

ORIGIN OF THE SULLIVAN ORE DEPOSIT

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The Sullivan orebody at Kimberley, BC, is one of a small number of giant lead-zinc-silver deposits on earth. Total mined production was 165 million tons (150 million tonnes) of ore at a grade of 2 oz Ag per ton, 5.95% Pb and 5.49% Zn. Adjusting for massive amounts of dilution incurred because of pillar mining and intentional dilution of the thick inter-ore waste that was eliminated prior to grinding, the initial deposit was close to 110 million tonnes at a grade of 17% Pb+Zn and 3 oz per ton Ag. Metal produced was 337 million ounces of silver, 9.8 million tons of lead and 9.1 million tons of zinc. At Nov 4, 2010 metal prices (Ag \$25.50 per oz, Pb and Zn \$1.13 per pound) the value of this production is about U\$50 billion. The orebody had a lens shape and was about 1.5 by 2 km across and from 10 to 100 metres thick.

Sullivan is a sedimentary exhalative (SEDEX) deposit that accumulated in the very bottom of an elongate sub-basin in an ancient ocean. Sediments that accumulated in this ancient ocean were muds, silts and sands. The sub-basin was a depression that formed on the marine floor in response to movement on faults. Some of the fault movement may have been initiated by intrusion of thick sub-horizontal tabular (50 to 300 metres thick) bodies of gabbro magma 1 to 2 km below the sea floor. Instability in the wet sediments on the ocean bottom resulted in collapse of the sides of the sub-basin. At the same time mud volcanoes developed where release of water from great depth fluidized and transported sediment up portions of some of the faults. A very irregular topographic surface was formed. Today rocks of the mud volcano feeder and mound are very distinctive pebble fragmentals and they contrast sharply with the layered sediments from and within and on which they developed.

Heat from the gabbro intrusions warmed water in the pores of adjacent sediment. This water dissolved trace amounts of metals and as it warmed it rose by convection and exited through vents on the sea floor. The faults and conduits of mud volcanoes provided discharge and recharge pathways for the convection cells that are believed to have been tens of kilometres across. At the discharge points metals combined with sulphur from sea water to form metal sulphide minerals. These minerals accumulated as a mound above the vent field and filled in adjacent low points. Thickness of accumulated sulphides was greatest in the vent area a lens shape deposit was the result. Veins of sulphide minerals beneath the deposit mark the pathways some fluids traveled. Distinctive tourmalinite alteration of footwall rocks in a zone about 500 metres in diameter beneath the central part of the deposit formed by introduction of boron-rich fluids immediately prior to introduction of the metals. Albitite dikes in the footwall, albite-chlorite-calcite-pyrite alteration at the ore horizon directly above the tourmalinite and extensive albitite alteration above the deposit mark the final sodium-rich phase of fluid introduction into the immediate post ore environment. This fluid was depleted in boron and ore metals. Part or all of the albite was related to the introduction of a pair of tabular gabbro bodies that form an arch primarily below, but at its highest levels crosscut the deposit.

The main sulphide minerals at Sullivan are pyrrhotite and pyrite (both iron sulphides), sphalerite (zinc sulphide) and galena (lead sulphide). When the sulphide mound formed above the vent field it was a topographically high feature and there are virtually no other sediments in it. In the surrounding moat-like depression both sulphides and normal sediments accumulated. In this part of the deposit the sulphide minerals are typically in thin (less than 10 mm) monomineralic layers interbedded with (from less than 10 mm to 10 metre thick) layers of sediment. This sediment regularly collapsed from the sides of the sub-basin or was introduced as part of the normal sedimentary influx onto the ocean floor. Some of the sediments that normally would have produced layers a few tens of centimetres thick over an area hundreds of kilometers across flowed into and were confined within the sub-basin resulting in beds up to 10 metres thick.

Since burial geologic forces have affected the deposit over the subsequent 1.5 billion years. Especially notable are the effects of folding and faulting that are well displayed by thin sulphide layers. When they were folded these rocks were at a depth of 3 to 5 km. At such depths ductility of sulphides is more like tooth paste, in contrast to adjacent normal rock which would have been relatively brittle.

It is interesting to note that when the sulphides were initially deposited they rapidly became brittle and rock hard, whereas the normal sediments depositing at the same time were water saturated muds that remained fluid until the water was ultimately squeezed out during compaction. Evidence of early brittle deformation of sulphides at Sullivan is common.

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