Geological Assessment of Cores from the Great Bay National Wildlife Refuge, New Hampshire

Scientific Investigations Report 2006–5203

U.S. Department of the Interior
U.S. Geological Survey

Cover: View of Great Bay National Wildlife Refuge; Great Bay is to the left of the rock-strewn shoreline. Photo courtesy of Great Bay National Estuarine Research Reserve (2004).

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By Nora K. Foley, Robert A. Ayuso, Joseph D. Ayotte, Denise L. Montgomery, and Gilpin R. Robinson, Jr.

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Preface

The Great Bay National Wildlife Refuge is located along the eastern shore of New Hampshire's Great Bay near the town of Newington. Geological sources of metals and metalloids in aquifer bedrock were evaluated for their potential to contribute to elevated levels of metals in ground water and surface waters in the refuge. Ayotte and others (1999, 2003) demonstrated that arsenic concentrations in ground water flowing through bedrock aquifers of eastern New England were elevated from their interaction with rocks. Specifically in southeastern New Hampshire, Montgomery and others (2003) established that nearly one-fifth of private bedrock wells had arsenic concentrations that exceed the U.S. Environmental Protection Agency's maximum contamination level for public water supplies. To evaluate potential rock sources, two wells were drilled to intersect metasedimentary and metavolcanic rocks of the Merrimack Trough in the Great Bay area in coastal New Hampshire and the cores were extracted for analysis. This report describes the bulk chemistry, mineralogy, and mineral chemistry data obtained from representative core samples from the two wells. The Great Bay National Wildlife Refuge is adjacent to the Great Bay-Piscataqua River estuary, a part of the National Estuarine Research Reserve System. An estuary is a partially enclosed body of water formed where freshwater from rivers and streams flows into the ocean, mixing with the salty sea water. Estuaries and the lands surrounding them are places of transition from land to sea, and from fresh to salt water. The Great Bay estuary is protected from the full force of ocean waves, winds, and storms by the land that make up the refuge. A variety of rich wildlife habitats, which support extensive bird populations including endangered and threatened species, can be found throughout the refuge. This work was done in conjunction with U.S. Geological Survey, Water Resource Discipline studies completed in cooperation with the U.S. Environmental Protection Agency (EPA Region 1: New England), the New Hampshire Department of Environmental Services, the New Hampshire Estuaries Project, and the New Hampshire Department of Health and Human Services.

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Conversion Factors, Datum, and Abbreviations

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
Area		
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
Volume		
ounce, fluid (fl. oz)	0.02957	liter (L)
pint (pt)	0.4732	liter (L)
quart (qt)	0.9464	liter (L)
Transmissivity*		
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

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By Nora K. Foley[1], Robert A. Ayuso[1], Joseph D. Ayotte[2], Denise L. Montgomery[2], and Gilpin R. Robinson, Jr.[1]

Abstract

Geological sources of metals (especially arsenic and zinc) in aquifer bedrock were evaluated for their potential to contribute elevated values of metals to ground and surface waters in and around Rockingham County, New Hampshire. Ayotte and others (1999, 2003) had proposed that arsenic concentrations in ground water flowing through bedrock aquifers in eastern New England were elevated as a result of interaction with rocks. Specifically in southeastern New Hampshire, Montgomery and others (2003) established that nearly one-fifth of private bedrock wells had arsenic concentrations that exceed the U.S. Environmental Protection Agency (EPA) maximum contamination level for public water supplies. Two wells drilled in coastal New Hampshire were sited to intersect metasedimentary and metavolcanic rocks in the Great Bay National Wildlife Refuge. Bulk chemistry, mineralogy, and mineral chemistry data were obtained on representative samples of cores extracted from the two boreholes in the Kittery and Eliot Formations. The results of this study have established that the primary geologic source of arsenic in ground waters sampled from the two well sites was iron-sulfide minerals, predominantly arsenic-bearing pyrite and lesser amounts of base-metal-sulfide and sulfosalt minerals that contain appreciable arsenic, including arsenopyrite, tetrahedrite, and cobaltite. Secondary minerals containing arsenic are apparently limited to iron-oxyhydroxide minerals. The geologic source of zinc was sphalerite, typically cadmium-bearing, which occurs with pyrite in core samples. Zinc also occurred as a secondary mineral in carbonate form. Oxidation of sulfides leading to the liberation of acid, iron, arsenic, zinc, and other metals was most prevalent in open fractures and vuggy zones in core intervals containing zones of high transmissivity in the two units. The presence of significant calcite and lesser amounts of other acid-neutralizing carbonate and silicate minerals, acting as a natural buffer to reduce acidity, forced precipitation of iron-oxyhydroxide minerals and the removal of trace elements, including arsenic and lead, from ground waters in the refuge. Zinc may have remained in solution to a greater extent because of complexing with carbonate and its solubility in near-neutral ground and surface waters. The link between anomalously high arsenic contents in ground water and a bedrock source as put forward by Ayotte and others (1999, 2003) and Montgomery and others (2003) is supported by the presence of some arsenic-bearing minerals in rocks of the Kittery and Eliot Formations. The relatively low amounts of arsenic and metals in wells in the Great Bay National Wildlife Refuge as reported by Ayotte and others (U.S. Geological Survey Water Resources Data, 2005) were likely controlled by local geochemical environments in partially filled fractures, fissures, and permeable zones within the bedrock formations. Carbonate and silicate gangue minerals that line fractures, fissures, and permeable zones likely limited the movement of arsenic from bedrock to ground water. Sources other than the two geologic formations might have been required to account for anomalously high arsenic contents measured in private bedrock aquifer wells of Rockingham County.

Introduction

Great Bay National Wildlife Refuge (NWR) was established in 1992 along the eastern shore of New Hampshire's Great Bay, near the town of Newington. The Great Bay NWR is adjacent to the Great Bay-Piscataqua River estuary, a part of the National Estuarine Research Reserve System (2004). A variety of rich wildlife habitats from uplands to open waters are found throughout the approximately 1,000-acre refuge. The present habitat (New Hampshire Estuaries Project, 2003; Great Bay National Wildlife Refuge, 2005) consists of forested uplands (55 percent), open grasslands (19 percent), shrub (13 percent), fresh water (6 percent), forested wetlands (4 percent), and salt marsh (3 percent). The refuge plays a significant role as a migration and wintering habitat for the federally protected bald eagle because of its open coastal waters and abundant prey. Bald eagles winter along the waters of Great Bay and frequently perch along the shoreline. The bay area also provides prime migration habitat for the peregrine falcon. Many state-protected species use the refuge, includ-

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ing the common loon, pied-billed grebe, osprey, common tern, northern harrier, and upland sandpiper. The bay area also serves as a major wintering area for black ducks, and includes the largest concentration of wintering American black ducks in New Hampshire.

The mission of Great Bay NWR (fig. 1) is to (1) preserve, restore, and enhance in their natural ecosystem when practicable, all species of animals and plants that are endangered or threatened with becoming endangered; (2) perpetuate the migratory bird resource; (3) preserve a natural diversity and abundance of fauna and flora on refuge lands; (4) provide an understanding and appreciation of fish and wildlife ecology and people's role in their environment; and (5) provide refuge visitors with high quality, safe, wholesome, and enjoyable recreational experiences oriented toward wildlife, to the extent that these activities are compatible with the purposes for which the refuge was established (Great Bay National Wildlife Refuge, 2005). The evaluation of the potential for rocks underlying the refuge to contribute arsenic contamination to ground water in southeast New Hampshire provides a framework to investigate well water chemistry as it relates to geology and provides scientific data in support of goals to understand and preserve the natural ecosystem and perpetuate the migratory bird resources.

