

A giant batch titration experiment - lime waste leaching into a pit lake

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Shale oil production (1941-1966) has severely affected the Kvarntorp area, 200 km west of Stockholm, Sweden, with open pits filled with water or waste material, and a 100 m high waste deposit. One of the open pits, Lake Norrtorpssjön, showed pH varying between 3.1 and 3.8 during 1993-1997 [1]. Weathering of exposed shale horizons with iron-rich sulphides causes acidic leachates and can explain low pH and elevated concentrations of metals such as Ni and U.

In 1998 pH started to increase and has been stable between 7 and 8 since 2002. The increase is probably due to nearby dumping of alkaline lime waste material between 1996 and 2001 in the connected open pit originally filled with municipal solid waste [2]. Increasing chloride concentrations, and practically no changes in Na, also support the conclusion that leachates from the dumping of waste have reached the pit lake and changed its conditions.

Decreased sulphate concentrations (from 1 700 mg/L to 1 200 mg/L) are possibly linked to COD increase. Pyrite precipitation, supported by modelling, and also by isotope studies, can be the mechanism behind sulphate decrease.

Sr concentrations suggest that weathering has not decreased despite neutralisation. Decrease of Ni (from 130 to 10 µg/L) is instead suggested to be due to adsorption. Uranium decreased from 89 µg/L to 2 µg/L, until pH reached 6.7, with an increase up to 30 µg/L noticed as pH stabilised between 7 and 8. Mo has increased from below 1 to a variation between 5 and 10 µg/L. Zn has decreased from 170 to 2-5 µg/L due to the increase in pH.

This giant titration experiment, although not planned, shows that stabilised pH was reached after the alkalinity had increased to about 24-30 mg/L (HCO₃). Highest concentrations were reached in 2010 (110 mg/L). After 2013 alkalinity is decreasing. Within a decade the buffering capacity might be consumed with pH decreasing to about 3.5. This would have implications for water quality and metal release from the weathering shale into receiving water courses.

[1] Kumla kommun (1993-2016) Water monitoring program in Kvarntorp. One report every year. In Swedish. [2] Allard B *et al.* (2014) *Environ Sci Pollut Res* **21** 6930-6938.