

## **Chapter SA (Streamwater Analyses)**

### **INFLUENCE OF HUE SHALE WEATHERING ON WATER CHEMISTRY IN HUE CREEK, ARCTIC NATIONAL WILDLIFE REFUGE, ALASKA**

*by* Bronwen Wang<sup>1</sup>

*in* The Oil and Gas Resource Potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska, by ANWR Assessment Team, U.S. Geological Survey Open-File Report 98-34.

1999

<sup>1</sup> U.S. Geological Survey, Anchorage AK, 99508

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards (or with the North American Stratigraphic Code). Use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U. S. Geological Survey.

## TABLE OF CONTENTS

Abstract

Introduction

    Previous Studies

    Hue Shale Outcrops And Hue Creek

Methods

Results

    Aqueous Samples

    Aqueous Blank And Duplicate Samples

    Stream Sediments

Discussion

Summary

References

## FIGURES

- SA1. Locations of Hue Creek and springs in the Arctic National Wildlife Refuge.
- SA2. Photograph of Hue Creek Shale outcrop on Hue Creek.
- SA3. Photograph of Hue Shale outcrops north of the Sadlerochit Mountains.
- SA4. Photograph of Hue Creek above Hue Shale outcrop.
- SA5. Photograph of Hue Creek within Hue Shale outcrop.
- SA6. Photograph of Hue Creek below Hue Creek outcrop.
- SA7. Photograph of Sadlerochit Spring.
- SA8. Photograph of Red Hill Spring.
- SA9. Trilinear diagram for water samples from Hue Creek, and Sadlerochit and Red Hill Springs.
- SA10. Comparison of Hue Creek, Sadlerochit and Red Hill Springs stable oxygen and deuterium isotopic value with the mean meteoric water.

## TABLES

- SA1. Major and trace ion concentrations in filtered water samples, organic carbon, tritium concentrations, and deuterium and oxygen isotope ratios.
- SA2. Semivolatile organic compound concentrations for filtered water samples.
- SA3. Volatile organic compound concentrations in unfiltered water samples.

- SA4. Aliphatic hydrocarbon concentrations in filtered water samples.
- SA5. Trace element concentrations in sediment samples from Hue Creek.

*[Tables SA1-SA5 are also available in spreadsheet form on this CDROM.]*

## ABSTRACT

Surface-water samples from Hue Creek and water samples from Sadlerochit and Red Hill Springs were collected during August 1996. The objective of the Hue Creek sampling was to characterize the relation between the weathering of the Hue Shale and water quality. The purpose of the spring samples was to evaluate the trace element composition of the springs. Hue Shale weathering alters both the aqueous major ion and trace element composition of Hue Creek. Above the contact with the Hue Shale, Hue Creek is a calcium magnesium bicarbonate water. Weathering of the shale unit changes the dominant anion from bicarbonate to sulfate. Calcium and magnesium increase and remain the dominant cations. The pH decreased 1.5 pH units and the alkalinity concentration nearly halved between samples taken from above and within the outcrop. Below the outcrop, pH and alkalinity increased. Sulfate, calcium, and magnesium increases are consistent with pyrite oxidation and continued dissolution of calcium magnesium carbonate. Aqueous concentrations of barium, cadmium, cobalt, iron, manganese, nickel, zinc, and aluminum increased between the sites above and within the outcrop. Iron concentrations in Hue Creek sediments increased downstream. Cobalt, copper, manganese, and nickel increased between samples taken within the outcrop and those below the outcrop. Sadlerochit Spring is a calcium magnesium bicarbonate water, while Red Hill Spring is a mixed calcium magnesium bicarbonate and sodium chloride water. Boron and barium concentrations were highest for Red Hill Spring. Chromium, copper, manganese, and zinc were detected in low concentrations in both springs. Stable oxygen and hydrogen isotope ratios for Red Hill and Sadlerochit Spring waters indicate that the water originated as precipitation and little rock-water interaction occurred. Tritium values indicated that both waters are post-bomb era (1950's). No volatile or semi-volatile organic compounds, or aliphatic hydrocarbons were detected in any water samples taken.

## INTRODUCTION

Surface-water samples from Hue Creek ([fig. SA1](#)) in the Arctic National Wildlife Refuge (ANWR) were collected during August 1996. Hue Creek originates in the Shublik Mountains and flows into Ignek Creek at the eastern end of the Ignek Valley. The objective of the sampling was to characterize the relation between the weathering of the Hue Shale and water quality. Heavy iron staining was noted in streams adjacent to the shale

outcrops during the 1995 field season. Major and minor elemental analysis for Hue Shale samples taken from test wells on the North Slope found moderate enrichment in uranium, vanadium, zinc, and iron, but the presence of sulfide minerals is not discussed (Brosgé and Tailleur, 1988; Isaacs and others, 1995). Oxidation of pyrite weathering can result in iron mobilization. In addition, pyrite-rich shale commonly produces acidic drainage during weathering, and trace metals can be mobilized in the process.

### **Previous Studies**

In a study of surface waters in Arctic Alaska, Brown and others (1962) found that local lithology controlled the cation compositions of arctic runoff. However, no changes in water quality from lithologic changes along a stream were discussed. Neither Brown nor any other study mentions the distinct change in stream color naturally occurring near the Hue Shale outcrops, noted during the 1995 field season.

