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The distribution of chlorine and iodine in soil in the vicinity of lead mining and smelting operations, Bixby area, S.E. Missouri, U.S.A.

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Abstract—Iodine and Cl are enriched in soils in the vicinity of the Magmont and Buick lead mines near Bixby, southeastern Missouri. The enrichments, up to 5.6 ppm I and 305 ppm Cl, are against regional backgrounds of 1.26 ppm I and 41 ppm Cl. The area of highest I and Cl is thought to reflect a zone of base metal sulphide mineralization occurring about 400 m below the surface. Iodine and Cl are also enriched in soils immediately adjacent to a tailings pond, hence these elements would appear to be leached from this source. A zone of enhanced I values (up to 2.65 ppm I) to the north of a lead smelter is superimposed on a much larger zone of lead enrichment (up to 12,000 ppm Pb) and is thought to represent I released from sulphide ores on smelting.

INTRODUCTION

MOST of the I and a large proportion of the Cl in soils is derived from the marine environment by way of the atmosphere (FUGE, 1974; FUGE and JOHNSON, 1986). For this reason the soils of central continental regions generally have significantly lower I and Cl concentrations than soils of coastal regions. Therefore, non-marine sources of I and Cl, such as rock weathering processes and the burning of fossil fuels, become more significant, and may be more easily investigated, in intra-continental environments.

Iodine is a chalcophile element and as such is enriched in sulphide minerals (FUGE and JOHNSON, 1984). Therefore, the smelting of metal-sulphide ores is extremely likely to release I into the atmosphere and this element may then be concentrated in soils in the vicinity of smelters. Anomalously high concentrations of I and Cl have been detected in soils developed around various types of base-metal sulphide mineralization (ANDREWS *et al.*, 1984; FUGE *et al.*, 1986; ANDREWS, 1987).

A study of I and Cl distribution in soils from Missouri, a central continental area, has shown the concentration of both elements to be relatively low with mean values of 1.15 ppm I (FUGE, 1987) and 40 ppm Cl (FUGE, unpublished data). This paper presents the results of a geochemical soil survey carried out over an area of 56 km^2 situated around the small settlement of Bixby, Iron County, Missouri (Fig. 1). Two major Pb mines and a large smelter are active in the study area. The aims of this survey were to investigate the contribution of I and Cl to the environment from these mineral extraction and smelting operations.

STUDY AREA

Much of the study area is forested, being located in the Mark Twain National Forest, and there are no settlements in the area other than Bixby. The whole area is overlain by fairly thick overburden, which in some regions exceeds 20 m in thickness (SWEENEY *et*

