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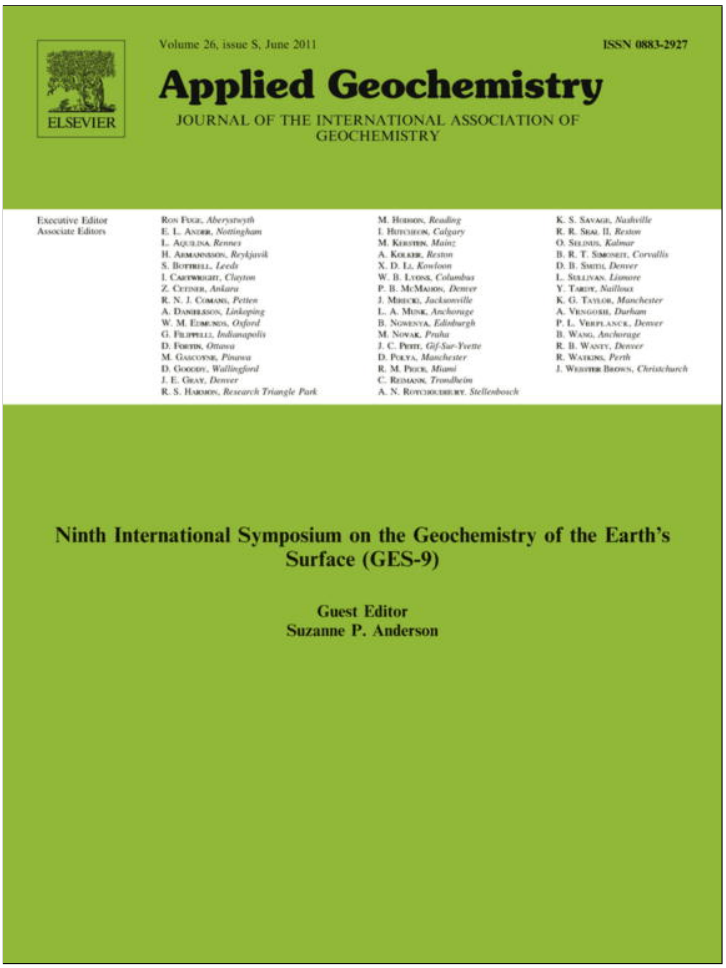


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# A national-scale geochemical and mineralogical survey of soils of the conterminous United States

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ABSTRACT

In 2007, the US Geological Survey initiated a low-density (1 site per 1600 km$^2$, c. 4800 sites) geochemical and mineralogical survey of soils of the conterminous USA. The ideal sampling protocol at each site includes a sample from 0–5 cm depth, a composite of the soil A horizon, and a sample from the soil C horizon. The <2-mm fraction of each sample is analyzed for Al, Ca, Fe, K, Mg, Na, S, Ti, Ag, Ba, Be, Bi, Cd, Ce, Co, Cr, Cs, Cu, Ga, In, La, Li, Mn, Mo, Nb, Ni, P, Pb, Rb, Sb, Sc, Sn, Sr, Te, Th, Tl, U, V, W, Y and Zn by inductively coupled plasma-mass spectrometry and inductively coupled plasma-atomic emission spectrometry following a near-total digestion in a mixture of HCl, $HNO_3$, $HClO_4$ and HF. Separate methods are used for As, Hg, Se and total C on this same size fraction. The major mineralogical components are determined by a quantitative X-ray diffraction method. Sampling was completed in 2010 with chemical and mineralogical analysis currently underway. Preliminary results for a swath from the central USA to Florida clearly show the effects of soil parent material and climate on the chemical and mineralogical composition of soils. A sample archive will be established and made available for future investigations.
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## 1. Introduction

