LEAD IN SOILS OF THE CONTERMINOUS UNITED STATES - NATURAL VS. ANTHROPOGENIC INFLUENCES

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Introduction

A survey by the U.S. Geological Survey has collected and analysed soils at 4,857 sites across the conterminous United States (U.S.), with each site sampled at three vertical levels. Variations in lead concentration, both laterally at regional scales and vertically through the upper meter of soil profiles, permit an assessment of the relative importance of natural vs. human influences in various parts of the country.

Methodology

Data, methods, and quality assurance are presented in Smith et al. (2013) and element maps are in Smith et al. (2014), both available at http://mrdata.usgs.gov/soilgeochemistry. At each site, soil samples were collected at about one meter depth (C horizon or lower B-horizon, referred to as C horizon for simplicity), a composite of the entire A horizon, and a composite of the uppermost 5 cm of soil. The lead concentration was determined by inductively coupled plasma-mass spectrometry after a four-acid digestion of the < 2-mm size fraction. Median lead concentrations vary from 14.9 mg/kg in soils of the C horizon to 17.8 mg/kg for the A horizon, and 18.1 mg/kg for the uppermost 5 cm of soil. Ninety-five percent of values lie between the lower limit of detection (0.5 mg/kg) and 28.9 mg/kg for the C horizon, 40.2 mg/kg for the A horizon, and 44.5 mg/kg for the upper 5 cm of soil. Quantitative mineralogical determinations were performed for all A and C horizon soils using x-ray diffraction and Rietveld refinement calculations, which helped in interpreting lead-distribution patterns.

Results and discussion

Lead concentrations in the C horizon soil (Figure 1A) show a prominent pattern of variability that can be attributed in large part to natural variations in parent material, including both underlying bedrock and unconsolidated materials. Lead is a common trace element in feldspars and the variations in feldspar content of soils appear to be responsible for much of the observed lead variation. Using our quantitative determinations of both K-feldspar and plagioclase, the degree of correspondence of feldspar and lead can be examined. The ratio of lead concentrations between coexisting K-feldspar and plagioclase in felsic igneous rocks is about 2.4 (Doe and Tilling, 1967) with K-feldspar invariably being more lead-rich than plagioclase. Applying that ratio to the K-feldspar and plagioclase content of soils and normalizing the lead content by that adjusted feldspar content (Pb/(plagioclase+2.4K-feldspar)) produces the map shown in Figure 1B. The feldspar-normalized lead content of soils in much of the western two-thirds of the country shows little variation, indicating that lead is contained dominantly in feldspar and is therefore naturally occurring lead from geological sources. Because the lead is probably bound within the crystal lattice of feldspars, which are chemically stable in most of that area, it is not likely to be environmentally available in soluble form.

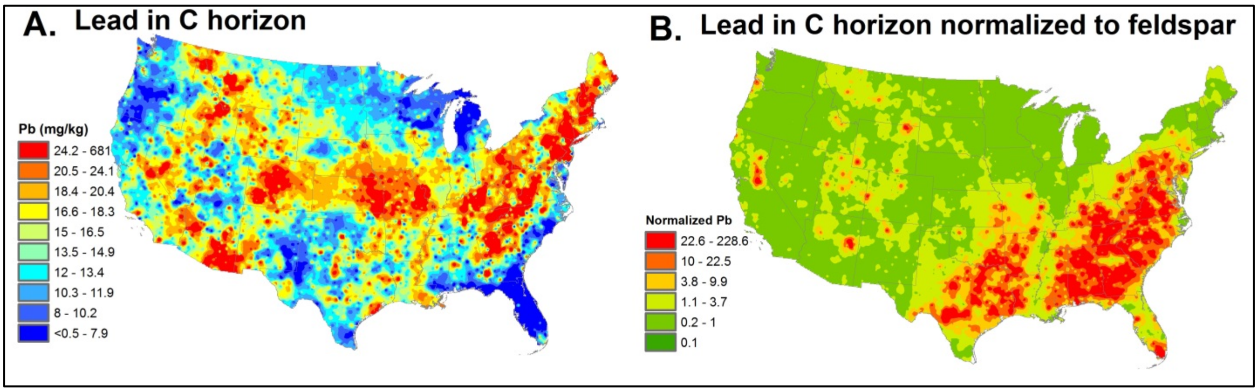

Figure 1. A- Lead concentration in C horizon soils. B- Lead concentration normalized to the feldspar content of soils by the formula (Pb_{norm}=Pb/(plagioclase+2.4K-feldspar)). Warmer colors are areas with the least influence of lead concentration by feldspars

However, in the southeastern and south-central parts of the U.S., the lead concentration is not controlled by feldspar content because feldspars are sparse in soils of that region. Figure 2A shows the total feldspar concentration in soils across the country including the large region of feldspar-poor soils in the southeastern U.S. In that region, high rainfall, relatively warm temperatures, and the lack of Pleistocene glaciation have contributed to the development of mature soils in which feldspars of the parent material have been largely converted to clays, mostly kaolinite (Figure 2B). Lead concentrations remain high in part of that region suggesting that lead originally held in feldspars resides in some other form, possibly adsorbed to clays or in ferromanganese grain coatings. In either of these cases, lead may be more environmentally available than where it is contained in feldspar.