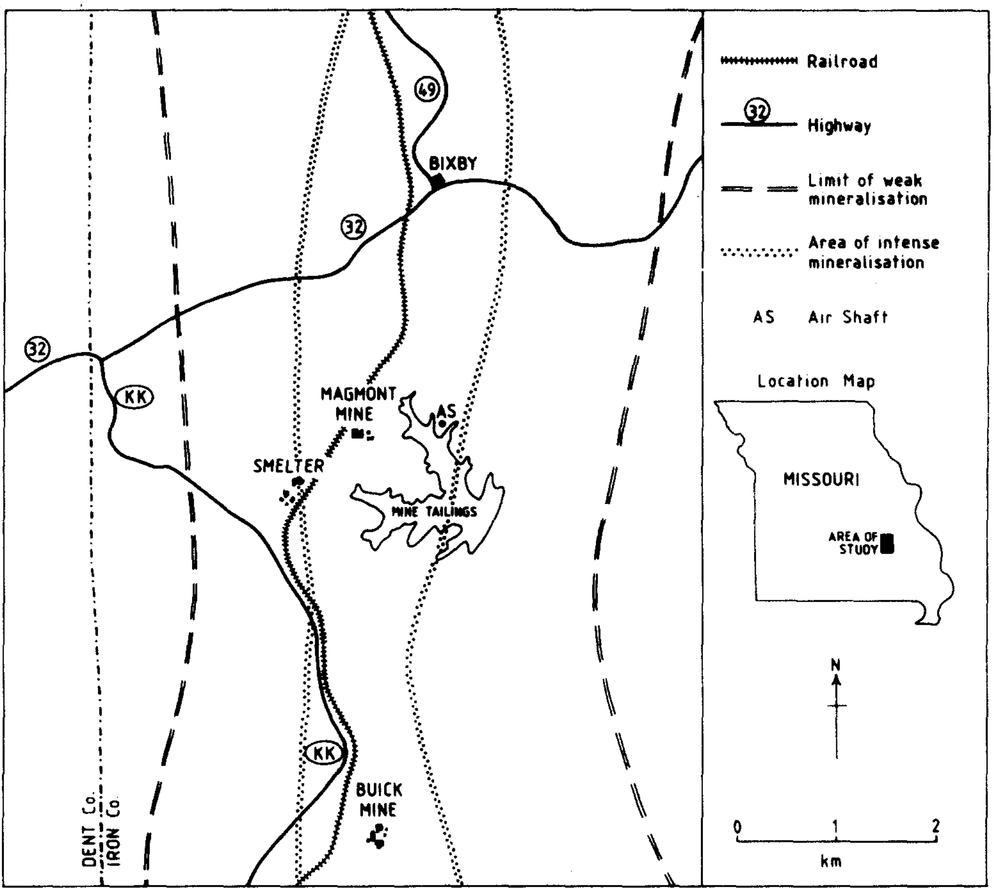

FIG. 1. The study area (location of zone of mineralization after THACKER and ANDERSON, 1977).

al., 1977). The underlying bedrock of this region comprises Upper Cambrian and Lower Ordovician dolomites which contain variable amounts of clastic detrital material (THACKER and ANDERSON, 1977). The area is traversed by a north–south trending, subsurface,mineralized zone, which is a part of the Viburnum Trend, a belt of mineralization up to 6 km in width, which extends north–south for approximately 72 km through the counties of Washington, Crawford, Iron, Reynolds and Shannon in southeast Missouri (WHARTON, 1975).

The geology of the two mines located within the study area, the Magmont and Buick mines, have been described by SWEENEY *et al.* (1977) and ROGERS and DAVIS (1977), respectively. The chief ore mineral is galena, with significant quantities of sphalerite and chalcopyrite and minor bornite and siegenite. The gangue minerals are essentially marcasite, dolomite, calcite and quartz. The main ore zone occurs about 400 m below the surface chiefly hosted in the Bonterre Formation, a dolomite of Upper Cambrian age.

A large smelter which processes locally derived ores (the Homestake smelter) is situated approximately 1 km south of the Magmont mine and a large tailings pond is located to the east of this mine.

The soils of the area are generally red-yellow to reddish brown in colour and are classified as ultisols. GILBERT (1971) has described similar soils of neighbouring Dent County, the eastern edge of which is 3.3 km from Bixby. The soils are mapped as the Clarkesville–Coulston association and comprise steep, excessively drained and cherty soils on narrow ridge tops, steepside slopes and narrow bottomlands. Bedrock is mantled by up to 15 m of decalcified, reddish, chert-rich residuum in which the soils are formed. The dominant soil series is the Clarkesville Cherty silt loam (Humic Haplaquept) containing 13–37% clay fraction with up to 4.2% organic matter in the A1 horizon.

METHODOLOGY

Surface soils were collected to a depth of 15 cm by sampling around concentric circles of 1–2 m using either a screw auger or trowel. Samples were collected from 77 sites during two periods (41 during May 1985 and 36 during August 1986). The initial sampling programme aimed to collect soils as near as possible to the intersections of a kilometre grid; however, the sampling scheme was modified in forested areas with difficult access. The second batch of samples aimed to extend the area covered and fill in a

Table 1. Comparison of I, Cl and Pb concentrations in soils from duplicate sampling sites

	I (ppm)	Cl (ppm)	Pb (ppm)
Sample 1	1.80	23	410
Duplicate	1.89	31	450
Sample 2	0.61	14	340
Duplicate	0.50	20	295
Sample 3	1.80	105	510
Duplicate	1.55	120	550

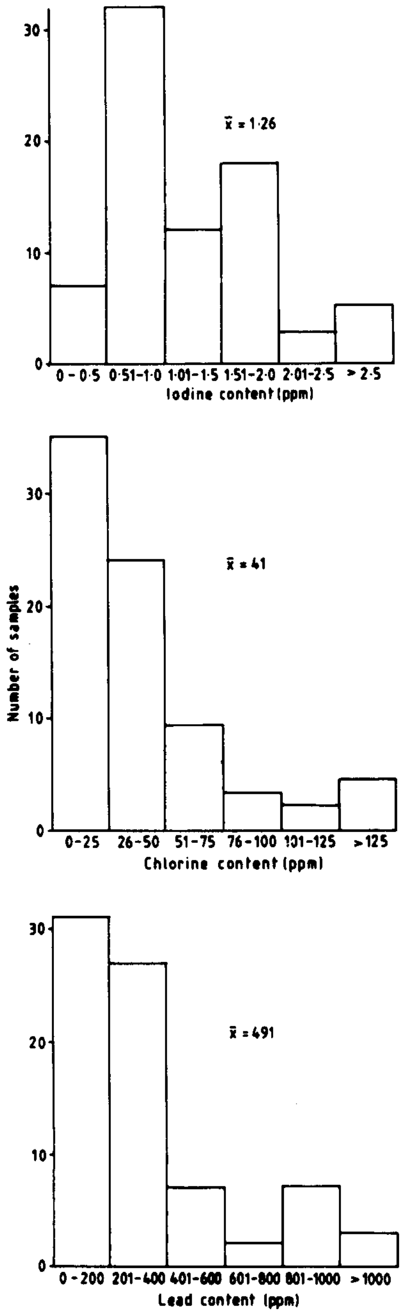

FIG. 2. Histograms of I, Cl and Pb concentrations in the 77 samples analysed.