Childers and others (1977) found good water quality in the open-water season during a reconnaissance of the eastern North Slope streams. Dissolved oxygen was at or near saturation, pH ranged from 6.8 to 7.8, alkalinity from 41 to 140 mg/L as CaCO<sub>3</sub>, specific conductance from 190 to 430 microsiemens/cm (µS/cm), and water temperature from 2.7 to 9.8 °C. During the winter, flow is virtually nonexistent in most North Slope streams and most winter flow is associated with springs (Childers and others, 1977). Springs are important features on the North Slope and are more abundant in the east, where the Brooks Range swings northward, than in the west. Within ANWR, 12 springs were studied between 1973 and 1975. The streams and springs have remarkably similar chemistry. The following ranges were found in springs: pH from 6.7 to 8.2, alkalinity from 95 to 150 mg/L as CaCO<sub>3</sub>, specific conductance from 210 to 410 µS/cm, and temperature from 1 to 13 °C (Childers and others, 1977). The notable exception is Red Hill Spring. This mineral hot spring has temperatures of about 30 °C, and a specific conductance of about 1,000 µS/cm.

Craig and McCart (1974) classified the streams on the North Slope as mountain, spring, or tundra depending on their origin. Mountain and spring streams were generally calcium carbonate to calcium magnesium carbonate type waters. Tundra streams originated outside the limestone area, and the tundra and standing water influenced the chemistry. Tundra streams had

lower calcium and magnesium concentrations, and lower pH, alkalinity, and specific conductance than the mountain and spring streams (Craig and McCart, 1974). Tundra streams were generally brown or yellow in color, indicating the presence of humic and fulvic acids.

Extensive sampling of the terrestrial, aquatic, and lagoon environments in ANWR was done as part of a contaminant and baseline study between 1988 and 1989 (Snyder-Conn and others, 1995). Lake water, sediments, invertebrates, sedges, birds, and fish were all sampled as part of this effort (Snyder-Conn and others, 1995). The ponds and lakes in the region were slightly more basic (pH between 7.6 and 8.3) than the streams and springs. Pond and lake alkalinity (20-40 mg/L as CaCO<sub>3</sub>) and specific conductances (100 and 300 µS/cm) were also lower than those in the streams and springs, and showed seasonal and distance-from-coast trends. Aqueous concentrations of arsenic, boron, beryllium, cadmium, chromium, molybdenum, nickel, selenium, thallium, and vanadium were below the detection limits. Only barium, manganese, and zinc were detected at mean values of 7, 7, and 6 µg/L, respectively.

Aliphatic hydrocarbons, range C<sub>12</sub>-C<sub>20</sub>, were detected in two water samples at two sites in 1988 and in two samples from two different sites in 1989 (Snyder-Conn and others, 1995). Based on the samples' aliphatic hydrocarbon composition, the source of the hydrocarbons in both 1988 samples and one 1989 sample was determined to be natural organic matter decay. The other 1989 sample had a 1:1 ratio of phytane to pristane, indicating that the detected hydrocarbons could be from fuel. No potential fuel source has been reported in the area near the site. Decay of naturally occurring organic matter appeared to be the most likely source for the aliphatic hydrocarbons in this sample, despite the unusual pristane/phytane ratio (Snyder-Conn and others, 1995).

Low levels of the polynuclear aromatic hydrocarbons dimethylnaphthalene, 1-methylnaphthalene, and 2-methylnaphthalenes were detected in one water sample from one site. The presence of methylated naphthalene in the absence of the naphthalene indicates that the source may have been from a hydrocarbon product spill. Traces of aromatic hydrocarbons consistent with a pyrogenic origin were detected in another sample from a different site (Snyder-Conn and others, 1995).

No organochlorine pesticide or PCBs were detected in any pond or lake water samples, sediment samples, or fish tissue (Snyder-Conn and others, 1995).

## **Hue Shale Outcrops and Hue Creek**

Hue Shale outcrops have been mapped along the Niguanak and Jago Rivers, Ignek and Hue Creeks, and at several locations along the north side of the Sadlerochit Mountains (Bader and Bird, 1986). Overflights of the area north of the Sadlerochit Mountains and along Ignek Creek confirmed the 1995 observation that a dramatic change in the streams and seeps occurred when in contact with the Hue Shale. Where streams contact the Hue Shale, distinct iron staining is evident (fig. SA2). Soils near seeps originating in the shale are stained orange with a white crust and have less vegetation than the surrounding areas (fig. SA3). The prominent outcrop along Hue Creek (fig. SA2) provided the best sampling site because of the outcrop size and because a sample could be collected upstream from the contact.

Hue Creek flows from the calcium magnesium carbonate Lisburne Formation and crosses outcrops of the Shublik, Kingak, and Kemik Formations before it contacts the Hue Shale outcrop (John Kelly, USGS, oral communication). Below the outcrop are the Canning Formation and turbidite sands. Above the Hue Shale outcrop, the stream is clear with a cobbled bottom (fig. SA4). At the contact, the stream becomes clouded with an orange floc and the bottom is armored with an iron-oxide laminate (fig. SA5). Staining was still evident below the shale (fig. SA6). Two springs, Sadlerochit and Red Hill Springs, were also sampled (figs. SA7 and SA8). The purpose of these samples was to evaluate the trace element composition of the springs. Selected organic compounds were analyzed for baseline purposes.