Knowledge about the concentration and spatial distribution of naturally occurring chemical elements in soils of North America is remarkably limited. There is, at present, neither a common soil geochemical database for the continent of North America nor a sound understanding of the processes that might control the variation of chemical elements at the continental scale (Smith, 2009). The United States Geological Survey (USGS), the Mexican Geological Survey (Servicio Geológico Mexicano), and the Geological Survey of Canada thus initiated the "North American Soil Geochemical Landscapes Project" in 2002 with the final objective of full continental-scale soil geochemical coverage at a sample density of 1 site per 1600 km$^2$ (13,500 sites for the continent). The specific goals of the project are to (1) develop a continental-scale design and protocols for generating soil geochemical and mineralogical data; (2) provide baseline soil geochemical and mineralogical data that are useful for a wide range of applications and disciplines, (3) interpret the resulting geochemical and mineralogical patterns in terms of processes acting at the broad scale of the project, and (4) establish an archive of soil samples for future investigators. The pilot phase of the project was conducted from 2004–2007. Results were published in a series of scientific papers in a special issue of *Applied Geochemistry* (Smith, 2009). The full-scale sampling of the continent began in 2007. This extended abstract presents the sampling and analytical protocols for the project and presents preliminary results for a portion of the conterminous USA.

## 2. Site selection and sampling protocols

Target sites were selected in the USA by a Generalized Random Tessellation Stratified Design (Olsen, 2005) at a nominal density of 1 site per 1600 km$^2$ for a total of 5813 sites, 4871 of those being in the conterminous USA (Fig. 1). If a target site was inaccessible for any reason, an alternative site was chosen as close as possible to the original site, matching as closely as possible the landscape and soil characteristics of the original site. The following guidelines were also used in the site selection process to ensure that samples were not collected from obviously contaminated areas:

1. No sample should be collected closer than 200 m from a major highway.
2. No sample should be collected closer than 50 m from a rural road.
3. No sample should be collected closer than 100 m from a building or structure.

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**Fig. 1.** Map showing the location of the c. 4800 soil sampling sites in the conterminous US.

