International Symposium on Regional Groundwater Flow:
Theory, Applications and Future Development

Karst and Regional Groundwater Dynamics at Pine Point MVT Lead-Zinc Deposits, NWT, Canada

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1. Introduction

The genesis of MVT ore deposits, like those at Pine Point Mines in Canada, has been the subject of debate for many years. The consensus is that the ore bodies were caused by hydrothermal saline water far in the geological past from the Middle Devonian age to the Tertiary age. *Garven* [1985] pointed out, however, that '*from a hydrologic perspective, ore genesis could have taken place at any period in which gravity-driven flow systems were operative*.' Presently those gravity-driven flow systems are in place. Understanding their groundwater dynamics could put in context some of the previously established Pine Point ore genesis hypotheses. It is generally said that, based on isotope and fluid inclusion data, the temperature of the ore forming fluid in the Pine Point area must have been hydrothermal in a temperature range approaching 100 °C or more. The average homogenized temperature in fluid inclusions in dolomite in the area is 116 °C and the burial temperature about 70 °C according to *Qing* [1991].

2. Groundwater dynamics and chemistry in ore formation

Skinner [1979, p. 9] lists six reasons for flow in modern hydrothermal systems, summarized here as:

1. Gravitational hydraulic flow between outcrop source and outlet of an aquifer,
2. Flow by lithostatic pressure,
3. Osmotic pumping,
4. Flow by density differences, convection cells,
5. Very saline liquid sinks to bottom, displaced water flows upward,
6. Upward flow from cooling magmas, the classic, magmatic hydrothermal solution.

None of these six systems confirm to the physics of *Hubbert's* (1940) force potential and its successors, modern groundwater flow systems theory introduced by *Tóth* (1962) and *Freeze and Witherspoon* (1967). Figure 1A and 1B show the differences in the role of aquitards.

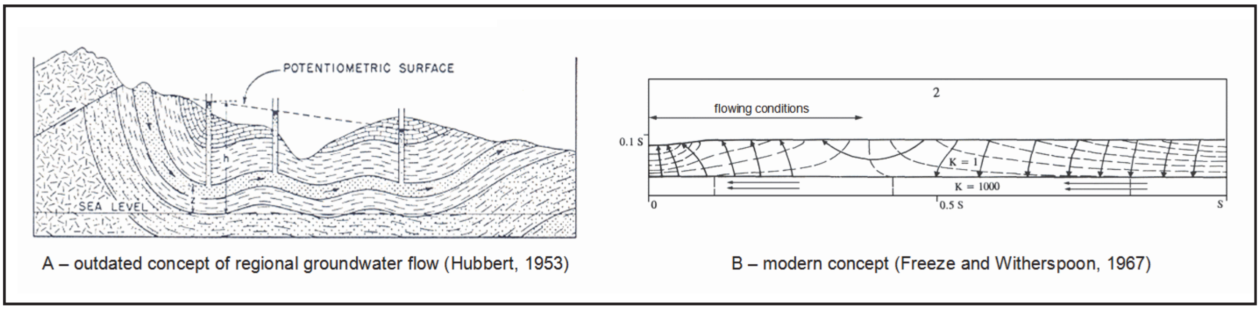

Figure 1. Comparison of outdated [Figure 1A; *Hubbert*, 1953] and modern [Figure 1B; *Freeze and Witherspoon*, 1967] concepts with respect to the role of aquitards in regional groundwater flow.

While the outdated gravitational flow concept of Skinner (Point 1 above), depicted here in Figure 1A taken from *Hubbert* [1953], restricted regional groundwater flow to the aquifer systems and considered the aquitards to be impermeable, *Freeze and Witherspoon* [1967] showed that the aquitards were an integral part of regional flow systems. This paper applies the paradigm shift introduced in 1967 by Freeze and Witherspoon. Accordingly, the Pine Point deposits will be put into a framework of present-day, physically consistent regional groundwater flow systems.

Skinner's [1979] six systems of contemporary hydrothermal flow, and hydrothermal flow considerations by other authors, generally assume abiotic processes to cause the actual ore precipitation. That is the reason elevated hydrothermal temperatures have so far been considered as a necessary precondition to create the chemical environment required for the precipitation of ore bodies.

This paper illustrates that a presentl microbacterial population creates and maintains reducing conditions at the Pine Point ore bodies, and, after abandonment of the mine, maintains a black-smoker-like artesian groundwater discharge within at least one borehole close to one of the abandoned open pits left behind after the nearby ore body had been mined (Figure 2B).

3. Regional and local hydrogeological investigations

When, in 1975, mining of ore at open pit R-61 was unexpectedly hampered by rising groundwater, a joint four year investigation was started by Cominco Ltd. (the owner of the Pine Point Mines) and the Hydrology Research Division of Environment Canada' resulting in an exhaustive shared report [*Weyer*, 1983].