## **METHODS**

Water and sediment samples were taken from reaches above, within, and below the Hue Shale outcrop. Stream discharge was measured using a pygmy meter, and five equal discharge increments (EDI) were calculated from the measured discharge. A DH-81 sampler with a Teflon\* head and a 1-L Teflon\* bottle was used to collect depth and width integrated water samples. Individual verticals were composited in a churn for samples for inorganic analysis and in a glass carboy for organic analysis. Samples from

the springs were collected at the orifice using a peristaltic pump and tubing weighted with Teflon weights.

Samples collected for major ion and trace element chemistry were processed according to methods described by Horowitz and others (1994). Major ion, trace element, and alkalinity samples were filtered through a 0.45- $\mu\text{m}$  capsule filter. Dissolved organic carbon samples were filtered through a 0.45- $\mu\text{m}$  silver filter and the filter was retained for suspended organic carbon analysis. Trace element samples were preserved with nitric acid. Samples for semi-volatile organic compound and aliphatic hydrocarbon analysis were filtered through a 0.45- $\mu\text{m}$  glass-fiber filter and extracted through a solid phase extraction cartridge, after which the cartridges were chilled. Samples for volatile organic compound analysis were collected in glass vials, cooled, and shipped to the USGS laboratory. Specific conductance, dissolved oxygen, pH, and temperature were measured at the EDI points using a Hydrolab in the field. Bed sediments for inorganic analysis were collected and processed according to methods by Shelton and Capel (1994). The U.S. Geological Survey laboratory in Arvada, Colo. or its contract laboratories, analyzed all samples. Inorganic analysis was performed according to methods by Fishman and Friedman (1989). Organic analysis was done according to methods by Fishman (1993) and Furlong (1995).

Duplicate water and sediment samples were collected at the site below the outcrop. Blank samples were collected before the sampling equipment was used, and after field cleaning the equipment prior to the next use.

## RESULTS

### Aqueous Samples

Hue Shale weathering alters both the aqueous major ion and trace element composition of Hue Creek ([table SA1](#)). The pH decreased 1.5 pH units and the specific conductance doubled between samples taken above and within the outcrop. Below the outcrop, specific conductance continued to increase, but pH rebounded by 0.8 unit. Above the contact with the Hue Shale, Hue Creek is a calcium magnesium bicarbonate water and the bicarbonate anion ( $\text{HCO}_3^-$  as calculated from alkalinity) accounts for about 85 percent of the anionic composition on a charge basis. In the reach within the outcrop, alkalinity dropped by nearly one half and the sulfate concentration increased by about one order of magnitude. The result is a change in the dominant



anion from bicarbonate to sulfate (fig. SA9). Sulfate concentration and alkalinity continued to rise below the contact, but their percent contribution to overall anionic composition on a charge basis remained constant. Fluoride concentration also increased slightly between the two sites, but chloride and bromide did not. Calcium, magnesium, and potassium nearly doubled, and sodium increased from below detection (< 0.2 mg/L) to 1.7 mg/L (table SA1). Calcium and magnesium remained the dominant cations in the system, however (fig. SA9).

Barium, cadmium, cobalt, iron, manganese, nickel, zinc, and aluminum increased between the sites above and within the outcrop (table SA1), indicating that weathering of the Hue Shale may be an important source for these constituents. Cadmium and zinc concentrations also decreased below the outcrop, but the manganese concentration continued to increase.

No volatile organics, semi-volatile organics, or aliphatic hydrocarbons were detected in any sample (tables SA2 - SA4).

Sadlerochit Spring is a mixed calcium magnesium bicarbonate water, while Red Hill Spring is a mixed calcium magnesium bicarbonate and sodium chloride water (fig. SA9). Red Hill Spring is the only site where sodium was the dominant cation, accounting for 53 percent of the cation charge with calcium and magnesium contributing 17 and 28 percent, respectively. Red Hill Spring is highly enriched in barium and boron relative to Hue Creek and Sadlerochit Spring (table SA1). High boron concentrations are found in many thermal springs (Hem, 1992). Copper is also slightly higher in Red Hill Spring relative to the other samples (table SA1). Sadlerochit Spring has higher concentrations of barium and boron relative to Hue Creek. Low levels of chromium, manganese, zinc, and aluminum were detected in the spring samples.

Stable oxygen and hydrogen isotope ratios ( $O^{18}$  and  $D$ , respectively) for waters from Red Hill and Sadlerochit Spring both plot along the mean meteoric water line (fig. SA10) (Drever, 1988). Local precipitation isotopic values were not available, but the agreement with the meteoric line indicates that the water probably originated as precipitation. No enrichment in  $^{18}O$  relative to precipitation is evident, indicating little rock-water interaction (Drever, 1988; van Everdingen, 1970). Both Red Hill and Sadlerochit Spring samples are depleted in the heavier isotopes relative to the Hue Creek sample.

Tritium values were 26 pCi/L (8 tritium units, TU) and 55 pCi/L (17 TU) for the Red Hill and Sadlerochit samples, respectively (table SA1). Waters derived from precipitation before nuclear-bomb testing occurred will have a maximum tritium concentration between 0.2 and 0.8 TU by the 1990's. Tritium values in precipitation peaked in the 1960's and have been declining since above-ground testing was banned. Based on the tritium values, the two spring waters represent post-bomb water, making them younger than 40 years. Tritium values from Red Hill Spring are consistent with current values for tritium in precipitation and may be only a few years old or a mixture of old and young water. Sadlerochit Spring tritium values indicate that the water is about 10 to 20 years old (Robert Michel, USGS, oral communication).