number of gaps. During the second period of sampling some sites sampled in the initial phase were re-sampled in order to obtain some measure of temporal variation, the results for these duplicate samples are listed in Table 1.

After drying, disaggregation and sieving (>120 mesh) the samples were analysed for I and Cl at the Geology Department, U.C.W., Aberystwyth. The method used was automated photometric analysis on the leachates following fusion with $Na_2CO_3/K_2CO_3/MgO$ using the procedures outlined by FUGE *et al.* (1978) and FUGE (1976). Lead was determined on the first batch of samples by ICP at the Water Resources Center, University of Missouri–Columbia. The 36 samples collected in the later period were analysed for Pb at Aberystwyth using atomic absorption.

RESULTS AND DISCUSSION

Histograms of the concentrations of I, Cl and Pb in samples collected are shown in Fig. 2, and the spatial distribution of these elements shown as contoured maps in Figs 3–5, the class intervals being taken at the 50, 70, 90 and 95 percentile concentration levels.

The general background levels of I in the study area are similar to that of the whole state with two thirds of the values being <1.5 ppm. The two highest recorded concentrations of 3.1 and 5.6 ppm occur in a small area immediately south of Bixby and form part of a linear high extending about 54 km in a general north–south direction (Fig. 3). This trend runs approximately 1 km east of the Magmont mine and is situated over part of the mineralized zone (Fig. 1).

Chlorine, like I, has a low background level with two thirds of the values <41 ppm, similar to the

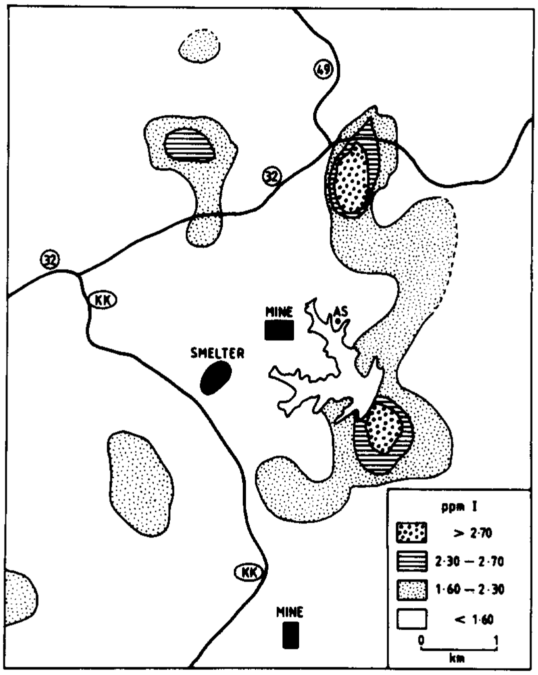

FIG. 3. The distribution of I in soils in the vicinity of Bixby, Missouri (contours at 50, 70, 90 and 95 percentiles of the data).

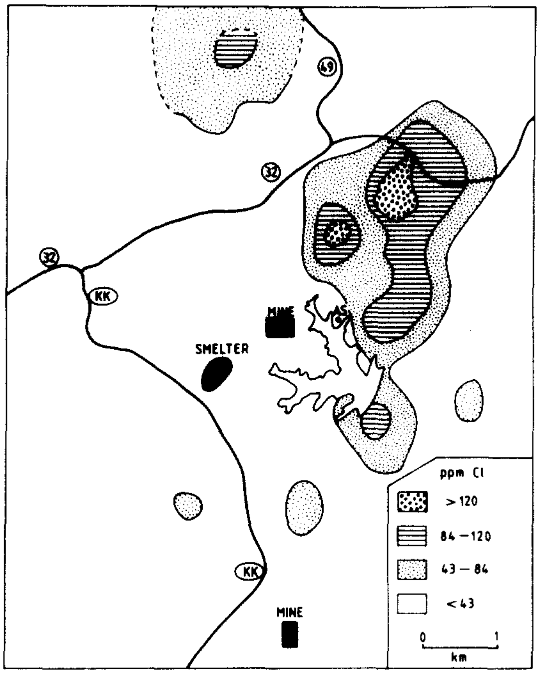

FIG. 4. The distribution of Cl in soils in the vicinity of Bixby, Missouri (contours at 50, 70, 90 and 95 percentiles of the data).

