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Groundwater Dynamics and Microbiological Reduction as Possible Factors in the Precipitation of the Pine Point MVT Pb-Zn Deposits

K. Udo Weyer[1] and David H. Adams[2]
[1] WDA Consultants Inc. (corresponding author: weyer@wda-consultants.com)
[2] Cominco Ltd. (retired).

Summary

At Pine Point, presently active groundwater flow systems precipitate mineralization at and close to known MVT ore deposits at a groundwater temperature of about 3°C. Metal-containing saline and sulfur-containing groundwater flow systems meet within karst at the site of the ore bodies. The necessary reducing conditions have been created and are maintained by bacteria.

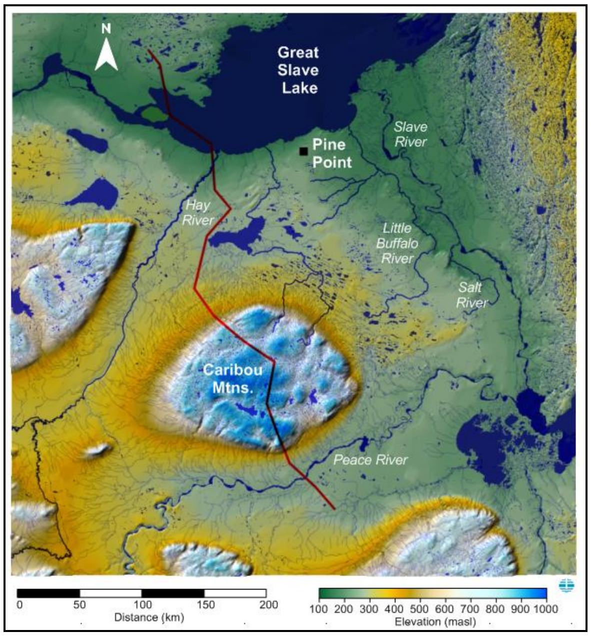
Introduction

The genesis of Mississippi-Valley Type (MVT) ore deposits, like those at Pine Point in Canada, has been the subject of debate for many years. The consensus is that the ore bodies were caused by hydrothermal saline water in the geological past from the Middle Devonian age to the Tertiary age. Garven (1985) pointed out that '*from a hydrologic perspective, ore genesis could have taken place at any period in which gravity-driven flow systems were operative*.' Presently favorable gravity-driven flow systems are in place. Understanding their groundwater dynamics puts some of the previously established hypotheses on the Pine Point ore genesis into a new context. It is generally said that, based upon 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 saddle dolomite in the area is 93-106°C (Qing and Mountjoy, 1994a) and the burial temperature has been estimated to be about 70 °C (Qing and Mountjoy, 1994b). Fluid inclusions suggest that the sphaelerite was deposited at temperatures from 51 to 99°C (Roeder, 1968; Kyle, 1981). This paper shows, however, that mineralization presently occurs at 3°C water temperature, driven by microorganisms.

Regional groundwater flow systems within the Pine Point hydrodynamic basin

For deep groundwater flow, the Pine Point hydrodynamic basin is dominated by the regional recharge areas Caribou Mountains and their forelands and the discharge areas Peace River towards the south, Hay River (downstream of the falls in the west), the Little Buffalo River, the lower reach of its tributaries and the Salt River in the east and Great Slave Lake in the north. The area south of the shoreline is part of this system with a pronounced discharge area which includes the linear locations of the Pine Point ore bodies (Figure 2). Besides hydrodynamic indications, the results of chemical and isotope data from samples taken by Weyer (1983) confirmed the existence and character of the discharge areas for deep regional groundwater flow and the general pathways of the discharging groundwater (Weyer at al., 1979).

Figure 3 shows schematically the deep groundwater flow systems within Cretaceous and Paleozoic layers. The upper cross-section with a vertical exaggeration of 85:1 is hydrodynamically severely distorted as the comparison to the lower cross-section with a vertical exaggeration of 10:1 indicates.



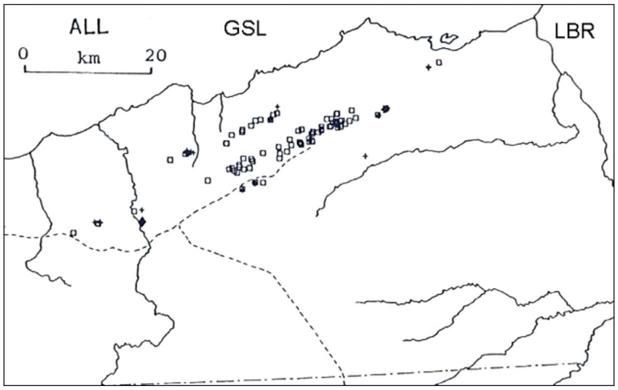


Figure 2: Location of ore bodies [squares] and mineral showings [crosses; >1% metal contents] from available borehole logs and other sources publically available for evaluation. GSL = Great Slave Lake. LBR = Little Buffalo River. Modified from Weyer (1983, Fig 3-50.)