Statement of the Problem

Recent work in eastern New England has shown that drinking water from bedrock aquifers (which consist of consolidated rock) contains high amounts of arsenic, in contrast to drinking water from unconsolidated bedrock aquifers (e.g., gravels), which have lower arsenic contents (Ayotte and others, 1999, 2003). Data for bedrock wells in calcareous metasedimentary rocks in coastal New Hampshire and Maine, in particular, denote a strong link to ground water with high arsenic contents greater than 10 micrograms per liter (Ayotte and others, 2003). However, detailed studies in New Hampshire also linked the highest ground water arsenic concentrations to areas containing abundant pegmatites and associated granitic rocks (Peters and others, 1999). In contrast, earlier studies related high contents of arsenic to human activities (Boudette and others, 1985). Thus, in New England, a complex interplay of possible arsenic sources has been suggested (Ayotte and others, 2003; Ayuso, Foley, and others, 2003). Anthropogenic sources of arsenic have been shown to significantly impact sediments, soils, and related surface and ground waters in New England in general (e.g., Ayotte and others, 1999; Robinson and Ayotte, 2002; Robinson and Ayuso 2004), and specifically in Coastal Maine, where extensive historical application of arsenical pesticides may be linked to arsenic in soils and sediments (e.g., Ayuso and others, 2004, 2005; Robinson and Ayuso, 2004; Foley and others, 2005). The key issue of whether anomalously high arsenic contents in ground water in certain portions of New England are related to contributions from geologic sources, anthropogenic contributions, or reflect a combination of geologic and anthropogenic sources has not been definitively answered. Arsenic levels in the region have been characterized by anthropogenic contributions (Marvinney and others, 1994), bedrock contributions (Peters and others, 1999; Loiselle and others, 2001; Ayuso and Foley, 2002; Ayuso, Foley, and others, 2003; Foley and others, 2004; Reeve and others, 2001; Robinson and Ayotte, 2002) and by a combination of sources (Loiselle and others, 2001; Loiselle and Hodgkins, 2002; Robinson and Ayotte, 2002; Robinson and Ayuso, 2004; Ayuso and others, 2004, 2005).

In southeast New Hampshire, private bedrock-aquifer wells supply approximately 40 percent of the drinking water and many of those wells contain levels of arsenic that exceed 10 micrograms per liter (µg/L) (Montgomery and others, 2003). An analysis of water quality by county demonstrated that for a three-county area (Rockingham, Strafford, and Hillsborough), 31 percent of wells contain arsenic greater than 5 µg/L, 19 percent contain arsenic greater than 10 µg/L, and 2 percent of the wells contain arsenic exceeding 50 µg/L (Montgomery and others, 2003). Data for Rockingham County alone, which contains the refuge proper, indicate that 125 tested wells contain arsenic in a range from less than 1 to 215 µg/L (Montgomery and others, 2003). Bedrock units in the region include the Kittery, Eliot, Rangeley, and Berwick Formations (Lyons and others, 1997). About 30 percent of the wells that intersect the Berwick and Rangeley Formations, and almost 50 percent of the wells in the Eliot and Kittery Formations contain arsenic levels exceeding 10 µg/L (Montgomery and others, 2003).

Purpose and Scope of the Study

This study was undertaken to establish possible geologic sources of metals and metalloids in the well waters, based on the identification of mineralogical hosts and geochemical processes occurring in the aquifer rocks, and to relate those findings to the regional problem. The report describes the detailed occurrence and distribution of rocks and minerals that contain arsenic, iron, manganese and other metals and metalloids occurring in permeable fracture zones in geologic core obtained from boreholes drilled in bedrock aquifers of the Great Bay National Wildlife Refuge (fig. 1). Results from this work provide data in support of regional-scale studies of ground-water quality. Included in this analysis is a classification of geologic data according to geochemical considerations. This report includes (1) a description of the mineralogical sources of metals and metalloids, (2) statistical and graphical presentations of geochemical and mineralogical data by depth, and (3) a description of the analytical methods (Appendix 1) and mineralogical and geochemical data collected during the course of the study (Appendixes 2–5).

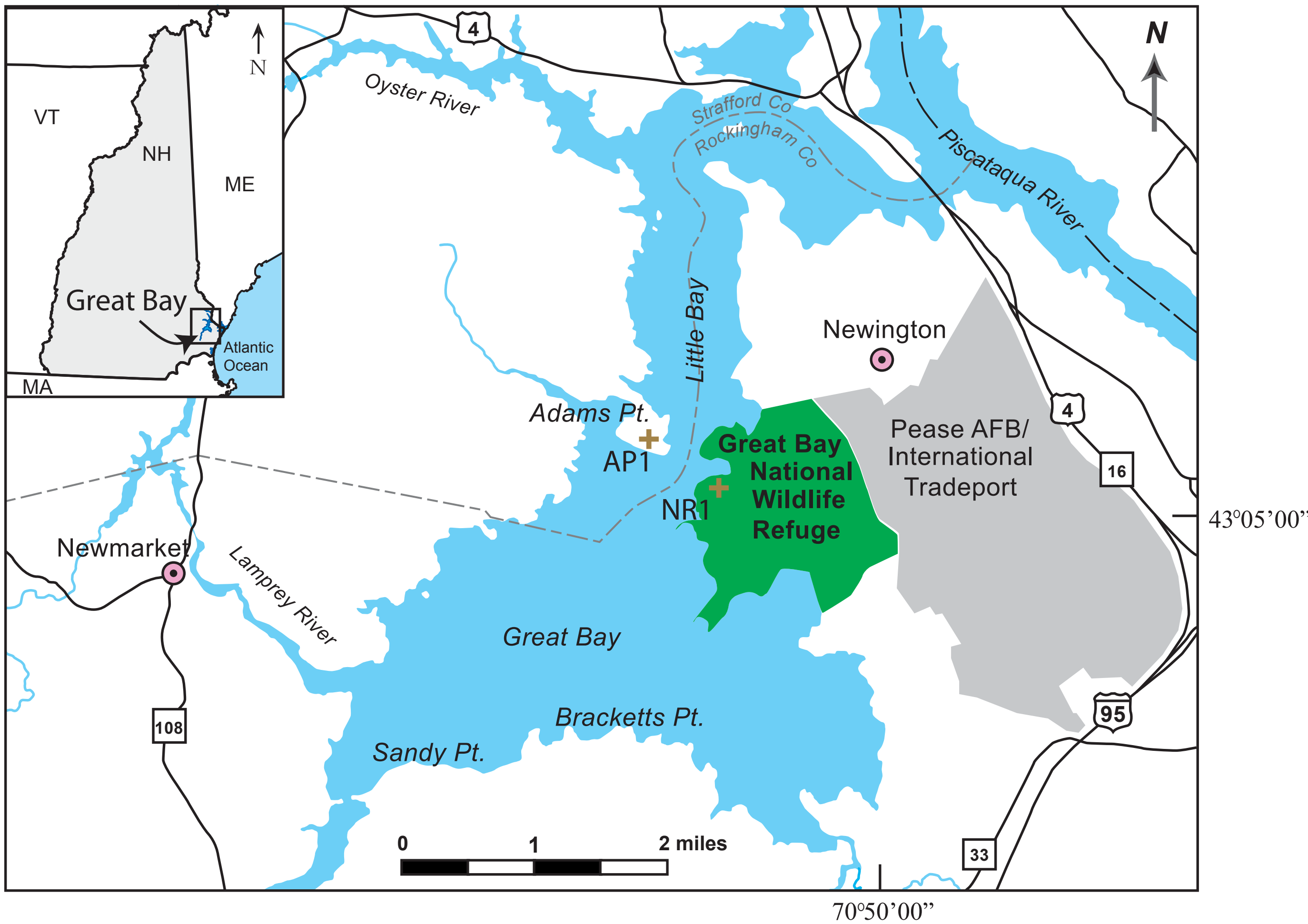


Figure 1. Index map showing locations of the Great Bay National Wildlife Refuge, the Great Bay–Piscataqua River estuary, Adams Point, and the locations of geographic features described in the study.

