Lupin Mine (Canada)

Description: The Lupin gold mine in the Nunavut Territory of Arctic Canada, has been studied as an analogue to the periglacial conditions that might possibly exist in northern Europe in the far future. More specifically, the effects of deep-penetrating permafrost on subsurface hydrogeological and geochemical processes have been studied. Proposals to study permafrost conditions 'in situ' in Finland arose from these observations, suggesting that a previous 'cold period' signal could be discerned in several Finnish groundwater studies.

During a reconnaissance phase between 2000 – 2001, the Lupin mine was chosen as a focus of study. Deciding factors were the presence of an adequate thickness of permafrost (about 500 m), a suitable bedrock formation and good mine infrastructure to enable underground work. The Research team consists of the Geological Survey of Finland (GTK), Posiva Oy, Finland, the Swedish Nuclear Fuel and Waste Management Co (SKB), Nirex, UK, Ontario Power Generation (OPG) and the University of Waterloo, Canada. Phase I of the agreed project was launched in summer 2001 and was completed and reported on one year later (Ruskeeniemi et al. 2002).

The main focus of the study is on the effects of permafrost on the hydrogeochemistry and hydrogeology of the permafrost base. Dissolved salts are not accommodated in the ice lattice, but are segregated during permafrost formation. The question then arises as to whether the segregated material remains in isolated pockets in the ice, concentrates on mineral grain boundaries, or forms an increasingly saline front below the propagating freezing front. Another point of interest concerns the formation of solid methane hydrates, so-called 'clathrates', in the freezing front. Clathrates are only stable in low-temperature-high-pressure conditions. The possibility of being able to make direct observations on the stability and mode of fracturing of frozen bedrock was also considered to be a possible outcome of the work. Unfrozen bedrock 'windows', known as 'taliks', develop below major watercourses even within continuous permafrost areas, and the near-by Lake Contwoyto was considered to be large enough to have a similar effect.

The Lupin mine is located about 1300 km north of Edmonton, from where the mine is serviced by air. An ice-road connection is available in winter, facilitating transportation of heavy equipment. The Lupin gold deposit was discovered in 1960 as a result of a reconnaissance sampling and mapping campaign. Gold production in Lupin started in 1982 and continued until being suspended temporarily in 1998, after which it was re-opened in 2000. During summer 2003 the mining operation was again suspended for the evaluation of economic factors and available ore reserves. The long-term average gold production has been about 5.5 tons per year.

The site is within the zone of continuous permafrost, where the thickness of frozen bedrock is typically more than one hundred meters. The site, about 80 km south of the Arctic Circle, on the western shore of Lake Contwoyto, lies in the continental sub-arctic climate zone. Monthly mean temperatures vary from about +10° C in July to about –30° C in January, resulting in an annual mean temperature of approx. –11° C.

Figure 1. The Lupin gold mine is situated in arctic Canada about 200 kilometers above the timberline.

Due to low precipitation and thin snow cover, the ground freezes completely during winter, while only the uppermost soil cover thaws during the summer. The vegetation at the site, some 200 –300 km above the timberline, is typical of tundra, consisting of low-growing shrubs, berries and grasses. Underground, below about 150 m, monthly temperature variations disappear. Below that depth, the rock temperature increases downwards, reaching $0^{O}C$ (i.e. the base of the permafrost) at a depth of 540 m in the mine.

The crystalline bedrock at the site is Archean in age (2.5 Ga). The gold ore is hosted by a banded amphibolitic iron formation, within a metasediment sequence. The original turbidite sediments, formed on the seafloor, have been metamorphosed and deformed into a sequence of crystalline metamorphic rocks. The main rock types are meta-graywacke, phyllite and a banded amphibolitic iron formation. The sequence belongs to the Contwoyto Formation, which is a part of the Yellowknife Supergroup. The geology of the site is described in detail by Bullis et al (1994).

The gold-bearing amphibolite horizon is nearly vertical and strongly folded. Mining is carried out as an underground operation. Access to the mine is by shaft or ramp. The main shaft reaches a depth of about 1200 m, but actual operations reached a depth of about 1500 m in 2003. A schematic 3D presentation of the mine is shown in Figure 2.