Figure 1: Area of the Pine Point Mines regional groundwater flow study showing position of cross-section by Meijer-Drees (1985), here redrawn as Figure 3.

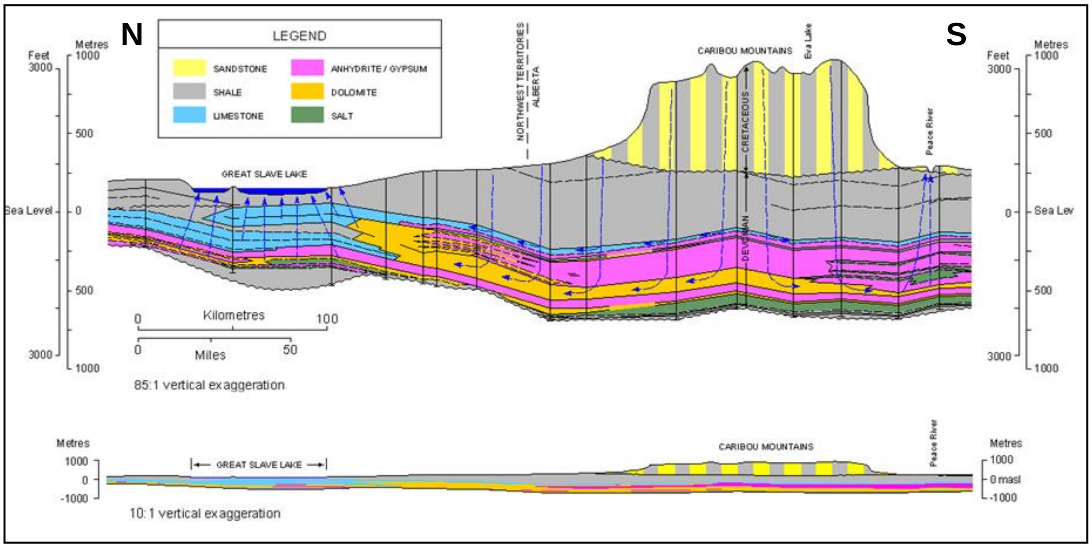


Figure 3: Schematic outline of deep groundwater flow systems in the Pine Point hydrodynamic basin. Geology and surface topography redrawn from Meijer-Drees (1985).

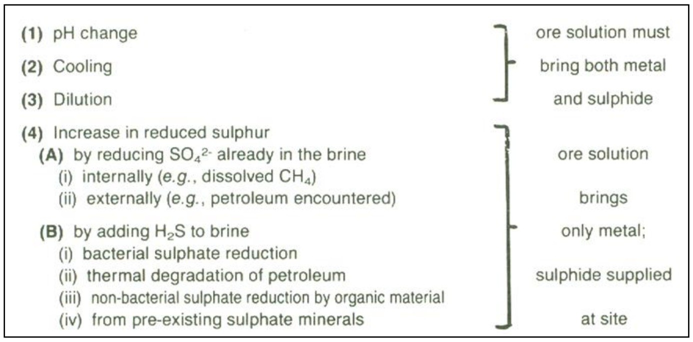
Conditions for MVT ore formation

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 successor, modern groundwater flow systems theory introduced by Tóth (1962) and Freeze and Witherspoon (1967). 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.

Anderson and Macqueen (1988, Table 2) give the following reasons for deposition of ore:



(1) pH change **(2)** Cooling **(3)** Dilution	ore solution must bring both metal and sulphide
(4) Increase in reduced sulphur **(A)** by reducing SO_4^{2-} already in the brine (i) internally (*e.g.*, dissolved CH_4) (ii) externally (*e.g.*, petroleum encountered) **(B)** by adding H_2S to brine (i) bacterial sulphate reduction (ii) thermal degradation of petroleum (iii) non-bacterial sulphate reduction by organic material (iv) from pre-existing sulphate minerals	ore solution brings only metal; sulphide supplied at site

Table 1: Reasons for deposition. From Anderson and Macqueen (1988, Table 2).

Figure 4 illustrates that, at present, a microbacterial population creates and maintains reducing conditions at the Pine Point ore bodies, and, since abandonment of the mine, maintains a black-smoker-like artesian groundwater discharge at an open borehole close to one of the abandoned open pits left behind after the ore body had been mined (Figure 4B).

Figure 4: Discharge of sulphurous water (Fig. 4A) and metal-containing saline water (Fig. 4B: a cold 'black smoker') from artesian open boreholes located close to each other in the area of the X-15 ore body. Flow from borehole on Fig 4B estimated to be 1-2 litres/sec. (Source: YouTube video "Pine Point Mine: History in the Landscape": http://www.youtube.com/watch?v=DgY6biryzQc)

Regional and local hydrogeological investigations at Pine Point Mines

When, in 1975, mining at the 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. The results were reported by Weyer (1983).