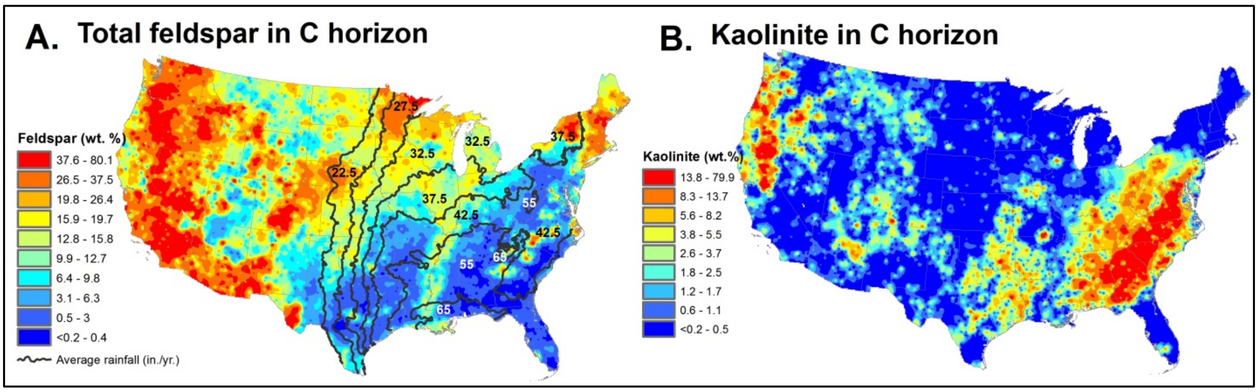

Figure 2. A-Total feldspar concentration in C horizon soil showing generalized contours of average annual precipitation (inches/yr) for the eastern U.S.; B-Kaolinite concentration in C horizon soils

The vertical distribution of lead within the soil profile may yield insights into the degree of anthropogenic additions of lead to soil assuming that anthropogenic lead will be present mostly in the near-surface soils. Figure 3A shows the ratio of lead in the A horizon to lead in the C horizon (Pb in A/Pb in C) for the country. For much of the country, the ratio is less than 1.5 indicating that there is little or no surface enrichment. But for some areas, particularly in the northeastern part of the country, the ratio is substantially higher and locally exceeds 5. There is a general correspondence between population density and the lead ratio in which the ratio is low for large areas in the central and western parts of the country where population density is less than 100 per square mile aggregated by county. There are some exceptions where high ratios do not correspond to high population, several of which correspond to areas with abundant mineral deposits, such as around the Leadville District in central Colorado, and southeastern Missouri, suggesting that such deposits or their mining and processing could produce surface enrichments in lead.

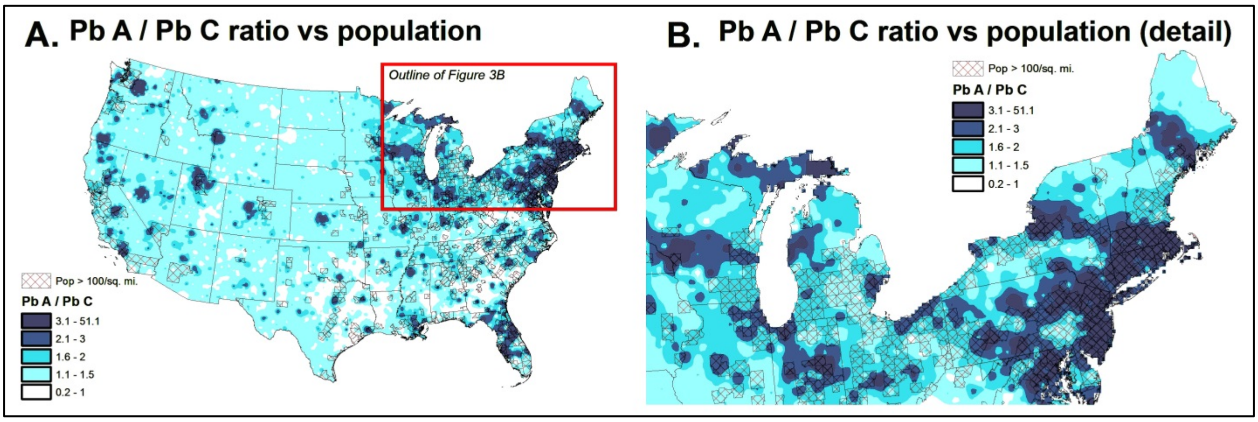

Figure 3. Ratio of lead in A horizon to lead in C horizon soil showing counties with average population of greater than 100 per square mile. B. Detail of the northeastern and north central U.S. where lead concentration in C horizon soil is most intense

The most prominent high ratios are in areas with high population densities, particularly the urban corridor from Washington, D.C. to Boston, MA where ratios commonly exceed 5. Figure 3B shows the northeastern U.S. in detail and emphasizes the correspondence of lead ratio and population. Because many of our samples are from areas where the immediate surroundings are not highly populated (although in counties with overall high population densities), it appears that anthropogenic lead additions may be dispersed beyond the population centers where many previous studies have documented strong anthropogenic lead additions. Such dispersed lead additions may be caused, among other factors, by burning of leaded gasoline, a once common practice that was ended nearly 30 years ago. Monitoring of lead in forest soils at 16 sites across the northeastern U.S. from 1980 until 2011, a period when atmospheric lead accumulation declined sharply, showed that although lead concentration in organic forest floor material has declined significantly at many sites, the lead has migrated downward to accumulate in mineral soils (Richardson et al., 2014). Those authors also showed that more than 60% of the lead in upper mineral soils is probably derived from leaded gasoline. Thus, we conclude that our data on the ratio of lead in the A horizon to lead in the C horizon documents, in large part, the dispersed effects of varying intensities of the use of leaded gasoline in the early and mid- 20th century as indicated by population density. The correspondence of surface enrichments and population density may also signal a variety of other anthropogenic lead releases.

References

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