Analytical Details

Bulk chemistry, mineralogy, and mineral chemistry data were obtained on a suite of representative samples of bedrock selected from core obtained from two boreholes drilled in coastal New Hampshire in and near the Great Bay National Wildlife Refuge: the Adams Point borehole (AP1), and National Refuge borehole (NR1). Thirteen samples (five samples from AP1 and eight from NR1) were analyzed by various methods for major and trace elements (see Appendix 1: WD-XRF, ICP-MS, ICP-AES, and INAA). Mineralogy was established by a combination of methods (Appendix 1), including petrography, scanning electron microscopy, x-ray diffraction, and electron microprobe analysis. For each drill core, selected trace element abundances, and mineralogy are plotted by sample depth and then compared to reported transmissivity data. The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used as reported.

Acknowledgments

The authors would like to acknowledge Fred Paollot for collecting the borehole geophysical data referred to in this study, and Anne Lyons, Jeremy Dillingham, and Nicole West for sample preparation and some analyses. The authors thank David Sutphin, Greg Wandless, and Avery Drake for their insightful reviews of this report.

Bedrock and Surficial Geology

Bedrock in the immediate area consists of highly folded and fractured Silurian and older metamorphic rocks. Metamorphic rocks sampled in the Great Bay area were at biotite-grade and consist of phyllitic rocks of the Kittery Formation, which grade upward into somewhat finer grained rocks of the Eliot Formation (fig. 2). General geologic descriptions of the rocks found in the two wells are summarized in the geological map of New Hampshire (Lyons and others, 1997). The Kittery Formation consists of metasandstone and phyllite that crop out along the northern and western shores of Great Bay and in the Pierce Point area of Greenland. The Eliot Formation is a phyllite containing layers of calcareous quartzite and quartz-mica schist that can be seen along the southern and eastern shores. The Great Bay synform, in the Eliot Formation, passes from the southwest, near Bracketts Point on Great Bay, to the northeast through the refuge.

Small Paleozoic or younger granite and diorite intrusions and mafic dikes are also present in the region. For example, diorite constituting the Exeter pluton is present northwest of Great Bay (fig. 2, Dz). The intrusions likely belong to a part of the New Hampshire plutonic series (Watts and others, 2000), which also contains pegmatites of the type implicated in studies of arsenic in ground water in New Hampshire (Peters and others, 1999).

The area surrounding the Great Bay is included in the Seaboard Lowland section of New England and was affected by multiple episodes of glaciation. The most recent glaciation of the area ended in the Wisconsin stage of the Pleistocene epoch (~10,000 to 20,000 years B.P.). Glaciation progressed through the area, resulting in the southeasterly orientation of many glacial deposits, including drumlins that typify the area. As the glaciers melted and retreated, substantial amounts of glacial till were deposited across the region. Much of the Great Bay area is overlain by thick deposits of glacial outwash, sand, and till. The Great Bay estuary is a drowned river valley. The present sea level was reached approximately 3,000 to 5,000 years ago.

The topography of the Great Bay National Wildlife Refuge is flat to gently rolling (figs. 1 and 2). The refuge slopes down to the west; its highest elevation is 100 feet above mean sea level. Six miles of intertidal shoreline constitute its western boundary with the Great Bay National Estuarine Research Reserve. The Great Bay estuary is a complex embayment on the New Hampshire-Maine border that consists of the Piscataqua River, Little Bay, and Great Bay. The estuary is a tidally dominated system and the drainage confluence of seven major rivers, several small creeks and their tributaries, and ocean water from the Gulf of Maine. Ocean tides and river runoff mix 15 miles inland from the Atlantic Ocean, making Great Bay one of the most recessed estuaries in the Nation. The Great Bay Estuary derives freshwater inflow from seven major rivers. Three of these, the Winnicut, Swampscott, and Lamprey, flow directly into Great Bay. The remaining four flow into the estuary between Furber Strait and the open coast. Overall, the seven rivers drain a watershed area of 2,410 square kilometers, two-thirds of which is within New Hampshire and the rest being in southern Maine.

Two boreholes were drilled to examine the quality of water derived from an aquifer consisting of consolidated bedrock underlying the refuge (Ayotte and others, 2003). The wells were sited to intersect parts of the metasedimentary and metavolcanic rocks that form the Merrimack Trough and are the aquifer units in the region. The formations of interest to the study are the Silurian to Ordovician Kittery Formation, which was cut by bolehole AP1, and the Silurian to Ordovician Eliot Formation, which was intersected by borehole NR1. Descriptions and specific features of selected samples from the study data set are given in Appendixes 2 and 3.