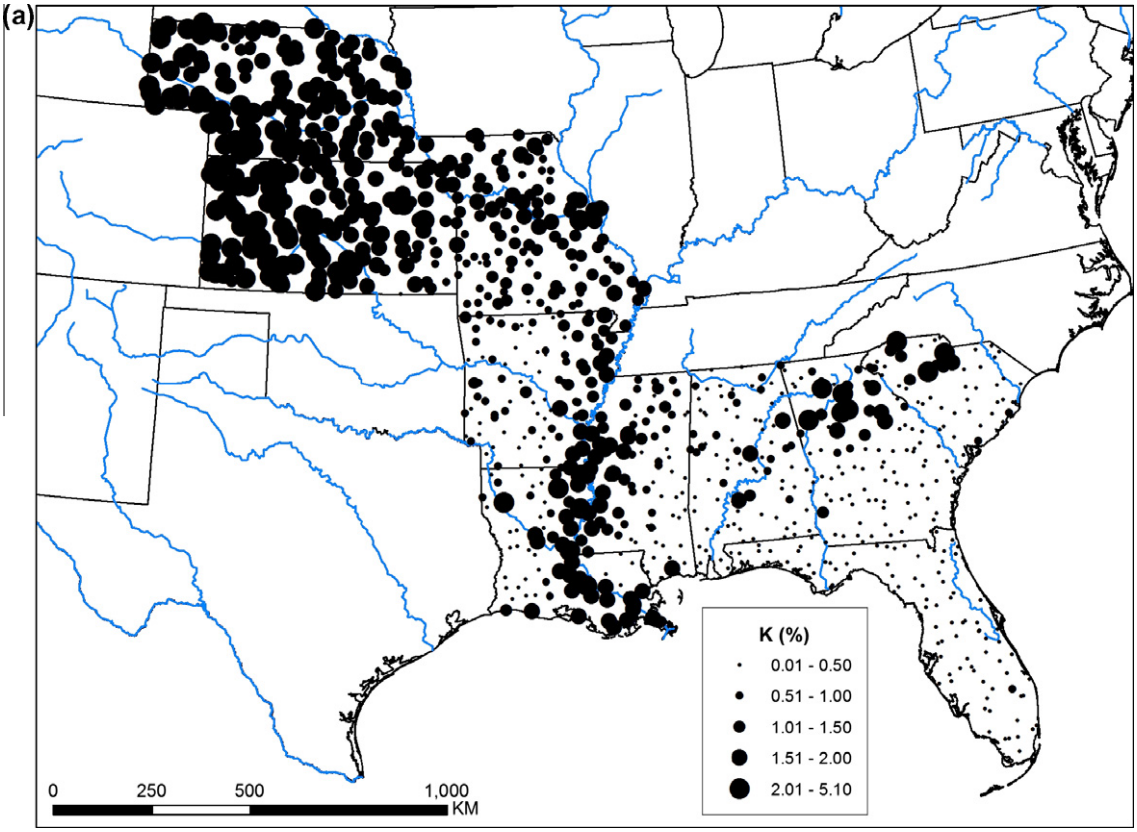


**Fig. 2.** Geochemical maps showing the distribution of K (a), As (b), Pb (c), and Zn (d) in soil A horizon samples along a swath from Nebraska to Florida.

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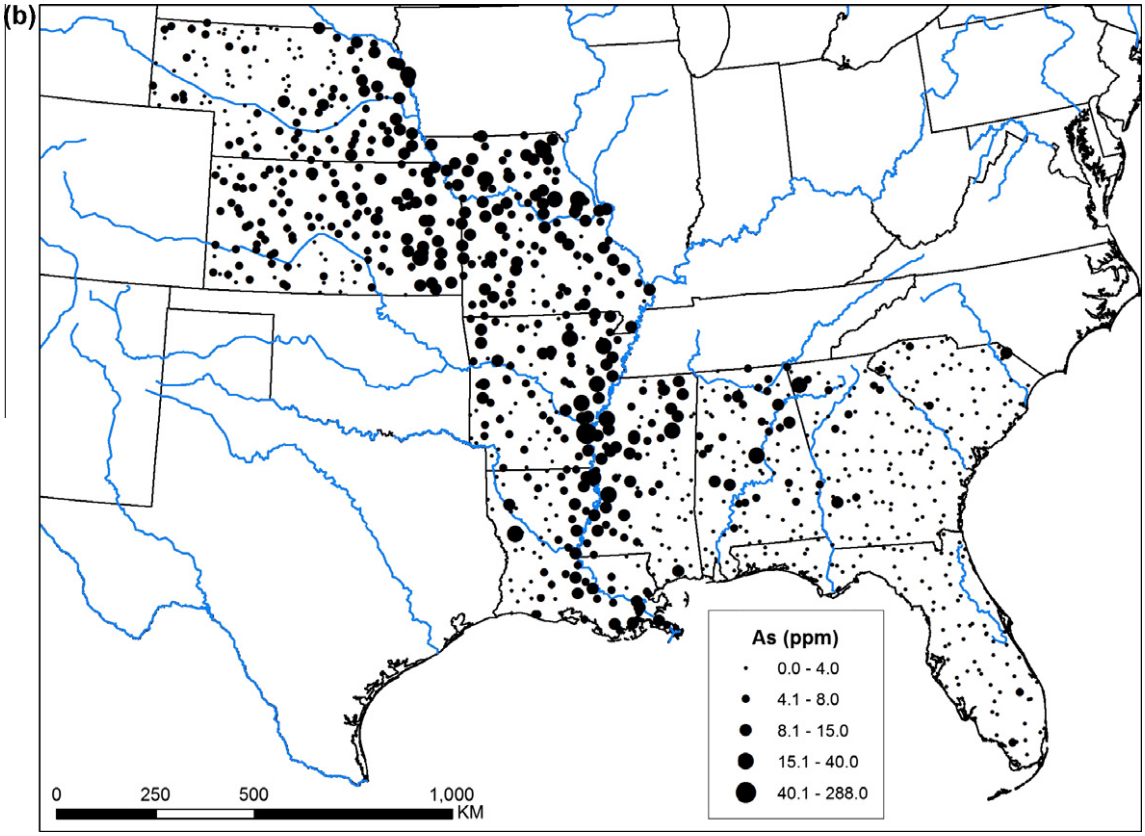