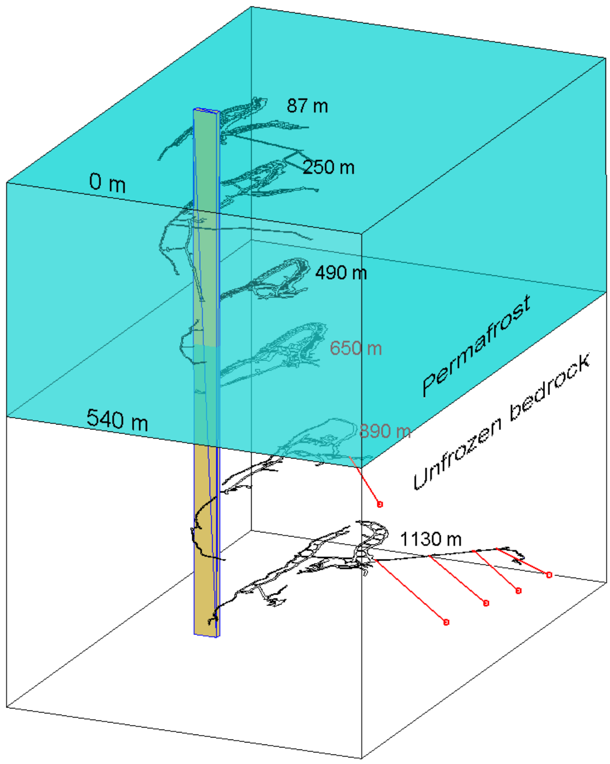


Figure 2. A schematic 3D representation of the Lupin mine. Main levels are shown, and the shaft is indicated in brown. Some of the flowing (horizontal) drill holes are shown in red.

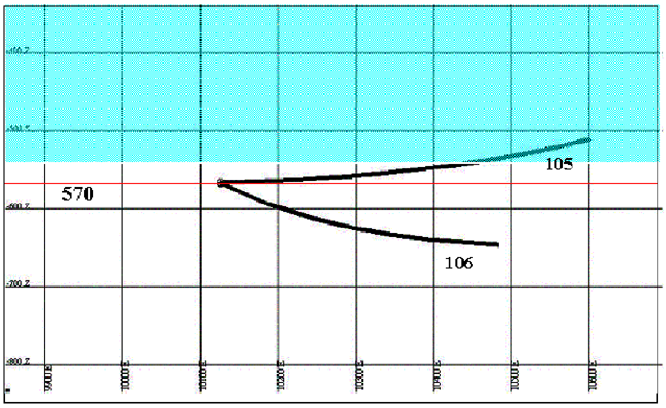
The main maintenance levels are shown, but operational mining levels are at 20 m intervals. The permafrost project had access to the ramp area and certain other secure areas. The 570m level was considered to be appropriate for the study of the base of permafrost (at 540 m) and of the conditions below the permafrost.

The mine is considered to be very dry, the average inflow being about 50 000 m^3/year. This is a small amount compared to the volume of the underground workings, as the figure also includes piped water for operational use. Flowing boreholes were encountered at the 890m and 1130m levels. Incoming water is collected in sumps and used as circulation water for drilling. Drilling in the upper frozen bedrock was carried out using brine (NaCl). As a consequence, most of the water samples near the shaft were considered to have been contaminated by the drilling water.

The first field trips to the site focused on the collection of existing data. Geological and structural information was provided by the mine authorities. On the surface, Quaternary formations and morphological features were studied, and seismic surveys carried out. Water samples were taken where possible, and the flowing boreholes at depth proved to be of special interest. When possible, a video survey of the drill hole was performed, in order to locate open fractures. Based on this preliminary information, a three dimensional structural model of the potential water-conducting structures was constructed. The existence of several vertical, possibly water-conducting, structures was postulated.

The presumption of a deep saline front below the permafrost was studied using a geophysical survey of the area between the mine and Lake Contwoyto. The method used, SAMPO, is a wide-band electromagnetic sounding system, which has been successfully used elsewhere to locate salinity contrasts in deep groundwater systems. The results indicated the presence of a weak sub-horizontal electrical conductor at depths between 400 and 700 meters (Paananen and Ruskeeniemi 2003), while the orientation of the geological units is nearly vertical.