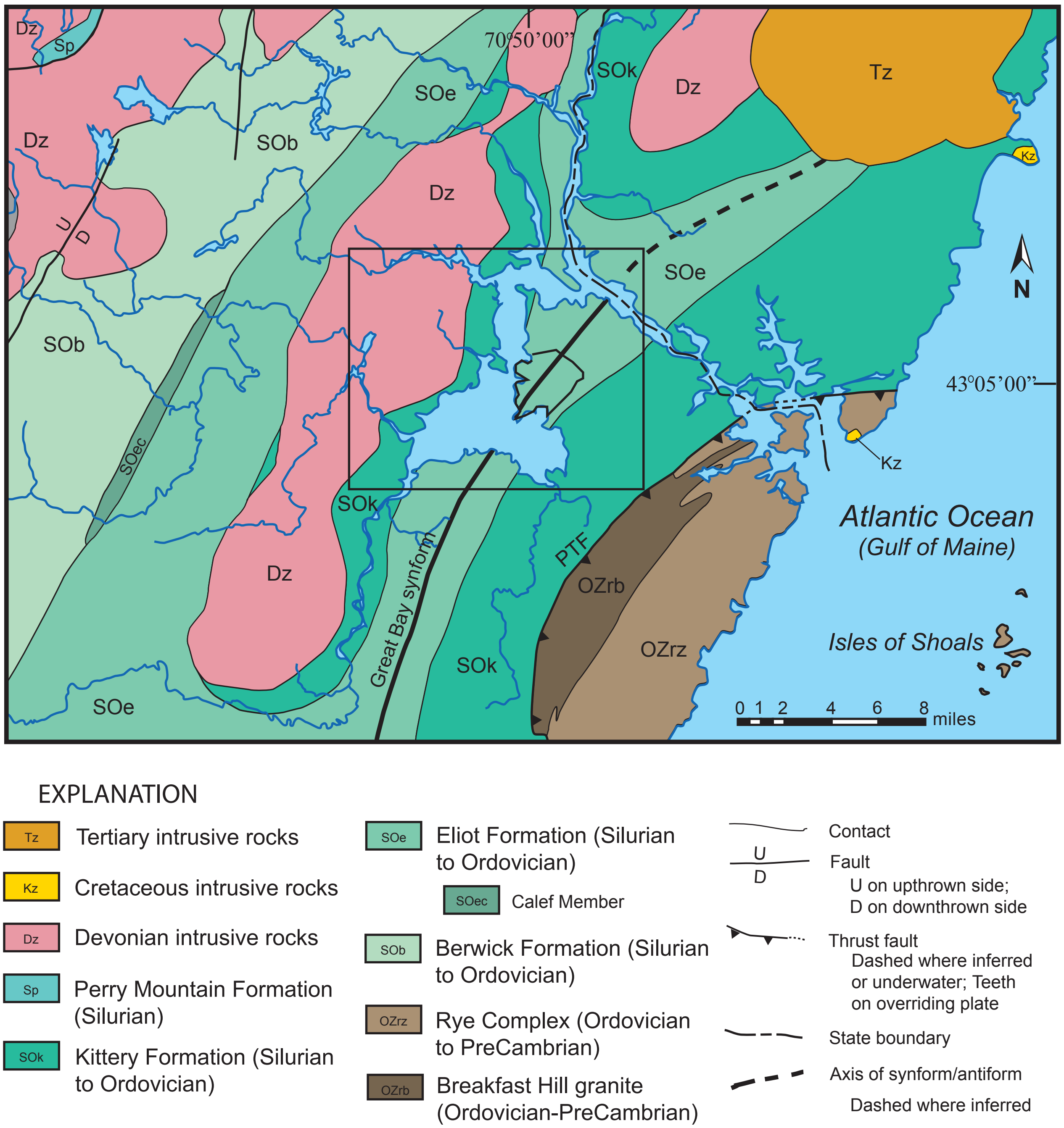


Figure 2. Bedrock geology map of the Great Bay National Wildlife Refuge (box outlines area of fig. 1) and surrounding areas; modified from Lyons and others (1997). The Kittery and Eliot Formations are the geologic units that constitute the bedrock in the refuge.

Bedrock Fractures, Transmissivity, and Well Water Data

Data for borehole geophysics and transmissivity (Fred Paollot, written commun., U.S. Geological Survey, 2000) and water compositions collected and described for the Great Bay area are summarized here to establish the character of the wells for comparison with the geological data later in this report. The ground water quality data is described by Ayotte and others (1999, 2003) and additional data is available online (U.S. Geological Survey Water Resources Data, 2005).

Borehole geophysical data document the presence of significant fractures in bedrock in both wells (table 1). Geophysical data for borehole AP1 indicate massive unfractured rock for most of its depth and a single transmissive fracture at a depth of about 70 ft. Televiewer images indicated that the fracture was an irregular feature having a significant halo of alteration, although resistivity data did not support substantial changes in bulk rock chemistry or mineralogy (Fred Paollot, U.S. Geological Survey, written commun., 2000). Thus, all transmissivity in AP1 is attributed to the fracture interval at about 70 ft. Geophysical data for borehole NR1 indicates several producing fractures, most of which appeared to be relatively unaltered in televiewer imagery. A significant drop in resistivity, suggesting substantial weathering of the bedrock, was observed below 45-ft depth in NR1 in spite of a lack of visible alteration. The most productive fractures in NR1 occurred at depths of approximately 27 ft, 67 ft, and below 94 ft, producing 65, 7, and 28 percent of the flow, respectively.

Ground-water-quality data (U. S. Geological Survey Water Resources Data, 2005) indicate levels of sulfate (up to 32.3 mg/L), iron (up to 36 µg/L filtered, up to 5600 µg/L unfiltered), aluminum (up to 24 µg/L filtered), zinc (up to 363 µg/L filtered), and arsenic (up to 6.1 µg/L filtered, and 14 µg/L unfiltered) for water samples taken from the two wells (table 2; Appendix 4). Measured pH values for both holes were generally neutral to slightly alkaline, having measured pH values in the range of 7.4 to ~9.0 (median value 7.7, mean 8.0). Measured values (table 2) for total arsenic (filtered), and for arsenic species (filtered), are at or below the current U.S. EPA ground-water standard (10 µg/L). Fracture zones having high transmissivity yielded the highest values of arsenic (table 2c). Measured values shown in table 2 for zinc (NR1: 12 to

Table 1. Summary of producing fractures and transmissivity data for the Great Bay National Wildlife Refuge.

[AP1, Adams Point borehole; NR1, National Refuge borehole; ft, feet; ft^2/day, feet squared per day; #, number; <, less than; ~, approximately]

Borehole ID and fracture number[1]	Depth from surface (depth below top of casing)		Interval (ft)	Transmissivity		Description of zone
	(ft)	(ft)		(ft^2/day)	(percent)	
AP1, # 1	25.31		0.13	<0.1	0	
AP1, # 2	37.27		0.4	<0.1	0	
AP1, # 3	69.59	(70)	0.57	1	100	Permeable zone: One permeable fracture, interval ~12 ft, with halo of alteration; irregular and altered feature, visibly altered and mineralized.
NR1, # 1	18.37		0	<1.0	0	
NR1, # 2	19.26		0.69	<1.0	0	
NR1, # 3	21.56		0.54	<1.0	0	
NR1, # 4	25.73	(27)	0.51	15	65	Permeable zone, narrow.
NR1, # 5	40.99		0.44	<1.0	0	Substantial drop in bedrock resistivity below ~45ft, suggesting weathering.
NR1, # 6	54.99		0.42	<1.0	0	
NR1, # 7	67.18	(67)	0.4	1.5	7	Permeable zone, ~10 ft interval.
NR1, # 8	94	(Below 94)		6	28	Permeable zone, narrow <5 ft interval.

[1]Fracture number identifies major breaks in core material resulting in a permeable zone with measurable fluid flow.

363 ppm, AP1: 238 ppm) exceed U.S. Environmental Protection Agency (2004) acute water-quality criteria for fresh and saltwater aquatic ecosystems in both criteria maximum concentration ($Zn^{CMC}_{freshwater}$ = 120 µg/L, $Zn^{CMC}_{saltwater}$ = 120 µg/L) and criterion continuous concentration ($Zn^{CCC}_{freshwater}$ = 81 µg/L, $Zn^{CCC}_{saltwater}$ = 90 µg/L) for an assumed hardness of 100 mg/L $CaCO_3$ (where Zn = zinc, CMC = criteria maximum concentration, CCC = criterion continuous concentration, $CaCO_3$ = calcium carbonate). The measured range for these sites is 99 to 148 mg/L $CaCO_3$. Chloride values (5 to 87 mg/L) document little or no current saltwater incursion.

Table 2. Selected ground-water chemistry data for boreholes NR1 and AP1 in the Great Bay National Wildlife Refuge.

[Refer to Appendix 4 for a complete listing. U.S. Geological Survey Water Resources Data, 2005; AP1, Adams Point borehole; NR1, National Refuge borehole; flt, filtered; unflt, unfiltered; pH scale, a reverse logarithmic representation of relative hydrogen proton concentration; E, estimated value; <, less than; ~, approximately; mg/L, milligram per liter; µg/L, micrograms per liter; As^T, total arsenic; As^3, trivalent arsenic; As^5, pentavalent arsenic; sax, sample passed through a syringe packed with 500 milligrams of a strong anion exchanger]

A. Anions, major elements, pH, and alkalinity

Data type	Type of analysis	Unit	NR1	NR1	NR1	NR1	NR1	AP1	AP1
Sampling date			1/10/00	7/26/00	7/26/00	7/26/00	7/27/00	2/16/00	8/1/00
Alkalinity (as $CaCO_3$)	flt, field	mg/L		142	E 97	111	99		148
pH scale	unflt, field		8.4	9.0	7.6	7.7	7.5	9.2	7.7
pH scale	unflt, lab			8.8	7.4	7.7	7.5		7.4
Chlorine	flt	mg/L		4.69	3.66	3.72	3.66		87.0
Sulfate	flt	mg/L		25.6	31.9	31.0	32.3		27.2
Aluminum	flt	µg/L		7	24	2	2		6
Iron	unflt	µg/L	5600					1500	
Iron	flt	µg/L		< 10	136	22	123		109

