ENRICHMENT OF ARSENIC, CHROMIUM AND LEAD IN SOILS NEAR THE STAWELL GOLD MINE, VICTORIA

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Geochemical background was determined based on the analyses of soil and sediment profiles in the Stawell region of NW Victoria. Stawell Gold Mine (SGM) is 2 km E of the town of Stawell. The SGM operation is mining Au-bearing sulphides which contain significant As (~2700 mg kg^{-1}) and metal concentrations which are released into the nearby environment. Since As, Cr and Pb can cause serious health problems, it is important to understand the dispersion of these elements in soil around the mine site, their possible anthropogenic and natural enrichment, and potential risks to human health.

The objectives of this research were to determine the potential hazards associated with high As, Pb and Cr concentrations around the mine, define the anthropogenic component, detect "hot-spots" of particularly high concentrations, and assess exposure levels to As, Cr, and Pb in soil for humans. The anthropogenic component is defined by the increase in bioavailability above background for selected elements, and also considers the distribution halo around major human disturbance areas, such as the mine site and town housing.

Geochemical backgrounds were determined from regional surface soils. Following the derivation of background soil compositions, surface soil samples were taken from the area surrounding the Stawell Gold Mine (Big Hill). All samples were digested using a 4-acid method and a bioavailable extraction (Munksgaard and Parry, 2002) recommended by ANZECC (2000). Electrical Conductivity (EC), pH, total C and a field estimation of % clay measurements were recorded for all samples.

Regional geochemical background is essential for assessing potential anthropogenic influences, as general crustal averages of 2-3 mg kg^{-1} (Francesconi & Kuehnelt, 2002; Mandal & Suzuki, 2002) are not representive for most study sites, particularly those in mining areas. The soils in gold mining districts of NW Victoria are more enriched in As than most other soils, with reported concentrations of 6-40 mg kg^{-1} (Dowling et al., 2005; Noble & Watkins, 2005; Pearce et al., 2005; Sultan et al., 2005).

Soils at Big Hill show greater maximum, mean and median concentrations of As, Cr and Pb than background. Single element plots for both extractions define natural and anthropogenic influence, and will be presented. The high soil As in the Stawell environment is attributed to two factors: natural enrichment due to a geochemical halo associated with the major ore body, and anthropogenic enrichment due to mining, agriculture and other human activities.

To assess the combined natural and anthropogenic enrichment of the Big Hill soils, a comparison of the regional background with the Big Hill soils was made for bioavailable and total soil As, Cr and Pb concentrations. The following formula (average enrichment over background for selected elements) was used to calculate a general enrichment factor (EF) for both the total and bioavailable extractions:

$$\overline{EF} = \frac{1}{n}\sum_{i=1}^{n} \frac{x_i - \bar{x}_B}{\bar{x}_B}$$

where x_i is the Big Hill soil concentrations, x_B is the regional background concentrations, and n is the number of samples.

The EF indicates how much the soil is enriched (both naturally and anthropogenically) relative to background. Scores less than 10 are considered to show little to no enrichment. However, many soils at Big Hill exhibited significant enrichment with scores greater than 10 (Figure 1). Enrichment factors were generated for the individual elements and will be presented, however a combined EF plot defines the hot spots associated all three of the elements of concern. One highly enriched and two moderately to highly enriched soil samples occur adjacent to the mine site. There is some enrichment of the soils around SGM, but dispersion is not very large, with soils 500 m or more away being close to background. The most enriched soils are close to the edge of town, indicated by potential "hot spots" with respect to environmental risk (Figure 1).