### **Aqueous Blank and Duplicate Samples**

Boron and aluminum were detected in both blanks (table SA1). Boron contamination could account for all the boron detected in the Hue Creek samples and up to 1.5 and 32 percent of the boron detected in Red Hill and Sadlerochit Springs, respectively. Contamination could account for up to 15 percent of aluminum found in the Hue Creek samples and all the aluminum in the Red Hill and Sadlerochit samples. Iron was detected at 5 µg/L in the blank from equipment that had not yet been used and zinc was detected at 2 µg/L in the blank after field cleaning (table SA1). Consequently, all iron detected for the Hue Creek above the outcrop and Sadlerochit Spring samples may be from contamination. Iron contamination could represent, at most, 1 percent for samples within and below the outcrop. Zinc contamination may account for most of the zinc detected in the two springs and in the sample taken above outcrop, and could account for up to 6 percent of the zinc in samples within or below the outcrop.

### **Stream Sediments**

Iron concentrations in Hue Creek sediments increased progressively downstream from the site above the outcrop. The highest concentrations were in samples taken from below the Hue Creek outcrop and were about 10 and 19 times greater than samples from the reach within and above the outcrop, respectively (table SA5). Cobalt, copper, manganese, and nickel all increased between samples taken within the outcrop and those below the outcrop, but only copper showed a slight increase between the samples taken

above and within the outcrop (table SA5). Concentrations of iron, cobalt, copper, manganese, zinc, and lead were all relatively higher in the duplicate sample taken below the outcrop (table SA5). Cobalt, copper, manganese, zinc, and lead were greater for the duplicate sample that had the higher iron concentration (table SA5). Analytical variation and association of these metals with the iron oxide surface may provide a partial explanation of the increased metal concentration with increased iron.

## DISCUSSION

Weathering of the Hue Shale resulted in an increase in iron and sulfate, and an initial decrease in pH and alkalinity in Hue Creek. The initial decrease in pH and alkalinity indicates that acid-producing reactions are occurring. Oxidation of sulfide minerals is the primary cause of acid drainage. Oxidation of pyrite, a common iron sulfide mineral, produces iron, sulfate, and acidity. Assuming that oxygen is the oxidant and that the released Fe (II) is further oxidized and precipitated as Fe (III) hydroxide, then pyrite oxidation can be written as:

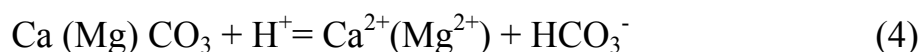


with a net reaction,



If pyrite oxidation were the source for the increased sulfate, then the total hydrogen ion concentration produced between the sampling sites above and below the outcrop would be 3.7 mmole/L. This amount of hydrogen ion would completely titrate the initial bicarbonate alkalinity (1.7 mmole/L as  $\text{HCO}_3^-$ , calculated from alkalinity above the outcrop), leaving an excess of 2 mmole/L acid. The result would be a solution with no bicarbonate alkalinity and a pH of about 2.7. However, after an initial decrease, both alkalinity and pH increased (table SA1), indicating that additional buffering capacity must exist within the system. Dissolution of solid phase calcium magnesium carbonate could provide a source of additional buffering and alkalinity along the stream course and is consistent with the downstream increase in calcium and magnesium concentrations.

The increase between samples from above and below the outcrop sites is 0.75 and 0.93 mmole/L for calcium and magnesium, respectively. If the increase in both calcium and magnesium is solely from reaction of the generated acid with calcium magnesium carbonate by the reaction,



then about 1.7 mmole/L of acid and bicarbonate would be consumed and produced, respectively. This corresponds reasonably well with the measured 1.5 mmole/L bicarbonate alkalinity in the sample from below the outcrop. Additional non-carbonate buffering is required, however, in order to account for the near neutral pH (pH = 7.8, table SA1) measured below the outcrop. One possible source of additional buffering is reactions of the acid with iron oxy-hydroxide surfaces.

Hue Creek is a mountain stream using Craig and McCart's (1974) classification, with moderate alkalinity. Weathering of the Hue Shale is an acid-producing process and the availability of solid phase calcium magnesium carbonate appears to have a role in buffering along Hue Creek. Spring and tundra streams in contact with Hue Shale outcrops may experience a greater pH decrease than was found in Hue Creek if the aqueous carbonate alkalinity is the only source of pH buffering.

## **SUMMARY**

Hue Shale weathering alters both the aqueous major ion and trace element composition of Hue Creek. Above the contact with the Hue Shale, Hue Creek is a calcium magnesium bicarbonate water. Weathering of the shale unit changes the dominant anion from bicarbonate to sulfate. Calcium and magnesium increase and remain the dominant cations. Aqueous concentrations of barium, cadmium, cobalt, iron, manganese, nickel, zinc, and aluminum increased between the sites above and within the outcrop. An initial decrease in the pH and alkalinity indicates that acid-producing reactions are occurring. The downstream increases in sulfate, calcium, and magnesium concentrations are consistent with pyrite oxidation and continued dissolution of solid phase calcium magnesium carbonate. Additional non-carbonate buffering must be occurring to account for the near neutral pH measured below the outcrop. Iron oxy-hydroxides are a possible source of additional buffering.

Iron concentrations in Hue Creek sediments increased downstream. Cobalt, copper, manganese, and nickel increased between samples taken within the outcrop and those below the outcrop. Between duplicate samples, cobalt, copper, manganese, zinc, and lead concentrations were greater for the sample with the higher iron concentration. Analytical variation and association of these metals with the iron oxide surface is a possible cause of the increased metal concentration with increased iron.

