# Effects of a Historical Cu-Au Mine on Testate Amoebae in Lacustrine Sediments in Southern Finland (Haveri, Ylöjärvi)

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**Abstract**
Sediment geochemistry and arcellaceans analysis were employed to track the environmental effects of a historical Cu-Au mine in SW Finland. Two short cores and five additional surface sediment samples were examined. Both cores had layers with elevated concentrations of heavy metals, P and S, suggesting the impact of the mine. Most of these elements also remained elevated after the initial peak. Arcellacean assemblages changed simultaneously with the geochemical shifts, referring to the existing relationship between these factors and suggesting a change in the trophic level of the lake. Surface samples suggest changes in redox conditions. Results are discussed and analysed with multivariate numerical methods.

**Key words:** historical mine, testate amoebae, metals, pollution

## Introduction

The old Haveri mine (Cu-Au) is situated between two lake basins in the former commune of Viljakkala, in SW Finland (Fig. 1). Small scale mining activity (Fe) has occurred periodically in the area since the 18$^{th}$ century, but the presence of sulphides made the exploitation of the iron ore unprofitable (Karvinen 1997). There are several ore bodies in the area, and the first Cu-Au deposit was discovered in 1935 which led to the onset of a mine in 1939. The most active period was 1942-1962, and the official production of the mine was ~1.5 million tons of ore, containing on average 2.85 Au g/ t and 0.39 %/ t Cu (Puustinen 2003). Mine tailings, formed during the years of production, are piled on a cape protruding into Lake Kirkkojärvi, and are exposed to air, snowmelt and rainwater. The oxidised surface layer of the tailings is producing acidic and heavy metal-rich waters (Parviainen & Eklund 2007), thereby affecting also the surrounding waters and ecology within. Furthermore, motocross is randomly practised on the partly covered tailings causing dusting of the finest particles.

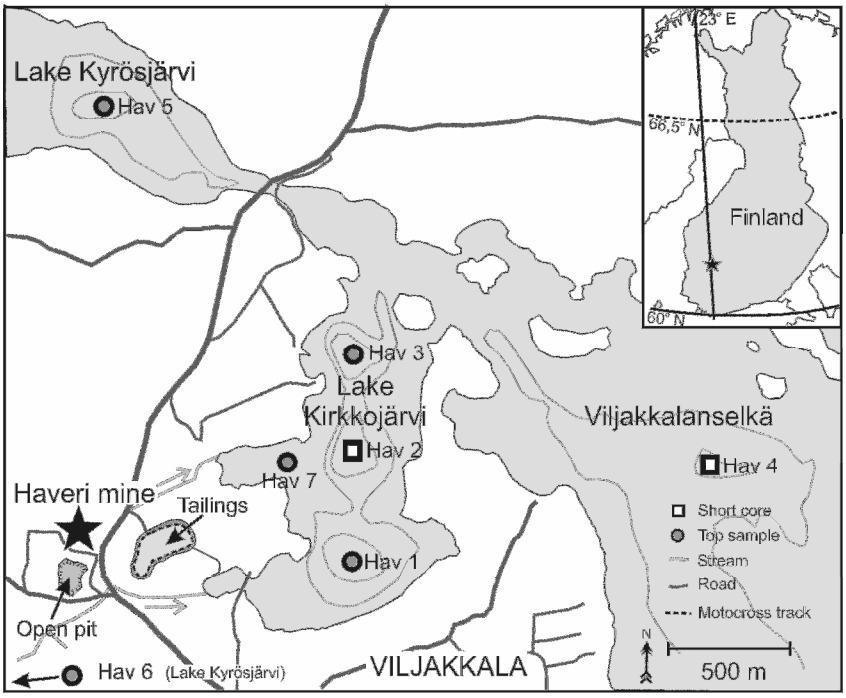
Testate amoebas are clonal, microscopic protozoans that can be found in moist habitats, for example different bodies of freshwater, peat, soil and moss. Lacustrine forms have been shown to be sensitive environmental indicators and have been used to indicate mine and industrial derived pollution, lake bottom acidity and rates of lake remediation after pollution (Asioli et al. 1996, Patterson et al. 1996, Reinhardt et al. 1998, Kumar & Patterson 2000, Kauppila et al. 2006). The living habitat in the sediment-water interface, fast regeneration and abundance, together with the environmental sensitivity, allow the usage of very small samples and provide a possibility to high resolution study.

By employing sediment geochemistry together with arcellaceans analysis, the closed mine of Haveri and the relatively long duration of human activities in the area give a good possibility to examine the historical and contemporary impacts, and the development trend of the present conditions.