It turned out that several karstic flow systems with differing chemistry do presently meet at the location of the ore bodies. While some of the flow systems are dominated by sulphur chemistry, a deep flow system penetrates upward from depth and is dominated by NaCl chemistry. By the example of dewatering the W-17 pit we show that these flow systems meet at ore bodies. At the ore body A-55, igneous rocks of the nearby Canadian Shield were found in the centre of the ore body (*Alldrick* 1982; *Weyer*, 1983). This find indicates an effect of the Laurentide ice sheet on the A-55 ore body and, by implication, also on others. There have been different explanations provided in the literature, all related to the karstic nature of the rock and the position of all ore bodies within karstic features.

At Pine Point, groundwater flow within the karst is very pronounced. In fact the mine eventually closed because of dewatering problems. The amount of flow exceeded 3 m^3/s at some ore bodies and thereby made mining uneconomical.

After the abandonment of the mine groundwater flow systems reverted close to their original state. Presently part of the area of Pine Point Mines is again a discharge area with artesian boreholes. At pit X-15 one of these boreholes discharges sulphur dominated water (Figure 2A), another one nearby discharges black water containing metal sulphides (Figure 2B). This would indicate that today's groundwater flow systems may replicate the situation which led to the genesis of the Pine Point MVT ore bodies. The temperature of the discharging groundwater is about 3 °C. In the area of the ore bodies SO_4 is reduced by bacteria to HS^- and H_2S.

Figure 2. Discharge sulfurous water (Figure 2A) and metal-containing saline water (Figure 2B: a cold 'black smoker') from artesian open boreholes located close to each other, probably in the area of the X-15 ore body. Flow from borehole on Fig 2B estimated to be 1-2 litres/sec.[Source: YouTube video "Pine Point Mine: History in the Landscape" (http://www.youtube.com/watch?v=DgY6biryzQc) uploaded by "*jsandlos*".]

4. Conclusions

This study, for the first time, puts the occurrence of the Pine Point ore bodies into a regional hydrogeological framework by collecting hard chemical, isotope, and hydrodynamic data for all of the groundwater flow systems in the area.

Regional groundwater flow systems recharge south of Pine Point on the Caribou Mountains and its foreland. There is presently no hydrothermal component of groundwater flow; the actual groundwater temperatures at the ore bodies are about 3 °C. Metal-containing saline and sulfur-containing groundwater flow systems meet within karst systems at the site of the ore bodies, which are also contained in karst systems. Ore bodies may have been precipitated and/or reworked since glacial times or before. Presently precipitation of metals occurs as indicated by the black-smoker-like artesian discharge from a borehole (Figure 2B). Rocks from the nearby Canadian shield were found within the A-55 ore body and possibly within others. Bacteria presently reduce the sulfur at the sites of the ore bodies and make H_2S available for mineral and possible ore precipitation. As the sulfur reduction is biotically driven and maintained, there is no need for an abiotic hydrothermal driven chemical reduction and precipitation mechanism which has been difficult to explain.

The results obtained indicate that there may be an alternate explanation available for the genesis of the Pine Point MVT ore bodies. More dedicated studies would be needed.

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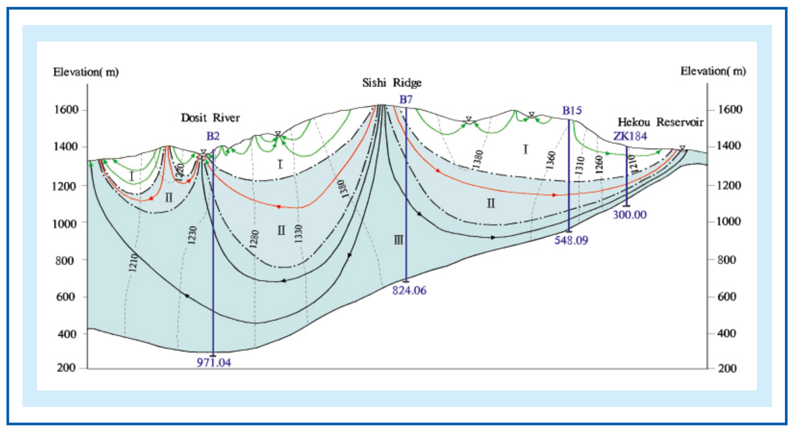

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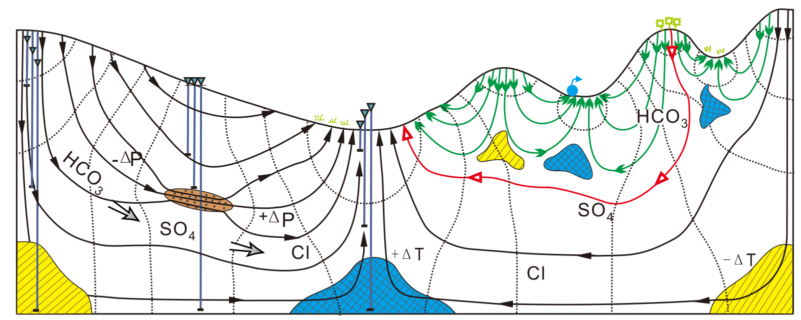

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