Sadlerochit Spring is a mixed calcium magnesium bicarbonate water, whereas Red Hill Spring is a mixed calcium magnesium bicarbonate and sodium chloride water. Boron and barium concentrations were highest for Red Hill Spring. Chromium, copper, manganese and zinc were detected in low concentrations in both springs. Stable oxygen and hydrogen isotope ratios for Red Hill and Sadlerochit Spring waters plot along the mean meteoric water line indicating that the water originated as precipitation and little rock-water interaction occurred. Tritium values indicated that both waters are post-bomb era (1950's). No volatile or semi-volatile organic compounds, or aliphatic hydrocarbons were detected in the water samples.

## REFERENCES

Bader, J.W., and Bird, K.J., 1986, Geologic map of the Demarcation Point, Mt. Michelson, Flaxman Island, and Barter Island quadrangles, Northeastern Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I-1791.

Brosgé, W.P. and Tailleur, I.L., 1988, Inorganic chemical analyses of black shale from wells in the National Petroleum Reserve in Alaska, *in* Gryc, G. ed., Geology and exploration of the National Petroleum Reserve in Alaska, 1974 to 1982: U.S. Geological Survey Professional Paper 1399, p. 563-582.

Brown, J., Grant, C.L., Ugolini, F.C., and Tedrow, J.C.F., 1962, Mineral composition of some drainage waters from Arctic Alaska: *Journal of Geophysical Research*, v. 67, p. 2447-2453

Childers, J.M., Sloan, C.E., Meckel, J.P., and Nauman, J.W., 1977, Hydrologic reconnaissance of the Eastern North Slope, Alaska, 1975: U.S. Geological Survey Open-File Report 77-492, 65 p.

Craig, P.C. and McCart, P.J., 1974, Classification of streams in Beaufort Sea drainages and distribution of fish in arctic and subarctic drainages: *Arctic Gas Biological Report Series*, v. 17, p. 1-47.

Drever, J.I., 1988, *The geochemistry of natural waters* (2d ed.): Englewood Cliffs, N.J., Prentice-Hall, 437 p.

Fishman, M.J., 1993, *Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory -- Determination of inorganic and organic constituents in water and fluvial sediments*: U.S. Geological Survey Open-File Report 93-125, 217 p.

Fishman, M.J., and Friedman, L.C., 1989, *Methods for determination of inorganic substances in water and fluvial sediments*: U.S. Geological Survey *Techniques of Water-Resources Investigations*, Book 5, Chap. A1, 545 p.

Furlong, E.T., 1995, *Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory -- Determination of semi-volatile organic compounds in bottom sediment by solvent extraction, gel permeation*

chromatographic fraction, and capillary column gas chromatography mass spectrometry: U.S. Geological Survey Open- File Report 95-719.

Horowitz, A.J., Demas, C.R., Fitzgerald, K.K., Miller, T.L., and Rickert, D.A., 1994, U.S. Geological Survey protocol for the collection and processing of surface-water samples for the subsequent determination of inorganic constituents in filtered water: U.S. Geological Survey Open- File Report 94-539.

Hem, J.D., 1992, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254.

Isaacs, C.M., Bird, K.J., Medrano, M.D., Keller M.A., Piper, D.Z., and Gautier, D.L., 1995, Preliminary report on major and minor elements in cores from the Triassic Shublik Formation, Jurassic and Cretaceous Kingak Shale, and Cretaceous pebble shale unit, Hue Shale, and Torok Formation, North Slope, Alaska: U.S. Geological Survey Open-File Report 95-236, 30 p.

Shelton, L.R., and Capel, P.D., 1994, Guidelines for collecting and processing samples of stream bed sediment for analysis of trace elements and organic contaminants for the National Water- Quality Assessment Program: U.S. Geological Survey Open-File Report 94-458.

Snyder-Conn, Elaine, Miller, Pam, and Lubinski, Mary, 1995, Contaminant baseline studies of the Arctic Coastal Plain 1002 area and adjacent lagoons, Arctic National Wildlife Refuge, Alaska, 1988-1989: U.S. Fish and Wildlife Service, NAES-TR-95-02.

van Everdingen, R.O., 1970, Thermal and mineral springs in the Southern Rocky Mountains of Canada: Environment Canada, 151 p.