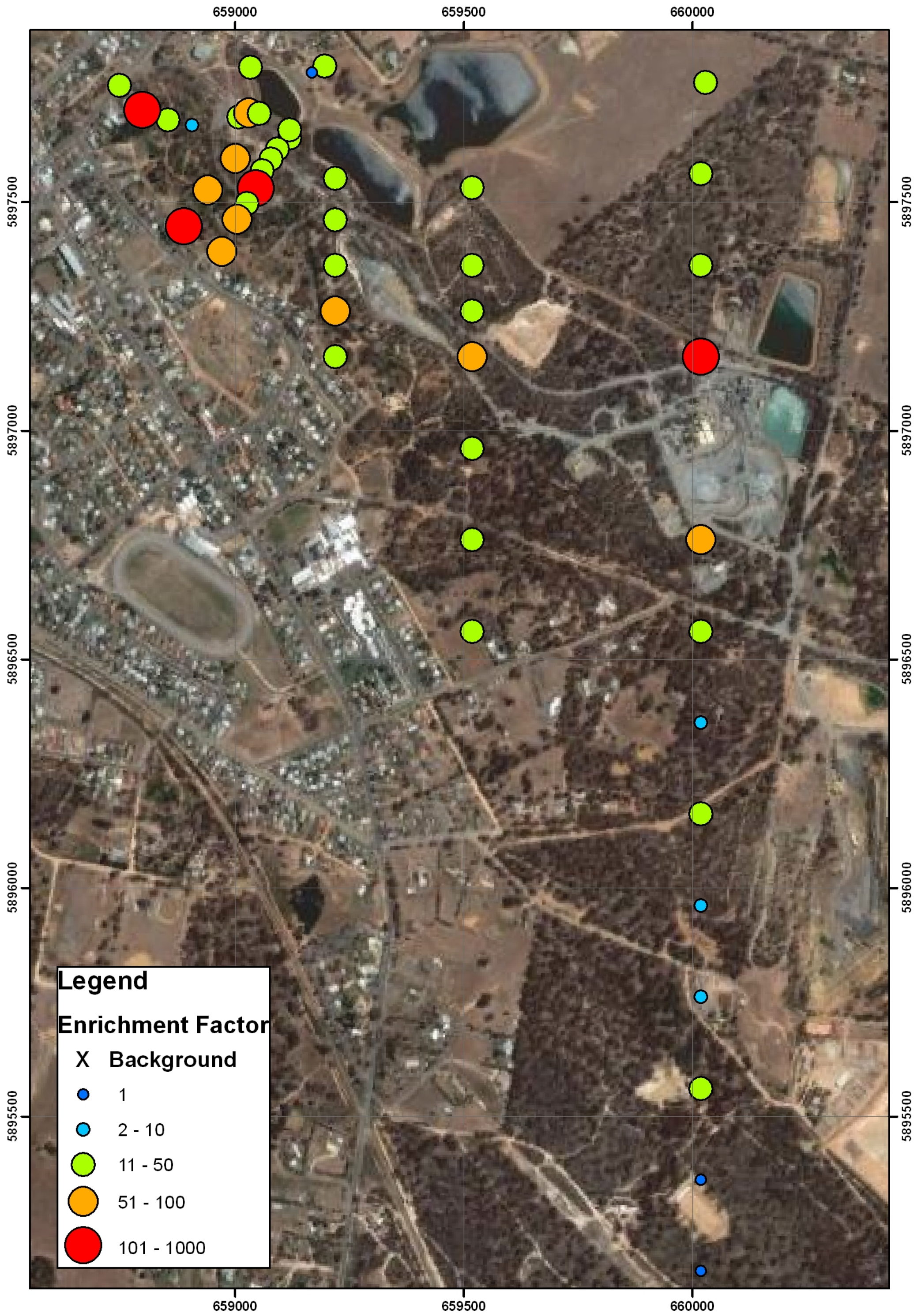

Figure 1. Enrichment factor scores combining As, Cr and Pb for both extractions to provide a general assessment of soils with the greatest enrichment (natural and anthropogenic).

The bioavailable element concentrations in the Stawell soils (Big Hill) were used to estimate the potential health risks associated with human exposure. This bioavailable extraction is considered analogous to stomach acid and potential absorption of metals into the body. The Risk Reference Dose (RfD) for As is 0.1 to 0.8 μg kg^{-1} body weight per day, for Cr (3+) it is 0.71-29 μg kg^{-1} body weight per day, and 6.1 μg kg^{-1} body weight per day for Pb (Dudka and Miller, 1999; U.S. EPA, 1996). Using the mean and maximum bioavailable concentrations for Big Hill soils, the following calculation determines the daily intake of soil in this region that will cause significant health risks.

Daily consumption $_{(kg\ soil\ /\ kg\ body\ weight)}$ *= RfD* $_{(\mu g/\ kg\ bodyweight\ /\ day)}$ */ Bioavailable concentration* $_{(\mu g\ /\ kg)}$

The results of the daily consumption rate calculated from the mean and maximum bioavailable As, Cr and Pb, using high and low RfDs and a 12 kg child are presented in Table 1. Most risk assessments based on ingestion of soils assume children consume less than 0.200 g of soil per day (Lottermosser, 2002; U.S. EPA, 1996). At that intake, the only soil element that would potentially pose a risk is the maximum bioavailable As. It seems unlikely that a child would be exposed to an area with such high soil As consistently, but it is possible and the risk is even greater for toddlers. The highest concentrations of bioavailable As were found close to the edge of Stawell and only 10-40 m away from houses (Figure 1). The risk is significantly enhanced for children that have a soil-eating disorder and may consume 25-60 g of soil per day (Calabrese et al., 1997). In this extreme and unlikely scenario, As and, potentially, Cr and Pb would exceed the safe daily consumption and pose significant risk.

