

A SEASONAL STUDY OF THE ARSENIC AND GROUNDWATER GEOCHEMISTRY IN FAIRBANKS, ALASKA

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1. INTRODUCTION

Groundwater arsenic concentrations are of increasing environmental concern due to the risk As poses to plant, animal, and human health. High arsenic concentrations are found in local drinking water supplies in Fairbanks, Alaska USA. Elevated groundwater arsenic concentrations were first recorded here in the mid 1970's, and subsequent studies determined the spatial distribution of high As content waters (Harrington et al, 1978; Wilson and Hawkins, 1978; Hawkins et al 1982, McCrum, 1984; Weber 1986).

In 1996, workers from the U.S. Geological Survey and University of Colorado began a geochemical investigation of groundwaters in the Fairbanks area with the intent of further assessing the factors controlling their dissolved As contents (Goldfarb et al., 1998; Farmer et al., 1999). In the summer of 1999, a year-long study was begun to evaluate seasonal trends and fluctuations in the groundwater major, minor, and trace element compositions. The preliminary results of this study are presented here.

1.2 Local Geology and Arsenic-Bearing Mineral Occurrences

The geology of the Fairbanks area has been described by Robinson et al. (1990), Foster et al. (1994), and Newberry and Bundtzen (1996). The rocks in the Fairbanks area are part of the Yukon-Tanana terrane, a complexly faulted pericratonic block of middle Paleozoic and older rocks that have been poly-deformed and poly-metamorphosed (Foster et al., 1994). The dominant lithologic unit of the terrane exposed in the Fairbanks area is the Fairbanks Schist. This is a heterogeneous unit comprised of mainly quartzite and muscovite-quartz+garnet+biotite+chlorite schist (Foster et al., 1994).

Gold-bearing veins are present in the Fairbanks area and were apparently emplaced in conjunction with the intrusion of granitic rocks in the Late Cretaceous. Where hosted by granitic rocks, the auriferous veins are extremely low in sulfide minerals (<0.1 volume percent), but where hosted by schist, the sulfide mineral abundances are relatively high, typically reaching 1-3 percent of the vein material and locally much higher volumes. Arsenopyrite, pyrite (often arsenian pyrite), and stibnite are the most common sulfide minerals in veins throughout the Fairbanks region (Newberry et al. 1996). Hydrothermally-altered metasedimentary country rocks surrounding the veins are commonly characterized by albite, sericite, ankerite and related carbonate minerals, chlorite and extensive silicification, as well as sulfidization.

2. METHODS

2.1 Sampling and Field Techniques

Groundwater samples were collected at two-month intervals, beginning in August of 1999 and ending August of 2000, from seventeen domestic water wells that penetrate the Fairbanks Schist along the Goldstream Valley. This area has been previously identified as yielding high As-bearing groundwater (Weddleton et al., 1989), and is located to the immediate east of Ester Dome and the Ryan Lode gold mine. Several additional sites were selected along the edge of and within the lowlands of the Goldstream Valley to evaluate the possibility that upstream placer tailings are contributing to the elevated groundwater arsenic concentrations. All wells in this study range in depth from 90-375 feet.

Water temperature, pH, and conductivity, were measured at each well site. Prior to sampling, wells were purged for up to 45 minutes. Alkalinity and dissolved oxygen (DO) measurements were taken at all sites. Filtered (0.45 micron filter) and unfiltered samples were taken for inductively coupled plasma-mass spectrometry (ICP-MS) analysis, as well as separate aliquots for anions, ferrous iron, and arsenic speciation. All samples were stored on ice until analyzed.

2.2 Analytical Methods

Concentrations of trace, minor, and major elements were determined by ICP-MS. Anions were determined by ion chromatography. Arsenate (As(III)) and arsenite (As(V)) was separated using a modification of the method of Ficklin (1983). Arsenic concentrations were determined using graphite-furnace atomic-absorption spectroscopy, with a detection limit of 3 ppb for each species. Iron speciation was measured using a Hach DR/2010 spectrophotometer and ferrozine reagent.