A



B

C

Figure 3. Drilling of new research boreholes in Lupin Mine, level 570 m (A, B) and installation of hydrogeological monitoring systems at the level 1130 m (C).

One of the principal goals of the permafrost study was the drilling of research holes below the permafrost, in order to obtain undisturbed, uncontaminated water samples from the bedrock near the base of the frozen rock. Fresh, labelled lake water was used as circulation water. Hole-to-hole hydraulic interference was monitored during drilling of the subsequent holes. Drill core was examined immediately after retrieval, with a special emphasis on fractures. Samples of the drill core were taken for crush and leach experiments, so as to study the presence and amount of readily-soluble salt in the rock.

Video-surveys, hydraulic tests and groundwater sampling of packed-off sections were performed after drilling was completed Preliminary observations appeared to indicate that there are several hydraulically conducting fracture zones parallel to the strike of the formation. However, the free water table appears to be at about 650 m. This observation is in agreement with the results of electromagnetic soundings carried out from the surface.

The activities at the deeper 890 and 1130m levels concentrated on hydrogeological and geochemical observations in the flowing boreholes. The mining company had originally sealed most of them, but – due to leakage – the original plugs were replaced by new ones and pressure gauges installed for head monitoring. In accordance with data from the 570m level and from geophysics, the measured head values indicate that the water table is at a level no higher than 650 m.

Deep groundwaters are slightly saline, TDS varying from 2 to 36 g/L, the main components being Ca, Na and Cl. Redox potential data (monitoring times from 20 to 55 hours) indicate only slightly negative Eh's, but the waters did not contain measurable amounts of dissolved oxygen.

Total gas contents up to 0,5 L/1 L water were measured, the main gas component being methane.

Relevance: Study of the effects of deep permafrost on hydrogeology at depths typical of a nuclear waste repository. Behaviour of bedrock-groundwater system in changing (cooling) climatic conditions. Behaviour of dissolved salts associated with an advancing freezing front.

Position(s) in the matrix tables: Cold climate events.

***Limitations**:* Possible effects of the observation system (a mine).

Quantitative information: No comments.

Uncertainties: The effects of mining may have influenced some results.

Time-scale: Quaternary (Ice Age).

PA/safety case applications: Construction of the effects of future climatic changes. Near-field environment during deep permafrost conditions. Effects on waste form, buffer and backfill and transport conditions.

Communication applications: Demonstration of the effects of permafrost in crystalline rock.

References:

Paananen, M. & Ruskeeniemi, T. 2003; Permafrost at Lupin. Interpretation of SAMPO electromagnetic soundings at Lupin. Geological Survey of Finland. Nuclear Waste Disposal Research. Report YST-117.

Ruskeeniemi, T., Paananen, M., Ahonen, L., Kaija, J., Kuivamäki, A., Frape, S., Moren, L., Degnan, P. 2002; Permafrost at Lupin. Report of phase I. Geological Survey of Finland. Nuclear Waste Disposal Research. Report YST-112 (http://arkisto.gsf.fi/yst/yst-112.pdf).

Ruskeeniemi, T., Ahonen, L., Paananen, M., Frape, S., Stotler, R., Hobbs, M., Kaija, J., Degnan, P., Blomqvist, R., Jensen, M., Lehto, K., Moren, L., Puigdomenech, I. & Snellman, M. 2004; Permafrost at Lupin: Report of Phase II. Geological Survey of Finland. Nuclear Waste Disposal Research. Report YST-119 (http://arkisto.gsf.fi/yst/yst-119.pdf).

Potential follow-up work: Mining operation at Lupin was terminated in January 2005. Last sampling campaign during October 2005 was carried out in cooperation with the scientists from the NASA Astrobiology Institute, and was concentrated on the study of deep sub-permafrost microbiology.

Keywords: climate change, palaeoclimates, permafrost, water table

Reviewers and dates: Lasse Ahonen, GTK (November, 2003)