Table 1. Daily human consumption of Big Hill soil required to exceed low risk levels.

Element	Bioavailable mean. Soil ingested g kg^{-1} body weight*	Bioavailable max. Soil ingested g kg^{-1} body weight*	Bioavailable mean. Soil ingested g for 12 kg child*	Bioavailable max. Soil ingested g for 12 kg child*
$As_{high\ RfD}$	1.03	0.14	12.3	1.72
$As_{low\ RfD}$	0.13	0.02	1.54	0.20
$Cr_{high\ RfD}$	17.1	14.5	204	174
$Cr_{low\ RfD}$	4.18	3.55	50.1	42.6
Pb	5.17	0.35	62.0	4.23

* Values are the minimum to exceed the RfD daily intake by ingestion (Dudka and Miller, 1999; U.S. EPA, 1996). Shaded values are ≤ daily average exposure/intake and could cause health problems with long term exposure.

This study did not consider the additional exposure pathways that could increase the risk such as skin absorption, inhalation and enrichment of metals in the food chain. The influence of these uptake mechanisms to human health requires further study. Small children typically are not exposed to soil everyday, and therefore the considered health risk from the soils around Stawell is minimal. However, care should be taken with small children ingesting soil around the Big Hill area.

REFERENCES

ANZECC, 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 1. Australian and New Zealand Environment and Conservation Council and Agriculture and Resources Management Council of Australia and New Zealand, Canberra, ACT.

CALABRESE, E.J., STANEK, E.J., JAMES, R.C. AND ROBERTS, S.M. 1997. Soil ingestion: a concern for accute toxicity in children. *Environmental Health Perspectives*, **105**: 1354-1358.

DOWLING, K. et al. 2005. Living in a mining environment: A case study of arsenic exposure pathways in the goldfields of Victoria, Australia. In: R.T. Watkins (Editor), 4th Asia Pacific Symposium on Environmental Geochemistry. Curtin University of Technology, Perth, pp. **O.4**.

DUDKA, S. AND MILLER, W.P. 1999. Permissible Concentrations of Arsenic and Lead in Soils Based on Risk Assessment. *Water, Air, & Soil Pollution*, **113(1 - 4)**: 127-132.

FRANCESCONI, K.A. AND KUEHNELT, D. 2002. Arsenic compounds in the environment. In: W.T. Frankenberger (Editor), Environmental chemistry of arsenic. Marcel Dekker, New York, pp. 51-94.

LOTTERMOSSER, B. 2002. Exposure assessment of naturally metal enriched topsoils, Port Macquarie, Australia. *Environmental Geochemistry and Health*, **24**: 183-190.

MANDAL, B.K. AND SUZUKI, K.T. 2002. Arsenic round the world: a review. Talanta, **58(1)**: 201-235.

MUNKSGAARD, N.C. AND PARRY, D.L. 2002. Metals, arsenic and lead isotopes in near-pristine estuarine and marine coastal sediments from northern Australia. *Marine and Freshwater Research*, **53**: 718-729.

NOBLE, R.R.P. AND WATKINS, R.T. 2005. Background characterization and exposure assessment of soils from the Stawell gold mine and surrounding areas. In: R.T. Watkins (Editor), 4th Aisa Pacific Symposium on Environmental Geochemistry. Curtin University of Technology, Perth, pp. **O.33**.

PEARCE, D.C., DOWLING, K., WALDRON, H. AND GARNETT, D. 2005. Child's play: Investigating exposure potential from arsenic in soil. In: R.T. Watkins (Editor), 4th Asia Pacific Symposium on Environmental Geochemistry. Curtin University of Technology, Perth, pp. **O.23**.

SULTAN, K., DOWLING, K. AND MCKNIGHT, S. 2005. Distribution of metals in soils of central Victoria (Creswick-Ballarat) with emphasis on arsenic in relation to geology and mining activities. In: R.T. Watkins (Editor), 4th Asia Pacific Symposium on Environmental Geochemistry. Curtin University of Technology, Perth, pp. **O.10**.

U.S. EPA, 1996. "IRIS: Integrated Risk Information System", U.S. Environmental Protection Agency, Micromedex Inc., Englewood, Colorado.

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