**Fig. 2** (*continued*)

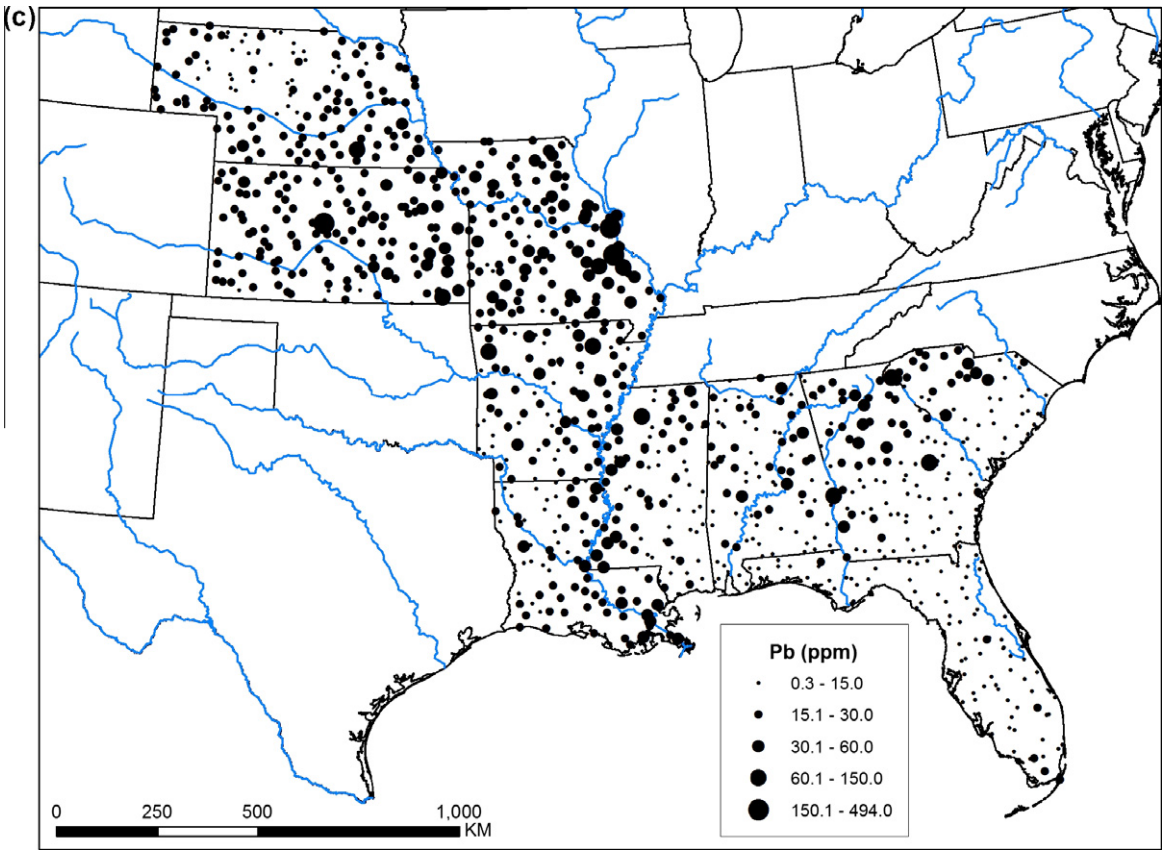


**Fig. 2** (*continued*)

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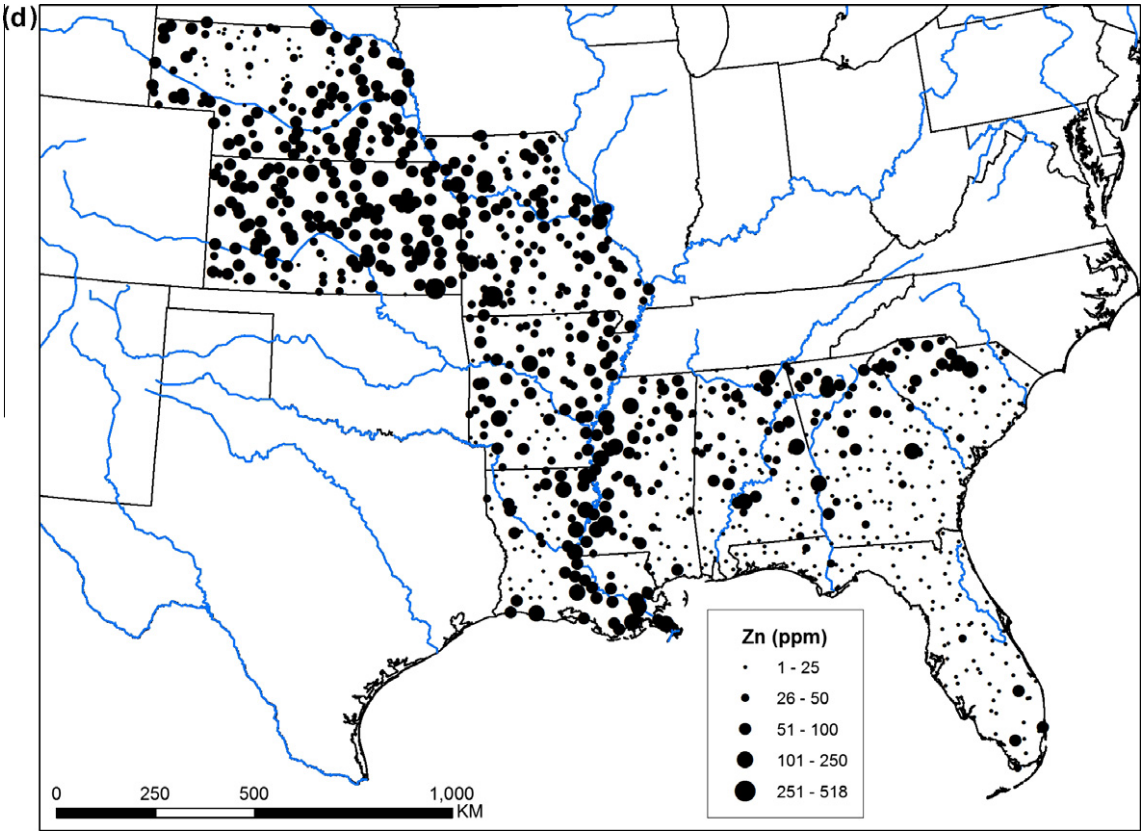


**Fig. 2** (*continued*)

4. No sample should be collected less than 5 km downwind from active major industrial activities such as power plants or smelters.

Sample-collection protocols were developed in a series of workshops with project stakeholders during 2003–2004. These protocols represent a combination of depth-based and horizon-based sampling. Ideally, at each site the following samples are collected: (1) soil from a depth of 0–5 cm, regardless of what soil horizon(s) this might represent; (2) a composite of the soil A horizon; and (3) a sample from the soil C horizon or, in cases where the top of the C horizon was more than 1 m below the surface, a sample from a depth of approximately 80–100 cm.

## 3. Analytical protocols

### 3.1. Chemical analyses

Each sample was air-dried at ambient temperature, disaggregated, and sieved through a 2-mm stainless steel screen. The <2-mm material was crushed to <150 μm in a ceramic mill prior to chemical analysis. Aluminum, Ca, Fe, K, Mg, Na, S, Ti, Ag, Ba, Be, Bi, Cd, Ce, Co, Cr, Cs, Cu, Ga, In, La, Li, Mn, Mo, Nb, Ni, P, Pb, Rb, Sb, Sc, Sn, Sr, Te, Th, Tl, U, V, W, Y and Zn were determined by inductively coupled plasma-mass spectrometry and inductively coupled plasma-atomic emission spectrometry following a near-total digestion in a mixture of HCl, $HNO_3$, $HClO_4$ and HF. Mercury

