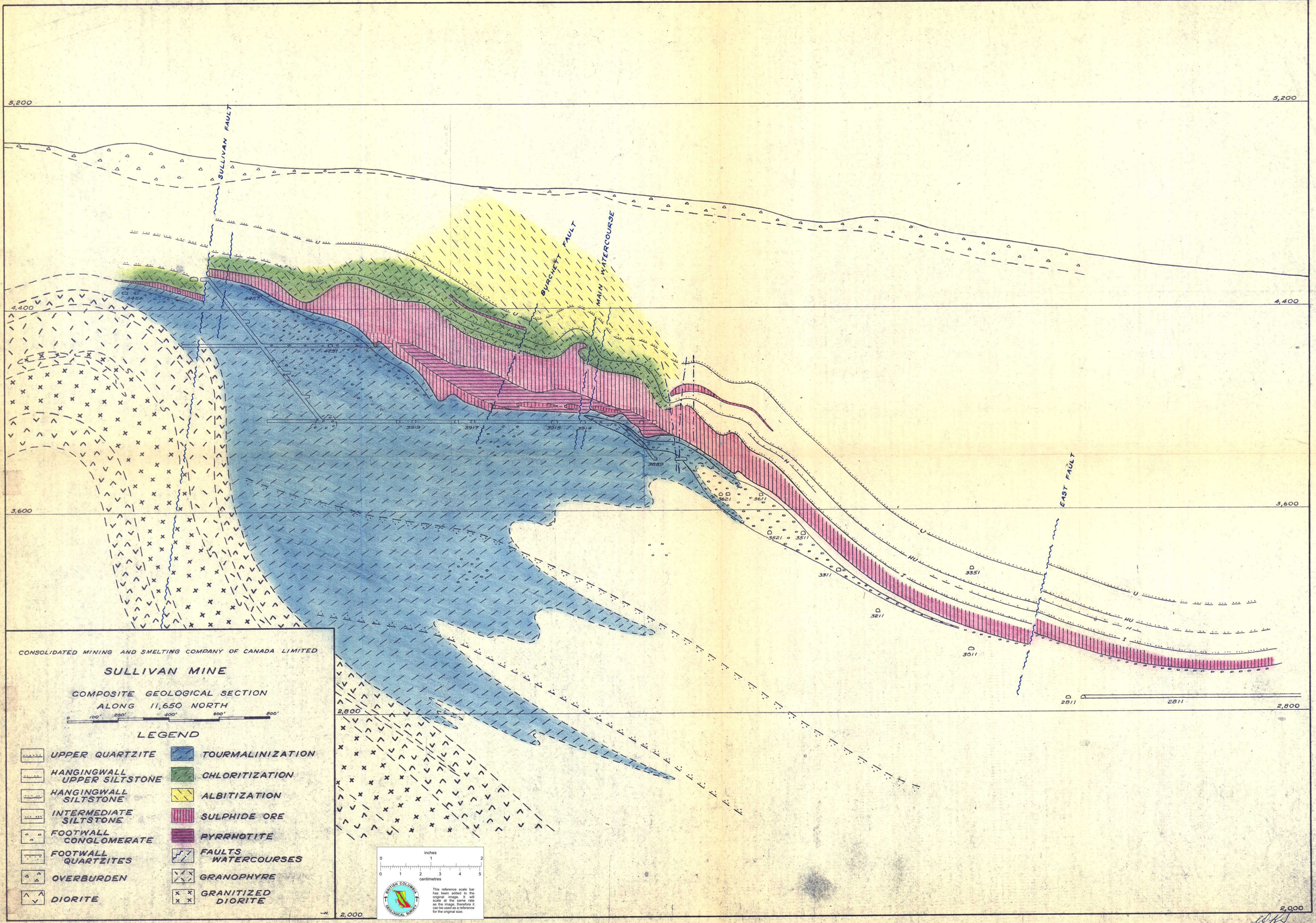
In the first part of the essay an attempt was made to give the reader an understanding of how various types of ore bodies are formed. With this knowledge an explanation of the ore at the Sullivan Mine was given. Although the discussion of the Sullivan ore is in no way complete it does give some insight into the nature of the ore and the problems involved in coming to a definite conclusion. At the present time the ore is considered to be hydrothermal but new evidence may or may not prove it to be different.

WORKS CONSULTED

Bateman, Alan M., Economic Mineral Deposits, 3rd Printing
1947.

APPENDIX

Composite Geological Section Along Latitude 11,650 North.



CONSOLIDATED MINING AND SMELTING COMPANY OF CANADA LIMITED

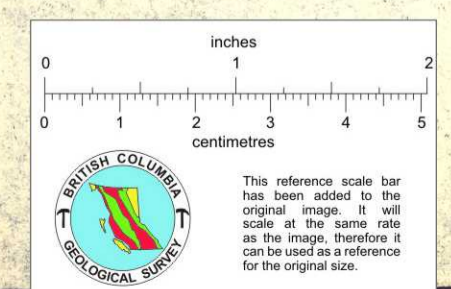
SULLIVAN MINE

COMPOSITE GEOLOGICAL SECTION
ALONG 11,650 NORTH



LEGEND

- | | | | |
|--|-----------------------------|--|--------------------|
| | UPPER QUARTZITE | | TOURMALINIZATION |
| | HANGINGWALL UPPER SILTSTONE | | CHLORITIZATION |
| | HANGINGWALL SILTSTONE | | ALBITIZATION |
| | INTERMEDIATE SILTSTONE | | SULPHIDE ORE |
| | FOOTWALL CONGLOMERATE | | PYRRHOTITE |
| | FOOTWALL QUARTZITES | | FAULTS |
| | OVERBURDEN | | WATERCOURSES |
| | DIORITE | | GRANOPHYRE |
| | | | GRANITIZED DIORITE |



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