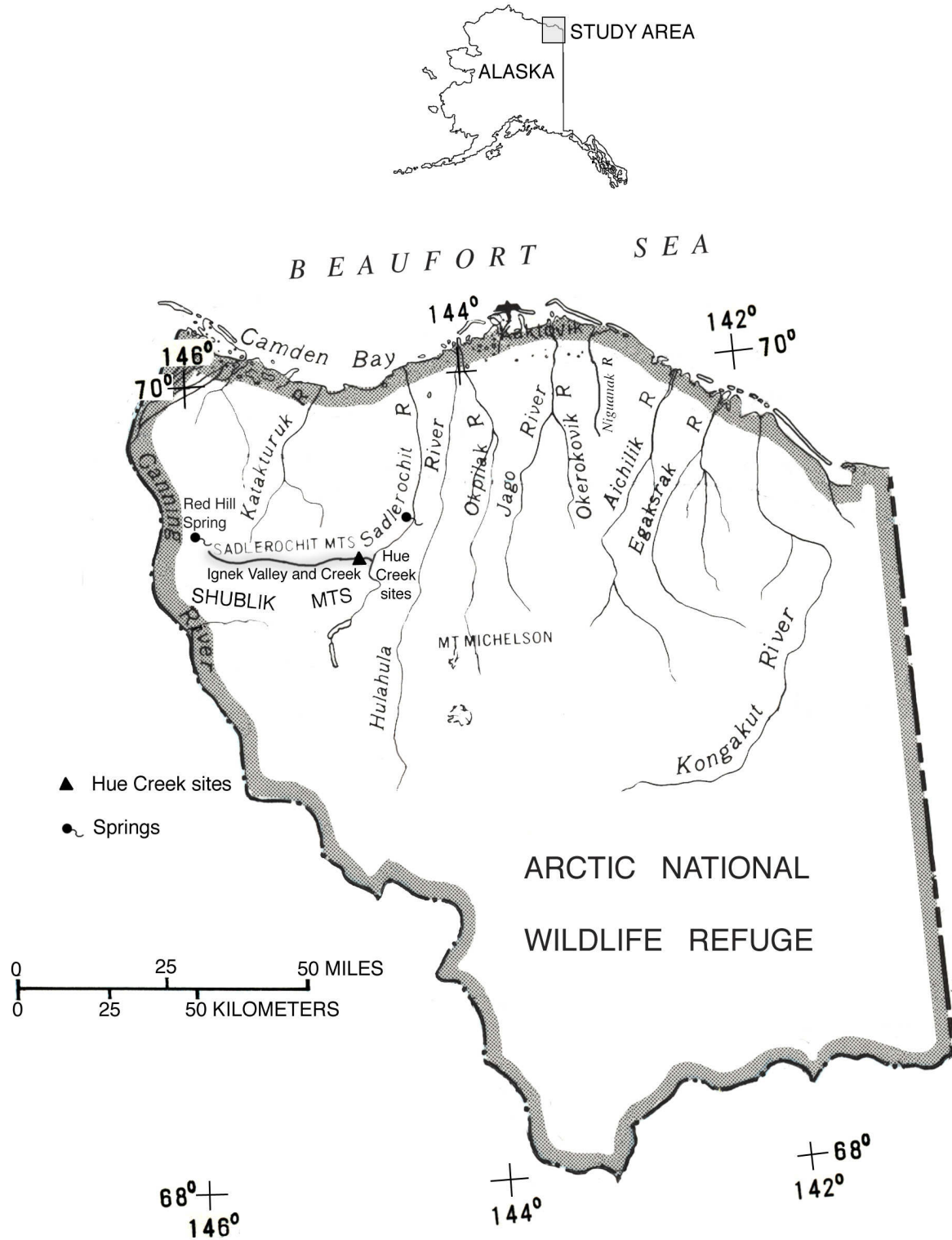


Figure 1. Locations of Hue Creek and springs in the Arctic National Wildlife Refuge.





Figure SA2. Hue Creek Shale outcrop on Hue Creek. Iron staining is evident both on the rock outcrop and in the adjacent creek.



Figure SA3. Hue Shale outcrops north of the Sadlerochit Mountains. Iron staining and lack of vegetation are typical for these exposures.



Figure SA4. Hue Creek above Hue Shale outcrop. Stream is clear and bed shows no iron staining.



Figure SA5. Hue Creek within Hue Shale outcrop. Stream has a milky appearance due to colloidal iron. Heavy iron stains evident.



Figure SA6. Hue Creek below Hue Creek outcrop. Stream still has milky appearance and iron staining evident.



Figure SA7. Sadlerochit Spring.



Figure SA8. Red Hill Spring.

- Above Hue Shale outcrop
- △ Within Hue Shale outcrop
- + Below Hue Shale outcrop
- × Sadlerochit Spring
- Red Hill Spring