It turned out that several groundwater flow systems with differing chemistry presently meet at the location of the ore bodies. While some of the flow systems are dominated by sulphur chemistry (Figure 4A), a second deep flow system penetrates upwards from depth and is dominated by NaCl chemistry (Figure 4B). By the example of dewatering the W-17 pit, we show how these flow systems meet at ore bodies (Fig 5, 6). 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 may indicate a profound effect of groundwater flow systems on the A-55 ore body at the time of the Laurentide ice sheet and, by implication, also on others.

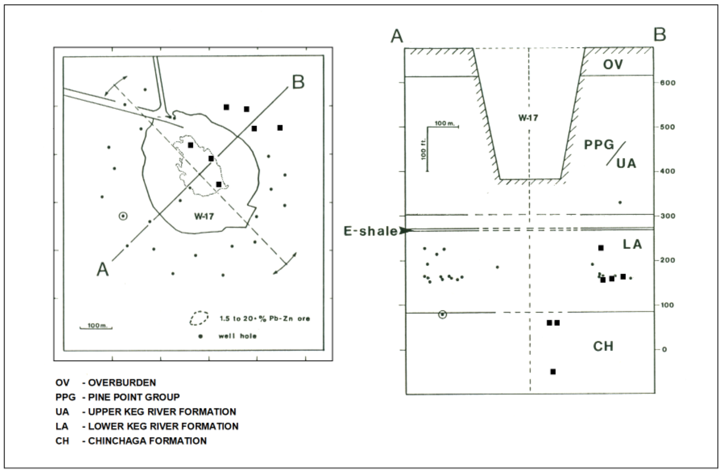


Figure 5: Plan and cross-section of open pit W-17, showing geologic cross-section, depth of pumping well and salt concentrations [squares = saline water]. Figure after Weyer (1983).

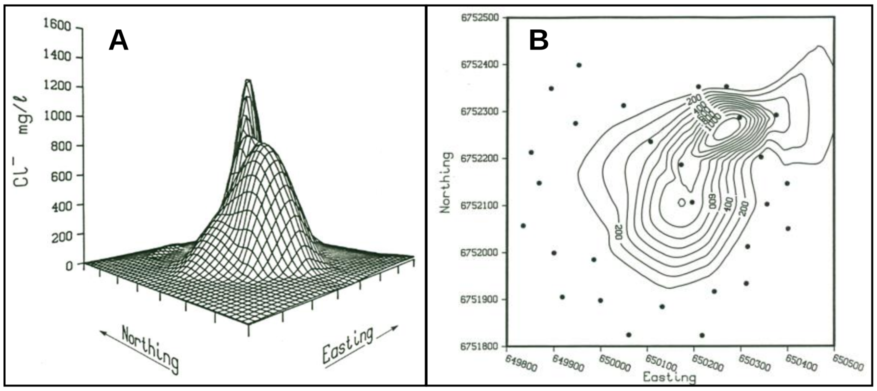


Figure 6 (above): 1977 Distribution of Cl- concentrations at open pit W-17. Dots indicate the wells sampled. Figures from Weyer (1983, Fig. 5-12 [B] and 5-13 [A]).

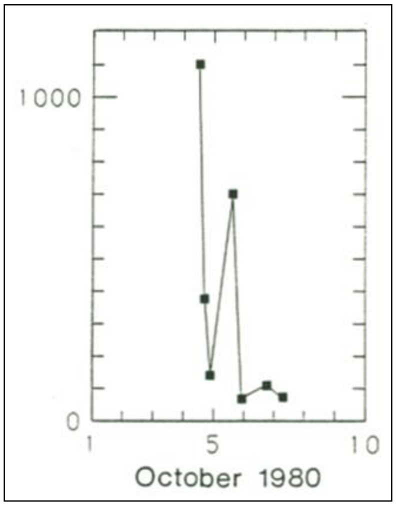


Figure 7 (right): Changes of Thiobacillus population [MPN/100 ml] during K-77 pump test. Figure modified from Weyer (1983, Fig 5-25).

The dewatering activity at Pine Point established that groundwater flow at some ore bodies exceeded 3 m^3/s which in the end made mining less economical and caused the closure of the mine. The temperature of the discharging groundwater has been about 3°C (Weyer, 1983). Close to the ore bodies dissolved SO_4 is reduced by bacteria to HS^- and H_2S as shown in Figure 7. 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.

Conclusions

At Pine Point, presently active groundwater flow systems precipitate mineralization at and close to known MVT ore deposits at a groundwater temperature of about 3°C. Metal-containing saline and sulfur-containing groundwater flow systems meet within karst at the site of the ore bodies. The necessary reducing conditions have been created and are maintained by bacteria.

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