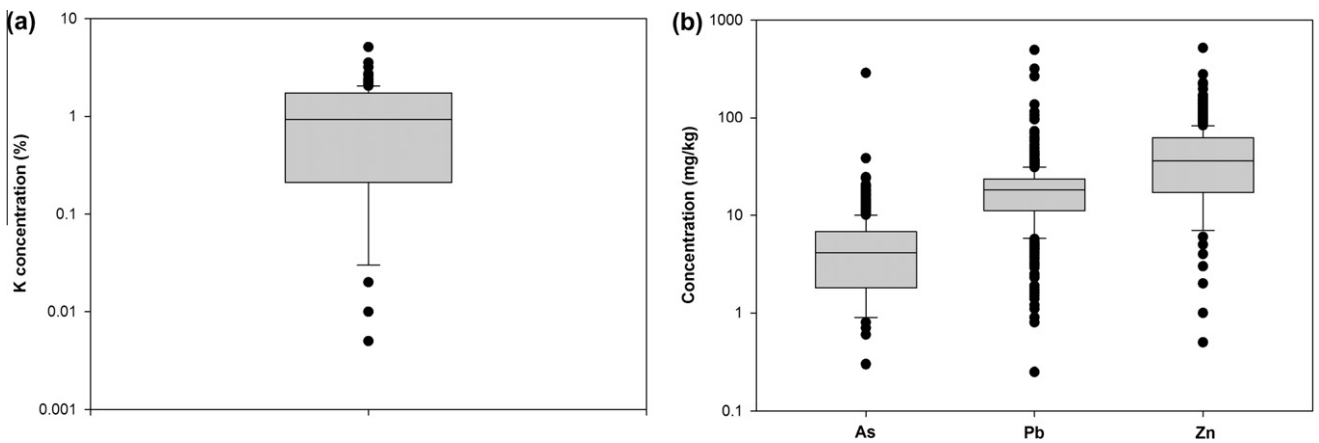


**Fig. 3.** Box-and-whisker plots showing the variation in the concentration of K (a) and As, Pb, and Zn (b) in soil A horizon samples in the mapped area shown in Fig. 2.

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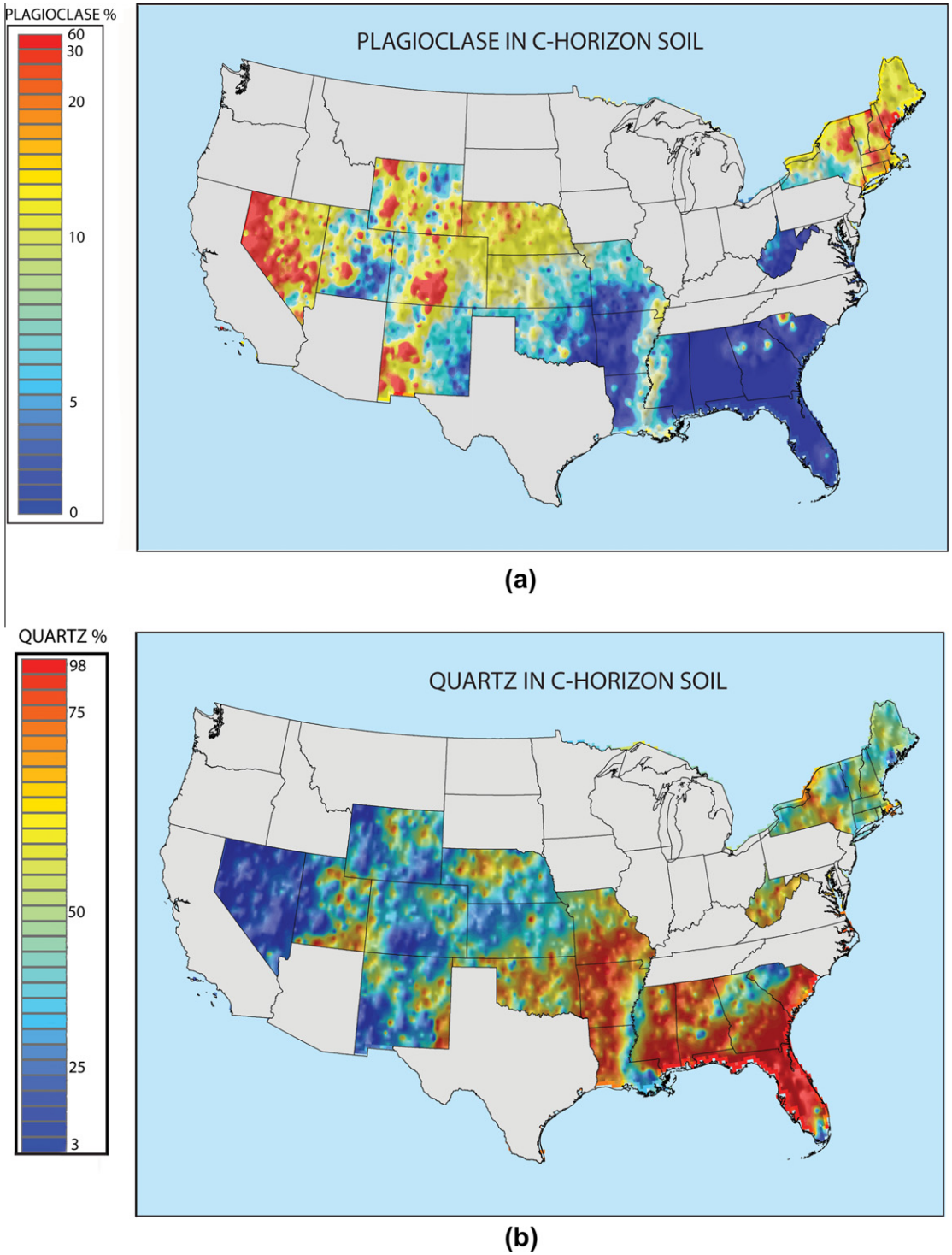


