DISPERSION OF ARSENIC FROM ARSENIC-ENRICHED COAL AND GOLD ORE IN THE SOUTHERN APPALACHIANS

M.B. Goldhaber (1), E. R. Irwin (2), J.B. Atkins (3), L. Lee (1), D.D. Black (2), H. Zappia (3), J.R. Hatch (4), J. C. Pashin (5), R. F. Sanzolone(1), L.F. Ruppert (6), A. Kolker (6), R. B. Finkelman (6).

(1)USGS, MS973, Denver Federal Center, Denver, CO 80225; (2) USGS, 331 Funchess Hall, Auburn University, Auburn, Al 36849-5414; (3)USGS 2350 Fairlane Drive, Suite 120, Montgomery, AL 36116; (4) USGS, MS977, Denver Federal Center, Denver, CO 80225; (5)Geological Survey of Alabama, P. O. Box O., Tuscaloosa, AL 35486-9780; (6) USGS, MS956, National Center, Reston, 20192.

Nearly 1000 analyses from the USGS coal quality (COALQUAL) database (Bragg et al., 1998) show that the highest arsenic concentrations for all U.S. coals, up to 2500 mg/kg on a whole coal basis, are found in Pennsylvanian bituminous coals of the Warrior Cahaba and Coosa coal fields, in northern Alabama (fig 1). The mean value for arsenic in Warrior coals (72 mg/kg) is three times higher than that for all U.S. coals (24 mg/kg). Investigation by SEM, electron microprobe, and Laser-Ablation ICP Mass Spectroscopy demonstrates that the arsenic is contained in the mineral pyrite (Kolker et al., 1999). Arsenic is also enriched in rocks from northern Alabama outside of the coal-bearing area. High concentrations of arsenic are common in small gold occurrences and deposits located 60-150 km east and southeast of the Warrior coal basin and hosted by metamorphic rocks. The residence of arsenic in these ores is the mineral arsenopyrite. We hypothesize that enrichment in arsenic and associated elements in both coal beds and gold ores, is the result of interaction of these rocks with metamorphic fluids generated during the Alleghanian orogeny (Goldhaber et al., 1997).

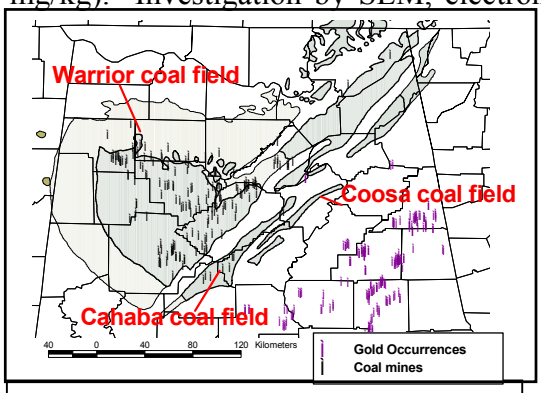

Figure 1; Map showing locations of Alabama coal fields, coal mines and gold occurrences

To evaluate the possible environmental dispersion of arsenic, a study of existing stream sediment samples from nearly 3000 sites was conducted, using samples collected in northern Alabama during the National Uranium Resource Evaluation (NURE) program of the early 1970's. These samples were retrieved and reanalyzed for arsenic by hydride generation atomic absorption spectroscopy. The arsenic concentration data are shown in figure 2 in two ways. The individual analyses are shown as red dots whose size is proportional to the stream sediment arsenic concentration. In addition, the data have

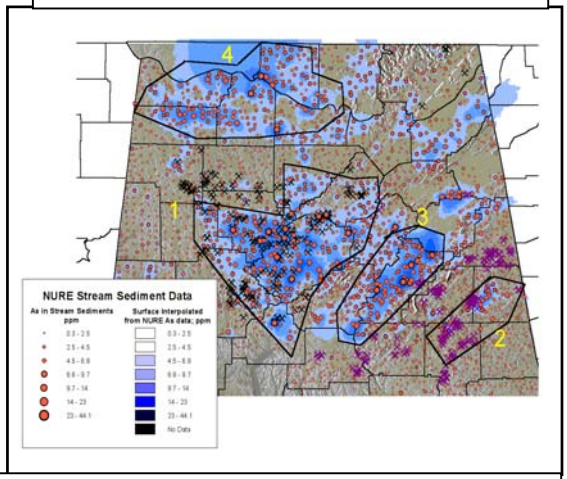

Figure 2. Map showing the concentration of arsenic in stream sediments of northern Alabama. Mine symbols as in Fig 1.

been gridded, and areas with systematically high values are colored in various shades of blue, depending on the value for that area. The overall range of arsenic in the NURE stream-sediments was from 0.3 to 44 mg/kg. The mean value was 4.3 mg/kg with a standard deviation of 4.1 mg/kg. For comparison, the crustal abundance of arsenic is 1.8 mg/kg. Shales are higher with average values of 15 mg/kg. A study of stream-sediments from throughout the U.S. by the USGS NAWQA program, reported that the 75th percentile for arsenic in 541 stream-sediments was 9.5 mg/kg (Rice, 1999). Stream sediments from the coal mining area (labeled area 1 on figure 2) are elevated in arsenic (generally 12-44 mg/kg) compared to adjacent areas (<12 mg/kg As). Given the relatively low crustal abundance of arsenic, a number of stream-sediment samples in this study may be considered geochemically anomalous in this element. Stream sediment arsenic enrichments were also evident in gold mineralized areas (area labeled 2 in figure 2).