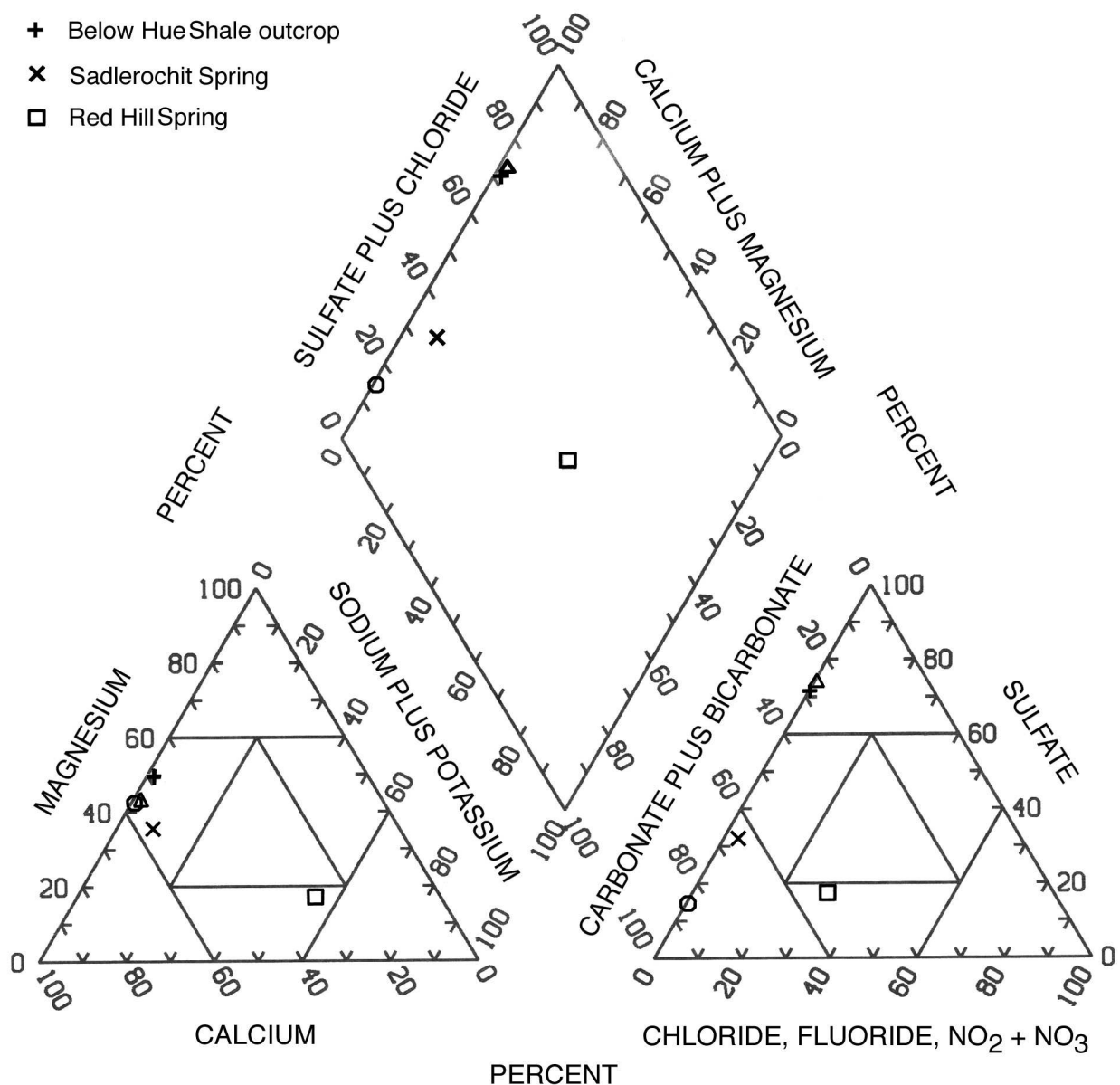


Figure SA9. Trilinear diagram for water samples from Hue Creek, and Sadlerochit and Red Hill Springs.



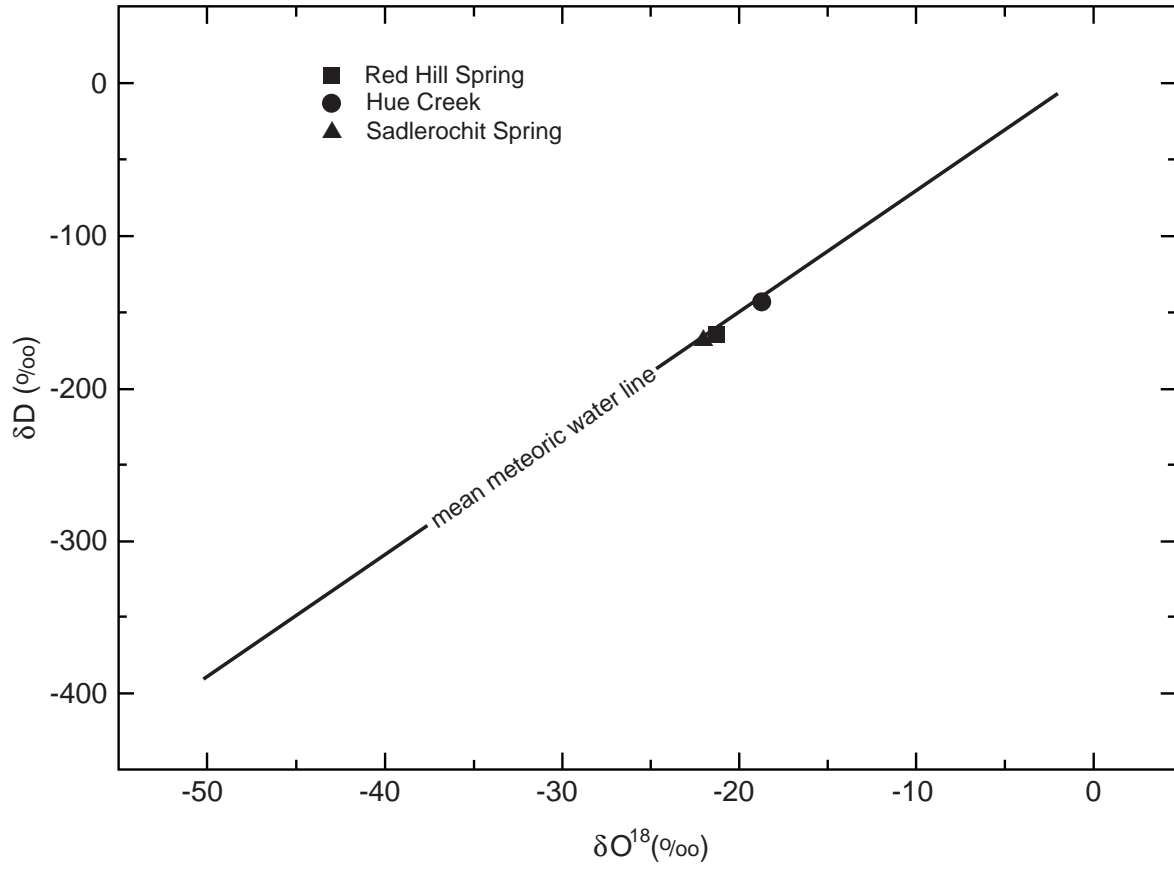


Figure SA10. Comparison of Hue Creek, Sadlerochit and Red Hill Springs stable oxygen and deuterium isotopic value with the mean meteoric water.

