Differences in water chemistry in pit lakes affected by alum shale mining

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Alum shale, enriched in nickel and uranium, was mined from open pits in Kvarntorp, Sweden, during 1942-1966 for oil and uranium production. Pyrite in the shale causes acid rock drainage leading to weathering and metal release [c.f. 1,2]. In this study four pit lakes are included - two in the western pit lake system (water turnover 1-2 years) and two in the eastern system (water turnover about 20 years). All four lakes are affected by alum shale and its mine waste.

Regular surface water monitoring since the 1990s [3] in addition to sampling of water depth profiles, solid samples and sediments reveal great variations, both spatial and temporal. Several factors control pH in the lakes: weathering of the exposed shale horizon and deposited waste around the lakes, dumped alkaline waste, exposure to the limestone horizon and turnover for the lakes. As a result only one lake is still acid (pH 3.2), another lake had a pH increase (<4 to >7.5) but the buffering is now decreasing, while the last two lakes have stable pH above 7. pH variations and the weathering rate are important for the distribution and concentration of elements resulting in differences for lakes with changing pH (e.g. Al from 2 000 µg/L to below 5 µg/L) and differences between the lakes (e.g. Sr 250-1 800 µg/L).

Vanadium concentrations up to 500 g/tonne are found in the shale, but in the water at the lake outlets the concentrations are lower than 1 µg/L. Leaching tests of alum shale waste have confirmed the limited solubility of V. Uranium concentrations are higher towards the depths than at the surface (up to 220 µg/L) but today none of the lakes show alarming U concentrations at the outlets (up to 30 µg/L). Arsenic displays low levels (less than 1 µg/L) except at the depths in one of the lakes (up to 24 µg/L).

Although the western lakes appear to have stable pH, progressing weathering and acid production is suggested by the increased sulfate concentrations and decreased alkalinity through the system. A slower water turnover could give a pH decrease. Understanding of the geochemical behaviour of the pit lakes and the variations of parameters affecting the water quality is necessary in order to understand the future implications for the downstream environment.

[1] Chi Fru E *et al*. (2016) Appl Geochem **74** 94-108. [2] Falk H et al. (2006) J Geochem Explor **90** 157-165. [3] Kumla kommun (1993-2018) Water monitoring program in Kvarntorp. Yearly reports. In Swedish.