B. Trace elements

Data type	Type of analysis	Unit	NR1	NR1	NR1	NR1	NR1	AP1	AP1
Arsenic	flt	µg/L		6.1	< .9	E .7	E .9		5.2
Arsenic	unflt	µg/L	14					4	
Zinc	flt	µg/L		12	311	214	363		238

C. Arsenic speciation in water samples as a function of depth and percent transmissivity

Data type	Analysis/Units	NR1	NR1	NR1	NR1	AP1
Depth	ft	20–23	53–63.5	82–95	20–82	66.5–72
Transmissivity	%	0	0	~ 28	100	100
As^T	flt	0.25	0.51	5.19	0.58	3.88
As^3	flt	0.25	0.51	1.74	0.58	2.97
As^5	flt	-0.2	-0.2	3.45	-0.2	0.91
As^3	sax	0.25	0.69	7.25	0.59	2.89
As^5	sax	0.05	0.09	1.00	0.09	0.45
As^T	sax	0.3	0.78	8.25	0.68	3.34

Results of the Study

This study was undertaken to establish possible geologic sources of metals and metalloids in the well waters, based on the identification of mineralogical hosts and geochemical processes occurring in the aquifer rocks, and to relate those findings to the regional problem. Minerals that contain arsenic, iron, manganese and other metals and metalloids occur in permeable fracture zones in geologic core obtained from boreholes drilled in bedrock aquifers of the Great Bay National Wildlife Refuge. Results from this work provide data in support of regional-scale studies of ground-water quality. Included in this analysis is a classification of geologic data according to geochemical considerations and a description of the mineralogical sources of metals and metalloids, based on mineralogical and geochemical data collected during the course of the study (Appendixes 2–5).

Descriptions of Rock Samples and Fracture Surfaces

The Kittery Formation is described as having bed-parallel, silicified, vuggy or open fracture zones up to 1 centimeter (cm) in width (Degnan and Clark, 2002). These features are present in many of the AP1 core samples (fig. 3). The Kittery Formation, in the core, consists of alternating layers of graded tan to gray calcareous metasandstone and purple and green phyllite. Areas of massive dark gray-green phyllite are cut by multiple generations of fine prominent fractures on the order of 1 millimeter (mm) to 1 cm in width. The fractures are filled with calcite or varying amounts of calcite, muscovite, quartz, and sulfides (table 3). Cubic pyrite is the most prominent sulfide mineral. A second fracture type consists of centimeter-wide alteration zones of chlorite, muscovite, pyrite, quartz, and clay minerals. The mineral coatings on vugs consist primarily of quartz, although fine-grained pyrite and crystalline calcite-lined surfaces are also abundant. Sulfide minerals are localized along minute fractures in the bedrock, and some of the fractures contain up to a few percent sulfide minerals. The fracture zone of high transmissivity (100 percent at depth of ~70 ft) contains base-metal sulfide, carbonate, and minor amounts of clay minerals, in addition to quartz and pyrite (table 3). Overall, total sulfide abundance is much less than 1 percent in most samples of the Kittery Formation from AP1.

The Eliot Formation that constitutes the core from NR1 is a gray to green phyllite, having layers of calcareous quartzite, rusty quartz-mica schist, and minor bedded calc-silicate rock. The core is dissected by multiple generations of fine prominent calcite-filled fractures, on the order of 1 mm to 1 cm in width (fig. 3), as well as irregular fractures filled with chlorite, sulfides, and rock fragments. The fractures also contain quartz, muscovite, fine pyrite cubes and other sulfides (table 3). Rusty alteration is mainly confined to bedding planes marked by disseminated pyrite cubes or coarse masses of aggregated pyrite. The zones of high transmissivity at 65, 7, and 28 percent correspond to high and variable amounts of sulfide, oxide, carbonate and clay minerals compared to unfractured core segments (table 3). In the Eliot Formation intersected by NR1, the bulk of the bedrock contains at least a few percent sulfide minerals, and some fractures and vuggy zones contain up to 5 percent of sulfide minerals. The deepest high transmissivity fracture (28 percent, below ~94 ft) shows evidence for hydrothermal mineralization (copper, gold, lead, silver, tin, zinc) and is associated with the most significant alteration zone in the core, which is characterized by clay minerals, calcite, chlorite, iron-oxide minerals, and wollastonite.

Table 3. Summary of fracture characteristics and mineralogy for core segments from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.

Segment ID	Transmissivity	Fracture mineralogy
		AP1
AP1-13-3	0	Pyrrhotite, pyrite, calcite, quartz, goethite, amorphous iron-oxides, muscovite, clinochlore
AP1-13-4		Pyrrhotite, pyrite, calcite, ankerite, quartz, albite, muscovite, clinochlore, chlorite-nimite
AP1-13-6		Pyrite, arsenopyrite, colbaltite, calcite, quartz, albite, muscovite, clinochlore, chlorite
AP1-14B-4	100	Pyrrhotite, pyrite, galena, chalcopyrite, goethite, calcite, quartz, albite, muscovite, chinoclore, clay minerals, chlorite-nimite
AP1-14B-6	100	Pyrrhotite, pyrite, galena, sphalerite, arsenopyrite, chalcopyrite, cobaltite, goethite, calcite, quartz, albite, muscovite, clinochlore, clay minerals, chlorite
		NR1
NR1-1-1	0	Pyrite, sphalerite, calcite, ankerite, quarz, muscovite, chlinochlore, montmorillonite
NR1-2	65	Pyrite, galena, sphalerite, arsenopyrite, chalcopyrite, amorphous iron-oxides, goethite, calcite, quartz, muscovite, clinochlore
NR1-15-2	0	Pyrite, galena, sphalerite, chalcopyrite, tetrahedrite, iron-ozides, goethite, calcite, quartz, albite, muscovite, microcline, clinoclore
NR1-15-3	0	Pyrite, galena, sphalerite, arsenopyrite, chalcopyrite, cobaltite, iron-oxides, goethite, calcite, quarz, albite, muscovite, clinoclore, montmorillonite
NR1-16-4	0	Pyrite, galena, sphalerite, chalcopyrite, tetrahedrite, iron-oxides, hematite, calcite, quartz, muscovite, clinoclore, anorthite, chlorite-nimite
NR1-17-4	28	Pyrrhotite, pyrite, galena, sphalerite, arsenopyrite, chalcopyrite, cobaltite, cassiterite, electrum, Bi-sulfosalts, iron-oxides, goethite, hematite, chalcocite, covellite, calcite, barite, quartz, albite, microcline, clinochlore, kaolinite
NR1-17-5C	28	Pyrite, galena, sphalerite, chalcopyrite, tetrahedrite, tellurides, Bi-sulfosalts, iron-oxides, goethite, hematite, chalcocite, covellite, calcite, barite, quartz, albite, microcline, clinochlore, kaolinite, wollastonite
NR1-17-6A	28	Pyrite, galena, sphalerite, chalcopyrite, tetrahedrite, tellurides, electrum, Bi-sulfosalts, iron-oxides, goethite, hematite, calcite, barite, quartz, albite, microcline, clinochlore, kaolinite