## Material and methods

Two short cores were studied: a presumably impacted one (28 cm), taken from the proximity to the tailings (Lake Kirkkojärvi), and a reference core (26 cm) taken from a more distal site, located in another basin of the lake. In addition to the cores, 5 top sediment samples were analyzed from different parts of the surrounding lake system: Three from Lake Kirkkojärvi, east from the mine, two from Lake Kyrösjärvi in the west. All sample sites are presented in Figure 1. For chemical determinations the freeze dried samples were first homogenized and then leached with the microwave-assisted nitric acid leach, following the US EPA method 3051 (US EPA, 1994). The extraction breaks down trioctahedral micas, talc, clay minerals, sulphides, carbonates, titanite and most salts. Analyses from nitric acid leachates were done with ICP-AES or ICP-MS. For arcellaceans analysis fresh sediment samples were weighed, sieved wet and splitted into aliquots. At least 200 specimens were counted per sample immersioned in water, by using stereomicroscope.

***Figure 1*** *Location of the Haveri mine area and sample sites*




**Results and discussion**

According to preliminary results of the geochemical and testate amoebae analyses, the mine has affected the environmental conditions in the lake. In the impacted core, many metals (such as As, Zn, Al, Fe, V, Co, Mn, Mg) were enriched at the depth of 15 cm, whereas concentrations of some elements such as S, Ni and Cu began to increase already deeper in the core. This was preceded with the rise in the concentrations of mineral matter related elements Mg, K, Na and Al. Some of the highest concentrations appeared as relatively distinct peaks and most of them remained elevated after reaching the highest level.

Faunal changes coincided with the geochemical shifts and the most notable change in arcellacean assemblages occurred at 15 cm as well. However, minor changes took place already deeper in the core, again parallel to the early changes in sediment chemistry, suggesting a relationship between these factors and possibly indicating minor human interference in the area. Certain arcellacean forms thrived despite the changes in geochemical conditions and enrichment of metals. In the reference core similar features were detectable, only feebler and with certain exceptions. This suggests that the core is not unaffected by the mine, despite its distant 'upstream' location. Similar to the impacted core, faunal changes of the reference core reflected the shifts in geochemistry. In the top sediment samples, concentrations of Fe, Mn and As, all redox-sensitive elements, have increased markedly at some sites. Also faunal compositions show some signs of environmental stress in these samples.

Besides the suggested mine impact, there was another simultaneous change in both geochemistry and faunal assemblages. Total P concentration increases all the way to the top in the cores, together with the proportion of arcellacean species that usually indicate eutrophic conditions.

All results are discussed and analysed with multivariate numerical methods. In addition, diatom-based TP inferences are used to study the influence of nutrient enrichment on arcellaceans.

**Conclusions**

Results from the lake sediments indicate past and more recent changes in the geochemistry and arcellaceans species assemblages, probably partly related to the mine. Also the trophic level of the lake has likely changed, possibly because of human interference in the area. Multivariate numerical analyses are used to specify the affecting environmental factors and to study the connections between variables.

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**References**
Asioli A, Medioli FS, Patterson RT (1996) Thecamoebians as a tool for reconstruction of paleoenvironments in some italian lakes in the foothills of the southern Alps (Orta, Varese and Candia). J Foraminifer Res 26: 248-263
Karvinen WO (1997) The Haveri Copper-Gold Mine Property, Southern Finland. In: Ehlers C (Ed) Research and exploration — where do they meet? 4th Biennial SGA Meeting, August 11–13, 1997, Turku, Finland, Excursion guidebook B3 Guide 44 Geological Survey of Finland, Espoo, p 20-22.
Kauppila T, Kihlman S, Mäkinen J (2006) Distribution of arcellaceans (testate amoebae) in the sediments of a mine water polluted bay of Lake Retunen, Finland. Water Air Soil Pollut 172: 337-358
Kumar A, Patterson RT (2000) Arcellaceans (thecamoebians): new tools for monitoring long and short-term changes in lake bottom acidity. Environ Geol 39: 689-697
Patterson RT, Barker T, Burbidge SM (1996) Arcellaceans (thecamoebians) as proxies of arsenic and mercury contamination in northeastern Ontario lakes. J Foraminifer Res 26: 172-183
Parviainen A, Eklund M (2007) Tailings oxidation and mineralogy of Haveri Au-Cu mine, SW Finland - preliminary results. In: Abstracts of the 17th Annual V. M. Goldschmidt Conference, Cologne, Germany, August, 2007. Geochimica et Cosmochimica Acta 71 (15S), A761.
Puustinen K (2003) Suomen kaivosteollisuus ja mineraalisten raaka-aineiden tuotanto vuosina 1530-2001, historiallinen katsaus etenkin tuotantolukujen valossa. 578 s. Geologian tutkimuskeskus, arkistoraportti, M 10.1/2003/3. In finnish. Also available in electronic form: http://www.gsf.fi/aineistot/kaivosteollisuus/index.htm
Reinhardt EG, Dalby AP, Kumar A, Patterson RT (1998) Arcellaceans as pollution indicators in mine tailing contaminated lakes near Cobalt, Ontario, Canada. Micropaleontology 44: 131-148
US EPA (1994) Method 3051. Microwave assisted acid digestion of sediments, sludges, soils and oils. http://www.epa.gov/epaoswer/hazwaste/test/pdfs/3051.pdf