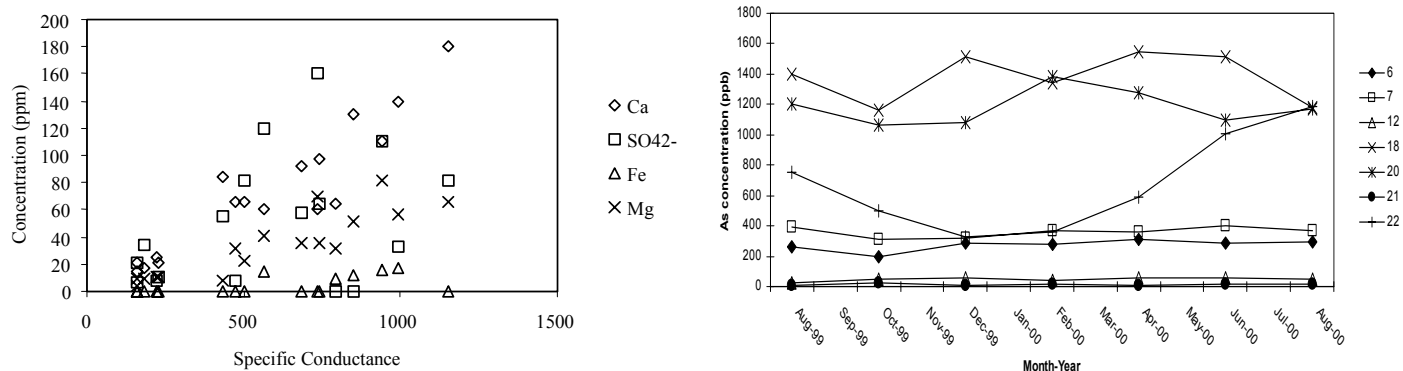


Figure 1. The left panel shows the variation in concentration of four of the elements measured for all seventeen samples during one collection. The right panel shows the seasonal variation of arsenic in the seven high-arsenic waters.

3. GEOCHEMICAL RESULTS

The groundwaters sampled in this study are generally neutral (pH ~6.2-7.4), calcium-bicarbonate waters, with specific conductivities ranging from 161-1154 $\mu\text{S}\cdot\text{cm}^{-1}$. Major and trace element compositions range widely between sampling sites (ie. Ca 15-180 ppm, Mg 3.9-82 ppm, Fe 0.05-17 ppm, SO42- 0.1-130 ppm), but fluctuations in the chemical composition of individual waters were minor throughout the year (Figure 1.). Similarly, no seasonal variations were observed in As or Fe speciation, pH, conductivity, or dissolved oxygen. However in our previous work, the wells can be divided into two basic chemical groups, high arsenic(As > 8.3-1400 ppb) and low arsenic (<2 ppb) waters. In general the iron concentrations in the low arsenic waters are <250 ppb and are predominately Fe(III). Whereas the iron concentrations in the high arsenic wells range from 50-17000 ppb, and are predominately Fe(II). Additionally the high arsenic waters tend to be dominated by As(III). The high arsenic waters generally have DO concentrations of <1.0 mg/L, while the low arsenic water DO concentrations range from <1.0-13.8 mg/L. The specific conductance of both groups ranges between 161-1154 $\mu\text{S}\cdot\text{cm}^{-1}$.

4. DISCUSSION

Our data show no evidence of seasonal variations in the chemical characteristics of domestic well-waters in Fairbanks. In particular, we see no systematic seasonal variations in groundwater arsenic concentrations. This observation precludes the possibility that the As concentrations in the sampled groundwaters are controlled by variations in the water table height, and resulting variations in DO and the degree of primary oxidation of As-bearing sulfide phases at a given well site. However, we do observe significant between-well variations in the compositions of the

groundwaters that are independent of sampling time. These well to well variations are most likely the result of the degree of interaction between groundwaters and country-rock, variations in the type of country rock weathered by a given groundwater, and /or variations in groundwater redox conditions. The lack of seasonal influences suggests that waters had significant, but otherwise unknown, residence times in the aquifer prior to collection in domestic wells.

It has been established by previous workers (McCrum, 1985; Weber, 1986; Hok, 1987) that groundwater flow in upland areas is controlled by features associated with the regional NW-trending fault system, and recharge for the bedrock aquifer is derived predominately from snow melt. In general, the variable conductivity of ground waters in the Fairbanks area suggest variable degrees of water-rock reaction within the porous fractured bedrock. The variations and inconsistent trace element patterns seen between sampling locations is most likely the result of subtle heterogeneities within the Fairbanks Schist subgroups (ie. water passing through a quartzite versus a biotite or chlorite schist). Additionally recent geologic studies (McCoy et al, 1997; Metz 1991) indicate that gold and related sulfide mineralization (associated with trace elements such as As, P, Sb, Fe,) within the schist, occurs within shears, faults and fault gouge materials, interaction between groundwater and these minerals (albite, sericite, ankerite and related carbonate minerals, chlorite and extensive silicification) could also be responsible for the variation in trace elements among sampling sites. The consistently variable redox conditions (as shown by As and Fe speciation and DO) can also be attributed to previous interaction between groundwater and redox sensitive minerals (sulfides) and residence time within the aquifer.

Two mechanisms that could be controlling the behavior of arsenic in the groundwater are: 1) oxidation of primary sulfide arsenic-bearing sulfide minerals, 2) the remobilization of arsenic from iron-hydroxides or other secondary arsenic-bearing phases. If oxidation of primary As-bearing sulfide minerals is responsible for the elevated groundwater arsenic concentrations then the data should show changes in the pH (acid production from weathering of sulfides) and HCO₃⁻ (buffering of acids produced), as well as concentration changes in redox sensitive elements such as iron, manganese, arsenic, and sulfate. Instead, we observe that these constituents remain fairly constant and are independent of sampling time..