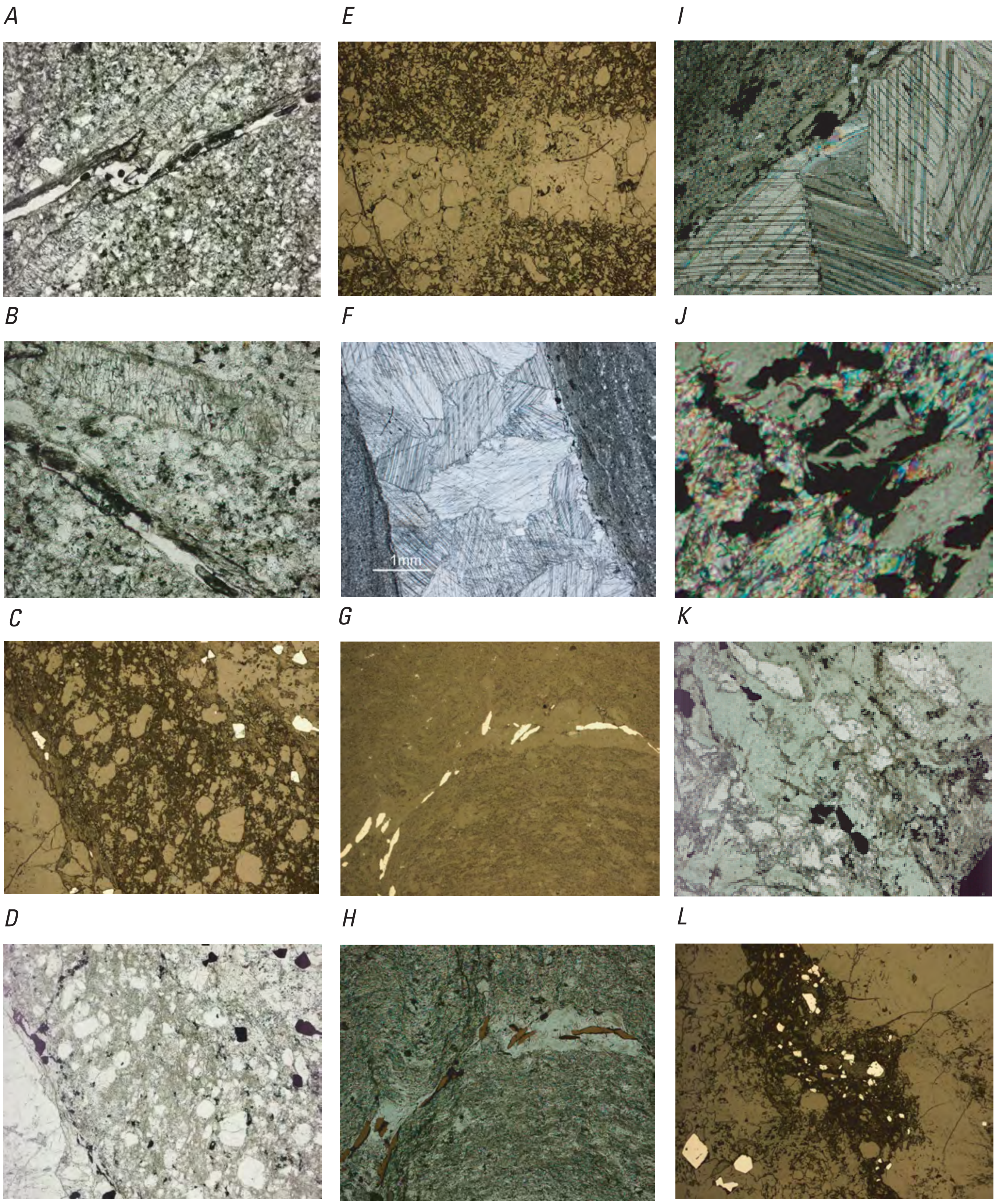
Changes in Bulk Rock Chemistry with Depth

Samples analyzed for bulk chemistry (Appendixes 2, 5) were selected from fracture zones of high transmissivity and from massive unfractured bedrock adjacent to fractures. All samples from the zones of high transmissivity contain sulfide minerals along fracture surfaces. Samples in massive unfractured bedrock above and below the zones of high transmissivity also contain sulfide minerals, either disseminated or in vuggy zones. AP1 and NR1 display contrasting abundances of many trace elements with depth. Figures 4 through 6 show distributions of arsenic, gold, bismuth, copper, ferric oxide, lead, rubidium, selenium, strontium, tellurium, zinc, and tungsten compared to depth and transmissivity. Elevated contents of gold, tellurium, bismuth, tungsten, and selenium occur in both AP1 and NR1, although values of gold and tellurium are highest in NR1 at or above the ~94 ft depth (figs. 5, 6), consistent with sulfide mineralogy (see below).

The highest measured total abundances of arsenic in rocks are in AP1 (fig. 4). Abundances of arsenic ranging from 25 to 40 ppm occur in AP1 in and near the depth interval of 100 percent transmissivity (~ 70 ft). Slightly below the interval in AP1, arsenic contents range from 25 to 16 ppm. Copper, lead, and zinc are also present in slightly elevated amounts in rocks of AP1. The values exceed crustal abundances (Rudnick and Fountain, 1995; Taylor and McLennan, 1995) by factors of 2 to 4. The abundances of copper and zinc in the zone of 100 percent transmissivity are slightly elevated over the abundances in rocks below the zone; lead values fall in the same range as abundances below the zone.

Rock analyzed from NR1 contains as much as 10 ppm arsenic (fig. 4). NR1 has three transmissivity intervals ranging from 65 percent near the top (27-ft depth), 7 percent in the middle (~67 ft), and 28 percent at the bottom (~94 ft). Arsenic contents of rocks within the fracture at the base of NR1 are only about 3 ppm, but rocks 15 ft above the producing fracture have arsenic contents ranging up to 9 ppm. The uppermost fracture with the highest transmissivity (at 65 percent) was not analyzed, but a sample from a few feet above has arsenic contents of less than 5 ppm. In contrast to AP1, copper, lead, and zinc values in NR1 are greatly elevated over crustal abundance values (Rudnick and Fountain, 1995; Taylor and McLennan, 1995). Within the zone of 28 percent transmissivity (~94 ft depth), copper values exceed 40 ppm and zinc and lead values exceed 100 ppm. A sample of rock taken 15 ft above the zone of 28 percent transmissivity contains zinc and lead values that exceed 400 ppm.

