MOBILITY OF ARSENIC IN AGRICULTURAL AND WETLANDS SOILS AND SEDIMENTS, NORTHERN COASTAL PLAIN OF NEW JERSEY

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Concentrations of arsenic that exceed the New Jersey Proposed Cleanup Standard (20 mg/kg (milligrams per kilogram)) have been found in soils developed on Cretaceous sediments in the northern Coastal Plain of New Jersey (Barringer and others, 1998). Because arsenic is toxic, human exposure to arsenic through contact with soils and sediments is of concern, as is the potential for arsenic migration through soils to ground water. Glauconite-rich sediments have contributed to elevated arsenic concentrations in overlying soils in the region (Kevin Schick, N. J. Department of Environmental Protection, written commun., 1998), but the arsenical pesticides used on former agricultural land have increased the arsenic content of other arsenic-poor soils and stream sediments; the latter relation also was observed by O'Brien (1997). Locally, industrial activities have contributed arsenic in high concentrations to soils and sediments (Barringer and others, 1998).

This paper summarizes results of an investigation of sources of arsenic in soils and sediments in parts of Middlesex and Monmouth Counties conducted by the U.S. Geological Survey in cooperation with the U.S. Environmental Protection Agency and New Jersey Department of Environmental Protection. The study area is underlain by the Cretaceous Englishtown Formation, a mica-rich quartz sand interbedded with clay lenses (fig. 1), which is used locally with varying intensity as a ground-water supply. Areas of well-drained sandy soils, extensively developed for agriculture in the 19th to mid-20th century, are now largely residential. Acidic, strongly bleached A and E soil horizons are underlain by orange iron hydroxide-rich B horizons that have remained largely intact despite agricultural or residential development. Organic-rich wetland soils (humaquepts) have developed along streams.
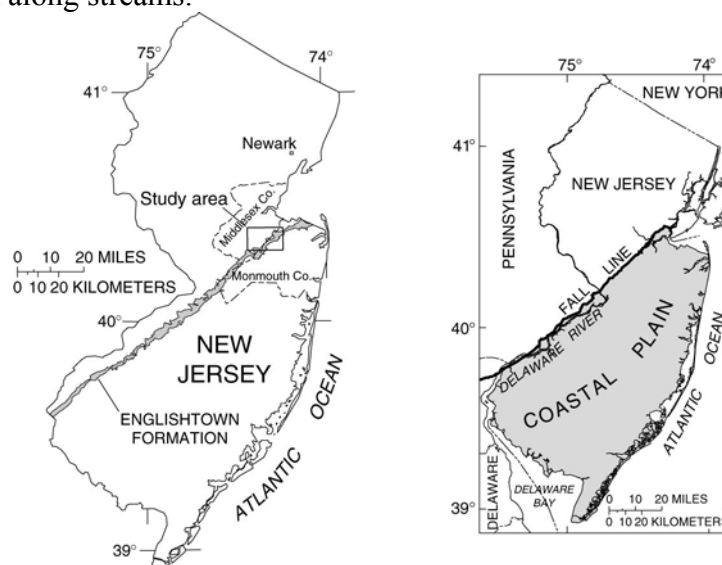

Figure 1. Location of the study area, Middlesex and Monmouth Counties, and the Coastal Plain of New Jersey. (Modified from Barringer and others, 1998)

Naturally occurring arsenic concentrations were low (1-15 mg/kg) in undeveloped sandy forest soils (A and B horizons) formed on the Englishtown Formation, but clay lenses within the Formation contained from 8 to 41 mg/kg of arsenic. Arsenic concentrations commonly were slightly higher in B-horizon soils than in A-horizon soils (fig. 2).
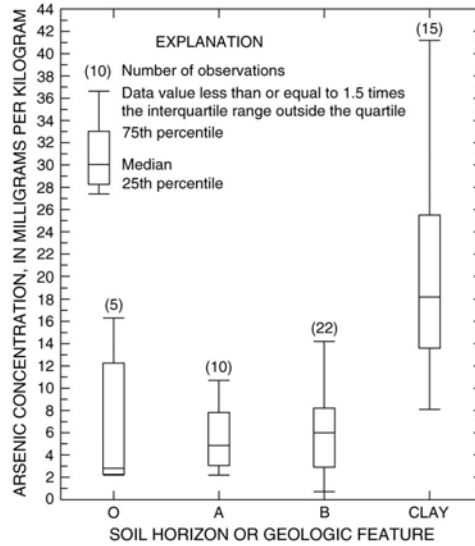