Follow-up studies on selected drainages in the Warrior and Cahaba coal fields (figure. 3) reveal that acid mine drainage (AMD) from coal mine waste piles is one of the major sources of arsenic to these stream sediments. Larry Barwick of the Alabama Mine Land Reclamation Division selected these study sites as representing abandoned coal mines with significant acid mine drainage problems. Chemical analysis of stream sediments associated with these AMD sites show elevated concentrations of As, Fe, Cu, Zn and Se. Arsenic concentrations range from 4 to 180 mg/kg with an arithmetic mean of 48 mg/kg. For comparison, the arithmetic mean of all the subset of NURE samples is 4.3 mg/kg as noted above. Based on these results, stream-sediments from the immediate vicinity of old abandoned coal mines contain significantly elevated concentrations of arsenic compared to stream-sediments from the overall NURE data set. This enrichment in arsenic is illustrated by a histogram (figure 4) comparing the stream-sediment samples immediately adjacent to coal mines with the overall Alabama NURE data set. Over half of the coal mine-related samples have higher arsenic concentrations than are present in the much larger NURE sample suite. Furthermore the highest value in the NURE data set (44 mg/kg As) is exceeded by at least one analysis from stream-sediments collected in the vicinity of each abandoned coal mine.

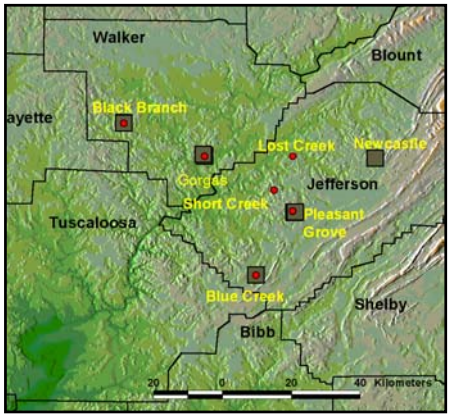

Figure 3; Locations of coal acid mine drainage sites sampled for stream sediment and coal waste geochemistry. Squares are coal mine waste samples, red circles are stream sediment and stream water samples

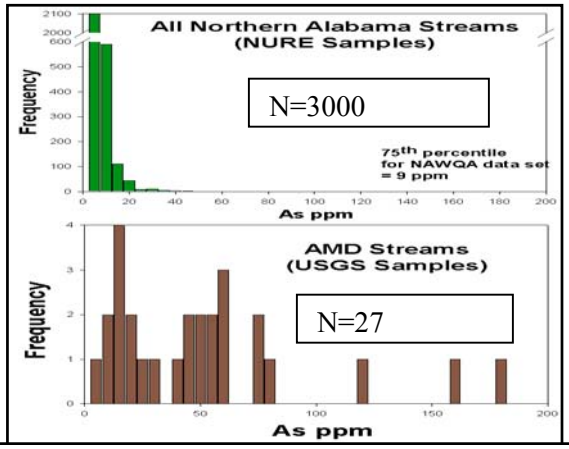

Figure 4. Histogram contrasting As concentration in the overall NURE data set (top), with values found in sediments immediately adjacent to coal waste piles

Surface oxidized samples of the coal mine waste (dump) materials were enriched in arsenic compared to average shale and coal values. The overall range for the coal waste samples was 7-470 mg/kg arsenic with an arithmetic mean of 122 mg/kg. The data indicate that both altered (oxidized) wastes from abandoned coal mines and stream-sediments in close proximity to the

abandoned mines are highly elevated in arsenic.

Based on selective leaching of stream sediment samples, the residence of arsenic is dominantly iron oxyhydroxides. Rock samples, which may represent original roof, floor, or parting material in the coal beds, collected from the surface of waste piles contain up to 470 mg/kg arsenic. In one intensively studied drainage, stream sediment arsenic enrichment was observed in a side drainage (Black Branch) that was impacted by AMD from an old abandoned mine. But arsenic enrichment was not evident in the main drainage (Cain Creek) adjacent to an active strip mine.

In contrast to solid phase materials, stream water samples from sites shown in figure 3 contain only low levels of dissolved arsenic. Concentrations of arsenic are below the proposed (lowered) drinking water standard of 10 μg/l, with the exception of a single sample collected from the Gorgas site that had 89 μg/l arsenic. This sample was collected by digging down to the water table in a plume of sediments that had slumped off a coal mine waste pile. Therefore, the sample represents shallow groundwater, not stream water. Production waters from coal bed methane degasification fields are saline and non-potible. These deep groundwaters average 25μg/l with a maximum of 475 μg/l (n=28) (O'Neil et al. 1993). Drinking water wells in the coal field are shallow and averaged 2 μg/l, with a maximum of 44 μg/l arsenic (O'Neil et al, 1993). Although more sampling is warranted, the potential exists locally for arsenic-enriched drinking water.

The Alabama studies may be a useful template for understanding the potential for arsenic impacts from coal mining elsewhere in the Appalachian coalfield and gold mining in adjacent metamorphic rocks. Widespread, though much more sporadic, arsenic enrichments occur in northern and central Appalachian Basin coal beds and gold ores. Preliminary data on stream sediment geochemistry from the eastern Kentucky coal-mining region (presented elsewhere at this meeting) show significantly lower arsenic concentrations than Alabama.

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