Figure 3. Photomicrographs of fracture types and mineral coatings in samples selected from Great Bay National Wildlife Refuge core: (*A*) transmitted light (TL) view of open fracture in Kittery Formation (Fm.), AP1-14, partially filled with clay minerals, cutting across earlier calcite-filled veinlets, field of view (f.o.v.) = 5.3 mm, (*B*) TL view of calcite and clay fractures in Kittery Fm., AP1-14, contains chlorite (light gray) and pyrite (black), f.o.v. = 2.7 mm, (*C*) reflected light (RL) and (*D*) TL pair showing open fracture in Eliot Fm., NR1-16, partially filled with fine clay and iron-oxide minerals and coarse fragments of bedrock including pyrite (bright white in RL) and other sulfides, f.o.v. = 2.7 mm, (*E*) RL view of calcite vein offset by clay-filled fracture containing minute grains of visible pyrite, Kittery Fm., AP1-14, f.o.v. = 2.7 mm, (*F*) TL view of bed-parallel calcite vein edged with blebs of pyrite (black) and laths of rutile (black) in Kittery Fm., AP1-13, f.o.v. = 2.7 mm, (*G*) RL and (*H*) TL pair showing deformed bed-parallel calcite + pyrite veins in Eliot Fm., NR1-16-4a, f.o.v. = 5.3 mm, (*I*) close-up TL view showing contact between calcite-filled fracture and bedrock; note pyrite (black) grains at boundary and within groundmass of Kittery Fm., AP1-13, f.o.v. = 1.4 mm, (*J*) TL view of chlorite (green) and pyrite (black) in fractures in Eliot Fm., NR1-17, f.o.v. = 1.4 mm, (*K*) TL view of chlorite (green), quartz, (white), rutile (gray), and pyrite (black) in open fractures in Eliot Fm., NR1-17, f.o.v. = 1.4 mm, (*L*) RL view of partially altered pyrite and iron-oxide minerals adjacent to quartz in fracture in the Eliot Fm., NR1-17, note unaltered pyrite in unfractured bedrock, f.o.v. = 5.3 mm.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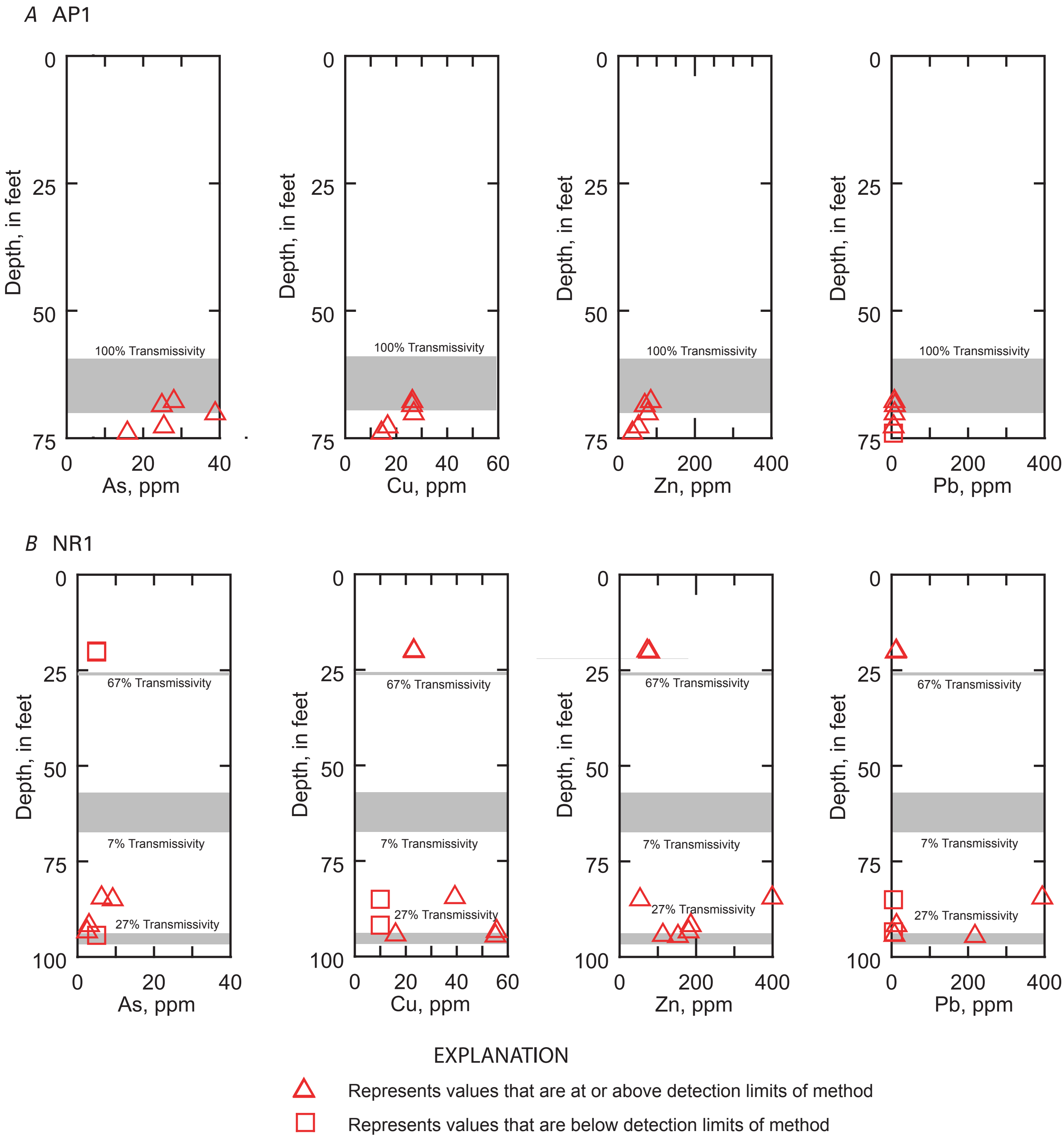

Figure 4. Depth profile showing contents in parts per million (ppm) of arsenic (As), copper (Cu), zinc (Zn), and lead (Pb) in core from (*A*) AP1 and (*B*) NR1 compared to transmissivity data and crustal abundance values.

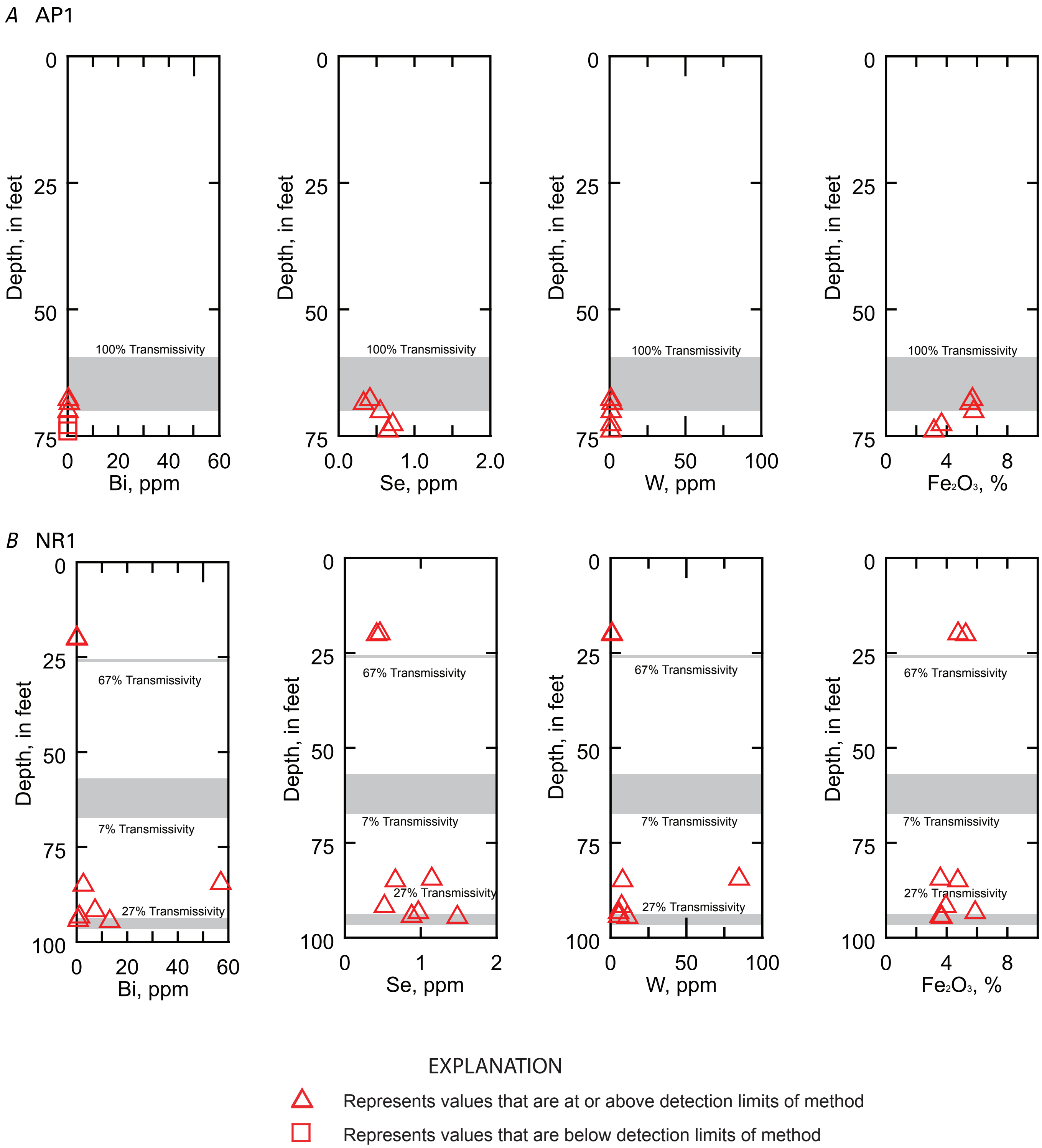

Figure 5. Depth profile showing contents in parts per million (ppm) of bismuth (Bi), selenium (Se), tungsten (W), and iron as iron oxide (Fe_2O_3) in core from (*A*) AP1 and (*B*) NR1 compared to transmissivity data and crustal abundance.