Figure 2. Distribution of arsenic concentrations in sandy soil and clay samples from undeveloped forested areas, Middlesex and Monmouth Counties, New Jersey. (Modified from Barringer and others, 1998)

As a result of applications of lead arsenate pesticide, arsenic concentrations tended to be higher in soils in inactive and active orchards than in forest soils, ranging up to 42 mg/kg (A-horizon; table 1). Arsenic exhibited limited mobility in the orchard soils, as A or E horizons contained higher concentrations than did B horizons in 9 of 13 samples. Arsenic concentrations in soils in a residential area built on former orchard land ranged up to 74 mg/kg (B-horizon sample) and were higher in A or E horizons than in B horizons in 11 of 18 samples. Arsenic concentrations may be higher in the residential area than in other former orchard areas as a result of greater pesticide use and (or) accumulation through disturbance. In disturbed soil near the residential area, arsenic concentrations in A-horizon samples were 21 and 30 mg/kg, whereas the concentration in the B-horizon sample was 149 mg/kg. Arsenic concentrations in forest, orchard, and residential soils tended to increase monotonically with aluminum and iron concentrations, indicating an association with the clay and iron hydroxide content of the soil.

Table 1. Arsenic concentrations in A-horizon soil samples from three land uses, Middlesex and Monmouth Counties [Values in milligrams per kilogram]

Statistic	Forest	Orchard	Residential
Maximum	11	42	70
Median	5	12	25
Minimum	2	5	7

About 7 acres of cultivated humaquepts on a farm adjacent to a brook apparently received inputs of arsenic not only from lead arsenate applications, but also from floodwaters carrying arsenic-bearing sediments in runoff from the site of a former chemical company upstream. Arsenic concentrations exceeded 100 mg/kg in some cases and tended to increase with depth in the humaquepts. Results of lead-210 measurements indicate the humaquepts were deposited at a rate of about 0.1 cm (centimeters) per year; therefore, organic matter at the base of the humaquepts (1-1.3 meters) probably is about 1,000 years old, precluding the possibility that anthropogenic arsenic was directly deposited on the basal humaquepts. Thus, the arsenic deposited at the humaquept surface in the early to mid 20th century likely has been mobile (Barringer and others, 2000).

The surficial humaquepts are acidic (pH 4.1-5.5), and much of the humaquept profile is partially saturated most of the year. Ground water, encountered at 1 meter below land surface, flows laterally toward the stream. The wet environment promotes a sharp geochemical gradient to strongly reducing conditions, indicated by the presence of hydrogen sulfide. Although arsenic and, generally, iron concentrations increased with depth (fig. 3), concentrations of lead, input at the land surface by either pesticide applications or atmospheric deposition, decreased with depth, indicating little mobility.
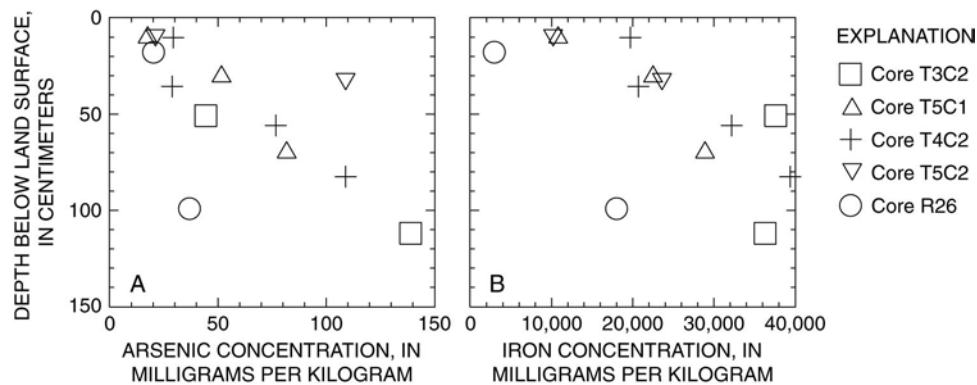