Table SA1 . Field measurements, major and trace ion concentrations in filtered water samples, dissolved and suspended organic carbon, and tritium concentrations, and D, and O <sup>18</sup> isotope ratios, August 1996.									
[ft <sup>3</sup> /s, cubic feet per second; mg/L, milligram per liter; µg/L microgram per liter; µS/cm, microsiemens per cm; °C, degree Celsius; pCi/L, picocurie per liter, <, actual value is less than value shown; -, no data]									
Constituent	Units	Hue Creek				Springs		Blank	
		Above Hue Shale	Within Hue Shale	Below Hue Shale	Below Hue Shale, duplicate	Red Hill	Sadlerochit	Office cleaned	Field cleaned
Discharge	ft <sup>3</sup> /s	1.7	1.7	3.9	-	0.34	24	-	-
Specific conductance	µS/cm	187	381	518	-	897	386	-	-
pH		8.2	6.7	7.5	-	7.0	7.4	-	-
Water temperature	°C	2	3.5	5.5	-	30.5	12.5	-	-
Dissolved oxygen	mg/L	13.3	12.6	10.6	-	0.4	5.4	-	-
Alkalinity	mg/L as CaCO <sub>3</sub>	84	46	78	-	286	132	-	-
Calcium	mg/L as Ca	21	39	51	49	51	44	<0.02	0.04
Magnesium	mg/L as Mg	9.6	19	32	30	19	17	<0.01	<0.01
Sodium	mg/L as Na	< 0.20	1.1	1.7	1.6	110	7.0	<0.02	<0.02
Potassium	mg/L as K	0.2	0.4	0.4	0.4	5.4	1.0	<0.10	<0.10
Sulfate	mg/L as SO <sub>4</sub>	14	130	190	190	94	63	<0.10	<0.10
Chloride	mg/L as Cl	< 0.10	< 0.10	<0.10	< 0.10	120	3.6	<0.10	<0.10
Fluoride	mg/L as F	< 0.10	0.1	0.1	0.1	1.1	0.7	<0.10	<0.10
Bromide	mg/L as Br	< 0.010	< 0.010	< 0.010	< 0.010	0.39	0.03	<0.10	<0.10
Silica	mg/L as SiO <sub>2</sub>	0.49	2.0	2.3	2.2	26	9.5	<0.01	0.01
Barium	µg/L as Ba	7	13	16	16	1110	30	<1.0	<1.0
Beryllium	µg/L as Be	<1.0	< 1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Boron	µg/L as B	19	12	23	8.9	1230	56	10	18
Cadmium	µg/L as Cd	<1.0	3	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Chromium	µg/L as Cr	2	<1.0	<1.0	1	2	2	<1.0	<1.0
Cobalt	µg/L as Co	< 1.0	14	16	16	<1.0	<1.0	<1.0	<1.0
Copper	µg/L as Cu	1	4	2	1	8	1	<1.0	<1.0
Iron	µg/L as Fe	5	3600	460	440	<3.0	5	5	<3.0
Lead	µg/L as Pb	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Manganese	µg/L as Mn	<1.0	170	646	632	5	<1.0	<1.0	<1.0
Molybdenum	µg/L as Mo	<1.0	<1.0	<1.0	<1.0	<1.0	2	<1.0	<1.0
Nickel	µg/L as Ni	1	45	41	40	< 1.0	1	<1.0	<1.0
Silver	µg/L as Ag	< 1.0	<1.0	< 1.0	< 1.0	-	< 1.0	<1.0	<1.0
Vanadium	µg/L as V	< 6	< 6	< 6	< 6	< 6	< 6	<6	<6
Zinc	µg/L as Zn	3	142	35	33	7	5	<1.0	2.0
Antimony	µg/L as Sb	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Aluminum	µg/L as Al	8	19	41	38	4	5	4	5
Dissolved organic carbon	mg/L as C	0.6	0.3	0.4	0.4	0.6	0.1	6.5	0.2
Suspended organic carbon	mg/L as C	0.1	0.1	0.1	0.2	0.3	0.1	<0.10	<0.10
Total tritium*	pCi/L	-	-	-	-	26	55	-	-
D *	Ratio permil	-	-	-143	-	-164	-168	-	-
O <sup>18</sup> *	Ratio permil	-	-	-18.66	-	-21.25	-22.0	-	-

\* unfiltered sample





Table SA5. Trace element concentrations in sediment samples from Hue Creek, August 1996.  
 [µg/g, microgram per gram; <, actual value is less than value shown]

Constituent	Unit	Hue Creek			
		Above Hue Shale	Within Hue Shale	Below Hue Shale	Below Hue Shale, duplicate
Arsenic	µg/g as As	32	31	19	19
Cadmium	µg/g as Cd	1	2	2	2
Cobalt	µg/g as Co	150	130	540	650
Copper	µg/g as Cu	2	10	32	37
Lead	µg/g as Pb	20	20	20	30
Manganese	µg/g as Mn	50	52	480	520
Nickel	µg/g as Ni	< 10	< 10	40	40
Zinc	µg/g as Zn	240	30	220	240
Selenium	µg/g as Se	< 1	3	2	2
Iron	µg/g as Fe	2000	17000	160000	170000