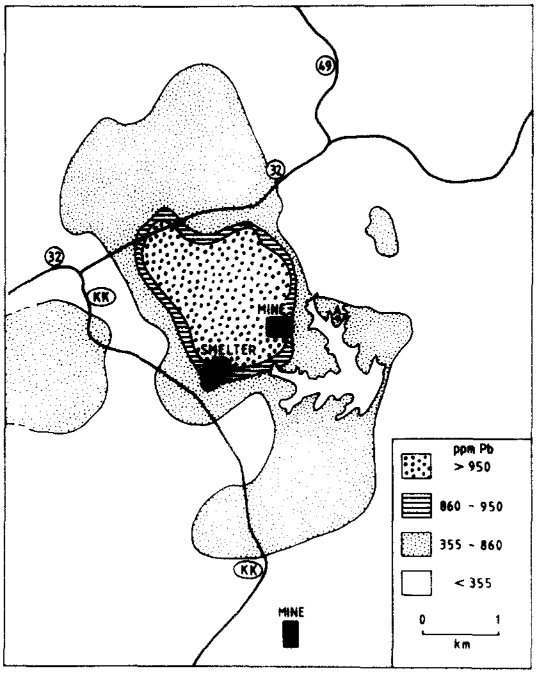

FIG. 5. The distribution of Pb in soils in the vicinity of Bixby, Missouri (contours at 50, 70, 90 and 95 percentiles of the data).

overall level in the state. As with I, the highest concentration of Cl (305 ppm) occurs in the region of Bixby, forming part of a zone of enriched values extending north–south, essentially coincident with, although somewhat broader than, the zone of I enrichment (Fig. 4).

It has been suggested that I and Cl in soils can be used as pathfinder elements for the location of concealed sulphide mineral deposits (FUGE *et al.*, 1986). In this study the coincident high values for I and Cl in the vicinity of the Magmont mine appear to reflect the subsurface mineralization. Soil data for Pb (Fig. 5), the main ore metal, do not highlight the zone of mineralization. The mineralized zone is about 400 m below the surface in this vicinity (SWEENEY *et al.*, 1977) and the enhanced I and Cl in the overlying soils may be a reflection of the greater mobility of these two elements in relation to Pb.

Part of the zone of high I and Cl values to the east of the Magmont mine occupies a fairly steep sided valley and it is tempting to speculate that part of the anomaly is due to groundwater transport of these halogens from the more intensely mineralized area to the west. However, it is also apparent that some of the highest values occur in samples collected from the higher ground on the eastern side of this valley. Thus, whereas groundwater transport of I and Cl cannot be ruled out as a mechanism for the apparent displacement of the anomaly to the east of the main mineralized zone, we feel that the halogen anomaly in the area is more likely to be controlled by faults and fractures providing pathways for fluid movement from depth. The absence of a coincident Pb anomaly is likely to be due to its immobility in an environment where the predominant bedrock is carbonate.

The soils of the study area are enriched in Pb and the levels are generally greater than those found in other parts of the state (DAVIES and WIXSON, 1985). The extremely high values found immediately to the north of the smelter (up to 1.2% Pb) are likely to be due to contamination from smelter exhaust, as the prevailing wind direction is from the south. This is also possibly the cause of the elevated values detected to the east and immediately to the south of the smelter. The Pb enrichment well to the south of the smelter is likely to derive from contamination by tailings from the nearby pond.

In the area around the tailings pond there is some overlap of the high Pb zone with the Cl- and I-enriched zones which might suggest that some soil I and Cl in this area are derived from tailings.

A small zone of enhanced I values, up to 2.65 ppm, occurs about 2 km due north of the smelter. This area of high I values overlaps the northern-most zone of Pb enrichment and is evidence for the derivation of I from the smelter gases.

CONCLUSIONS

This study has identified underlying bedrock mineralization, contamination from mineral processing tailings and smelter exhaust as possible sources of I and Cl in soils in this area of Missouri.

Enrichment of I and Cl in soils appears to be spatially related to the underlying zone of mineralization, evidenced by the north–south trending zone of high concentrations occurring to the east of the Magmont mine. Iodine and Cl enrichment is detected immediately adjacent to the tailings pond shown on Fig. 1, hence these elements would appear to be leached from this source. The small zone of enhanced I values north of the smelter partly overlapping a zone of high Pb values is probably due to smelter exhaust fumes.

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