Figure 3. Distribution of (A) arsenic and (B) iron concentrations with depth in five cores from cultivated humaquepts at the farm, Monmouth County, New Jersey. (Modified from Barringer and others, 2000)

Arsenic in humaquepts at the farm appears to be mobile as a result of reduction of relatively immobile arsenate species (containing As (V)) to mobile arsenite (As (III)) species. Reduction of iron hydroxide coatings on sand grains in the humaquepts probably has led to iron mobility; some or all of the arsenate may have been adsorbed to the iron hydroxides. Sands of the Englishtown Formation underlying the humaquepts contain arsenic at background concentrations, indicating that arsenic apparently has not migrated into the sands, but has accumulated at the base of the humaquepts.

Humaquepts from stream banks and channels were sampled in nearby watersheds with predominantly agricultural and residential land use. Arsenic concentrations in samples from the upper 30 cm ranged from 18 to 43 mg/kg, but concentrations in deeper samples generally were in the range of 5 to 14 mg/kg. Sand at the surface of one sampling site contained 82 mg/kg of arsenic. Concentrations of lead, copper, and chromium in all

surface samples decreased with depth, indicating surficial anthropogenic sources of these metals. The presence of hydrogen sulfide indicated reducing geochemical environments in most of the humaquepts from other watersheds. The mobility of arsenic, accompanied by iron, was less pronounced than in the humaquepts at the farm, however, as concentrations did not increase consistently with depth, and, in some cores, even decreased with depth (fig. 4). Arsenic may be less mobile in humaquepts from other watersheds than in those at the farm because (1) arsenic inputs at the surface were smaller, (2) these humaquepts are more heterogeneous (interlayered with sands and clay lenses) causing strongly reducing zones to be more heterogeneously distributed, and (3) these humaquepts are areally much less extensive and likely are more thoroughly flushed by oxic waters.
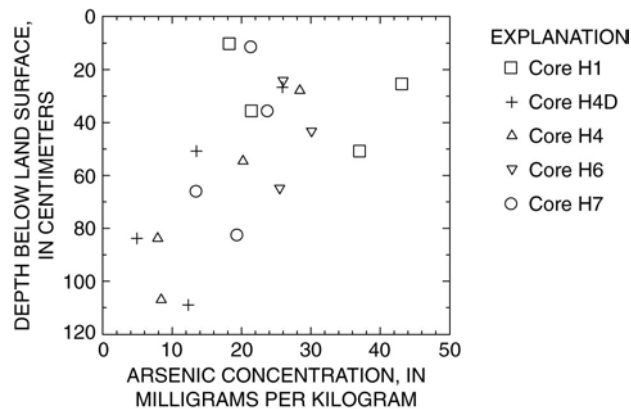

Figure 4. Distribution of arsenic with depth in five soil cores from humaquepts in watersheds in Middlesex and Monmouth Counties, New Jersey.

Overall, inputs of arsenic to soils, much from use of arsenical pesticides and some from a localized industrial source, appear to be widespread in non-forested parts of the study area. Mobility of arsenic in the sandy soils is limited but may be promoted by soil disturbance. A reducing geochemical environment appears to be an important factor in transporting arsenic from the land surface to depth in organic-rich soils. Human exposure to arsenic in soils is most likely where arsenic mobility is limited and surficial concentrations remain high. Mobile arsenic in wetlands probably has little effect on local ground-water resources, as Coastal Plain wetlands typically are areas of ground-water discharge.

REFERENCES

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