Therefore the more probable mechanism, given the consistent, predominately reducing conditions in the high-As groundwater, is that the arsenic concentrations are being controlled by small fluctuations in the water table that are causing the remobilization of arsenic from iron-hydroxides or secondary arsenic bearing phases, including ferric arsenate, scorodite and/or sorbed components on ferric-hydroxides. Oxyanionic species, such as arsenite, phosphate, and dissolved silica are readily absorbed onto iron-hydroxides. Under the strongly reducing conditions and near neutral pH, observed throughout this study, it seems likely that any such mineral phase would undergo reductive dissolution and subsequently release arsenic into solution. Furthermore, elevated arsenic concentrations consistently accompanied by high concentrations of Fe (17 ppm), Mn (5690 ppb), P (1100 ppb) and Si (24 ppm) throughout the year.

5.SUMMARY

The goals of this one-year-long study have been to evaluate seasonal trends in major minor and trace element geochemistry, with the focus on understanding the behavior of arsenic in the groundwater. The preliminary results shown here indicate that the majority of chemical constituents, including parameters such as pH and specific conductivity, remained fairly constant throughout this study. This data suggests that the groundwater has not been influenced by seasonal variations in the local water table heights, and that oxidation of primary arsenic bearing sulfide minerals is not responsible for the variations in groundwater As contents in the sampled groundwaters. The speciation results for both iron and arsenic, as well as the presence of elevated

manganese, phosphate, and silica suggest instead that the arsenic is being remobilized from iron-hydroxides or other secondary arsenic-bearing phases under reducing conditions.

6. REFERENCES

- Farmer, G.L., R.J., Lilley, M.R., Bolton, B., Meir, A.L., Sanzolone, R., 1999. The Chemical characteristics of groundwater near Fairbanks, Alaska .
- Goldfarb, R.J., Farmer, G.L., Cieutat, B.A., and Meier, A.L., 1999, Major element, trace element, and strontium isotope systematics of natural waters in the Fairbanks mining district- Constraints from local geology: in Kelley, K.D. (ed), Geological Studies in Alaska by the U.S. Geological Survey, 1999: U.S.G.S. Professional Paper
- Foster, H.L., Keith, T.E.C., Menzie, W.D., 1994, Geology of the Yukon-Tanana area of east-central Alaska, in Plafker, G., Berg, H.C., ed., The Geology of Alaska, Volume G-1, United States Geological Survey, p. 205-240.
- Hawkins, D.B., Forbes, R.B., Hok, C.I., Dinkel, D., 1982, Arsenic in the water, soil, bedrock, and plants of the Ester Dome area of Alaska: Fairbanks, University of Alaska, p. 82.
- Harrington, J.M., Middaugh, J.P. Morse, D.L., Housworth, J., 1978, A survey of population exposed to high concentrations of arsenic in well water in Fairbanks, Alaska: American journal of Epidemiology, v. 108, p. 377-385.
- McCoy, D., Newberry, R.J., Layer, P., DiMarchi, J.J., Bakke, A., Masterman, J.S., Minehane, D.L., 1997, Plutonic-related gold deposits of interior Alaska, in Goldfarb, R.J., Miller, L.D., ed., Economic Geology Monograph 9 Mineral Deposits of Alaska: Economic Geology Monograph: Stanford, Economic Geology, p. 466.
- McCrum, M.A., 1985, A chemical mass balance of the Ester Creek and Happy creek watersheds on Ester Dome, Alaska [MSc. thesis]: Fairbanks, University of Alaska, p.370.
- Meier, A.L., Grimes, D.J., Ficklin, W.H., 1994, Inductively coupled plasma mass spectrometry-- A powerful tool for mineral resource and environmental studies: *Geochimica et Cosmochimica Acta*, v. 59, p. 1773-1786.
- Metz, P.A., 1991, Metallogeny of the Fairbanks Mining District, Alaska and Adjacent Areas: Mineral Industry Research Laboratory, School of Engineering, University of Alaska.
- Newberry, R.J., Bundtzen, T.K., 1996, Preliminary geologic map of the Fairbanks mining district, Alaska: Fairbanks, Alaska Division of Geological and Geophysical Surveys, p. 2.
- Preece, S.J., Westgate, J.A., Stemper, B.A., Pewe, T.L., 1999, Tephrochronology of late Cenozoic loess at Fairbanks, central Alaska, Geological Society of America, p. 71-90.
- Robinson, M.S., Smith, T.E., Metz, P.A., 1990, Bedrock Geology of the Fairbanks mining district: Fairbanks, Alaska Division of Geological and Geophysical Surveys, p. 2 sheets.
- Weber, E.F., 1986, A stochastic model and risk analysis of arsenic, well depth and well yield in the Fairbanks area, Alaska [MSc. thesis]: Fairbanks, University of Alaska,.
- Weddleton, J., Richards, H., Seifert, R., 1989, guide for assessing risks and costs of water drilling in the Fairbanks area: Fairbanks, Institute of Northern Engineering, Water Research Center, p. 11.
- Wilson, F.H., Hawkins, D.B., 1978, Arsenic in streams, stream sediments and groundwater, Fairbanks area, Alaska: *Environmental Geology*, v. 2, p. 195-202.