**Fig. 4.** Maps showing the distribution of plagioclase (a) and quartz (b) in soil C horizon samples for a portion of the conterminous US.

was determined by cold-vapor atomic absorption spectrometry, As and Se by hydride-generation atomic absorption spectrometry, and total C by combustion. The details of the analytical protocols are given by Smith et al. (2009).

### 3.2. Mineralogical analysis

Splits of the <2-mm material were mixed with a ZnO internal standard, ground in a micronizing mill, lightly pressed into back-loaded mounts, and analyzed by X-ray diffractometry (Cu Kα radiation) for the major mineralogical components. Mineral percentages were quantified using a Rietveld refinement technique. About 20 minerals or mineral groups can be quantified by this technique.

## 4. Results

Sampling was completed in the conterminous USA in late 2010. Chemical and mineralogical analyses are progressing, but

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it will likely be 2012 before the data set is complete. Geochemical maps for K, As, Pb and Zn in soil A horizon samples for a swath across the USA from Nebraska to Florida are shown in Fig. 2. The natural variation observed for this area is between 2 and 3 orders of magnitude for each of these elements (Fig. 3). Fig. 4 shows the distribution of plagioclase and quartz in soil C horizon samples in a portion of the conterminous USA for which data are available.

## 5. Discussion

The geochemistry and mineralogy are influenced primarily by the composition of the soil parent material, but climate (i.e., average annual precipitation) also is a major factor as pointed out by Bern (2009), Eberl and Smith (2009), and Woodruff et al. (2009). Low concentrations of As, Pb and Zn are seen in areas underlain primarily by quartz-rich sediments (e.g., the Sand Hills of northern Nebraska and the coastal plains of Florida, Georgia and South Carolina) and higher concentrations in areas underlain by parent material of more diverse mineralogy (Fig. 2). Enriched Pb concentrations are also seen in areas of southeast Missouri where Mississippi Valley type ore deposits occur. Feldspar content decreases from central Colorado through Missouri with a resulting decrease in the concentration of major elements such as K and Na. These decreases do not seem to be related to parent material composition, but correspond with a steady west-to-east increase in average annual precipitation from approximately 400 mm to 800 mm. The pattern shows the probable effect of weathering on soil geochemistry and mineralogy. This type of variation in these important soil-forming factors control the wide natural variability observed in element concentrations.

## 6. Conclusions

Sampling for a soil geochemical and mineralogical survey of the conterminous USA by the US Geological Survey has been completed and analyses are ongoing. The resulting data set for both chemical elements and mineralogical constituents in soils will be freely available to the public and will provide a valuable resource for a variety of decision makers ranging from environmental regulators to public health specialists. The data illustrate the wide variation of natural background concentrations of both major and trace elements in soils of the USA. The sample archive will also be available for future investigations by interested researchers.

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