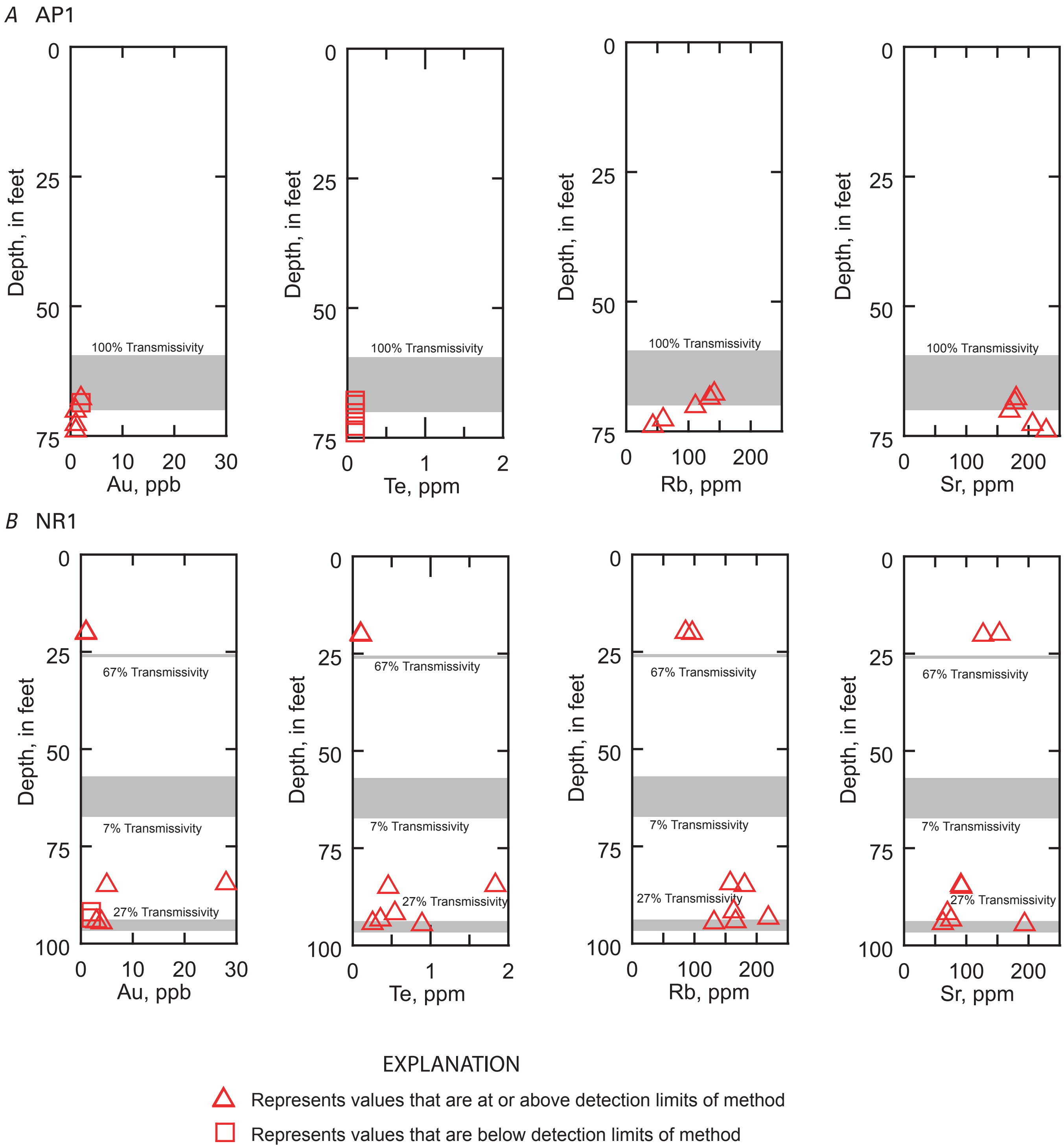

Figure 6. Depth profile showing contents in parts per billion (ppb) of gold (Au), and in parts per million (ppm) of tellurium (Te), rubidium (Rb), and strontium (Sr) in core from boreholes (*A*) AP1 and (*B*) NR1 compared to transmissivity data and crustal abundance.

Sulfide Mineralogy and Mineral Chemistry

Total sulfide abundance is less than a percent in most samples from AP1; up to a few percent sulfide minerals are localized in parts of NR1. Table 4 lists the name and general formula of sulfide and selected silicate minerals found in core extracted from the Great Bay National Wildlife Refuge that have the potential to affect water chemistry data. The type and composition of sulfide minerals varies between boreholes.

Table 4. Minerals of interest in core samples, Great Bay National Wildlife Refuge.

[Listed in alphabetical order; x, phase is present; a, phase is arsenic-bearing]

Mineral/material	Chemical formula	Kittery Formation	Eliot Formation
Albite[1]	$NaAlSi_3O_8$	x	x
Amorphous iron-oxides	Fe_xOH_x trace elements	xa	xa
Anglesite	$PbSO_4$	x	x
Ankerite	$Ca(FeMn,Mg)(CO_3)_2$	x	x
Arsenopyrite[2]	FeAsS	xa	xa
Barite	$BaSO_4$		x
Bi-sulfides and sulfosalts	Various (PbBiSb)S, Bi_2S_3		x
Calcite[1]	$CaCO_3$	x	x
Cassiterite	SnO_2		x
Chalcocite	Cu_2S		x
Chalcopyrite[2]	$CuFeS_2$	x	x
Chlorite-nimite[1]	$(Ni,Mg,Al)_6(Si,Al)_4O_{10}(OH)_8$	x	x
Clay minerals[1]	Mixed, kaolinite, illite-smectite		x
Clinoclore[1]	$(Mg_5Al)(Si,Al)_4O_{10}(OH)_8$	x	x
Cobaltite	CoAsS		xa
Covellite	CuS		x
Dolomite[1]	$CaMg(CO_3)_2$		x
Electrum	AuAg		x
Galena[2]	PbS	x	x
Goethite[2]	Fe_3+O(OH)		xa
Gold	Au		x
Halotrichite[2]	$FeAl_2(SO_4)_4$·22H2O		x
Hematite	Fe_2O_3		x
Illite[1]	$(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$		x
Kaolinite[1]	$Al_2Si_2O_5(OH)_4$	x	x
Melanterite	$FeSO_4$·7H2O		x
Microcline[1]	$KAlSi_3O_8$		x
Monazite	$(Ce,La,Nd,Th)PO_4$	x	x
Muscovite[1]	$KAl_2(AlSi_3O_{10})(OH)_2$	x	x
Ni-As pyrites[2]	$(Fe,Ni)(S,As)_2$		xa
Bravoite[2]	$(Fe,Ni)S_2$		x
Pyrite[2]	FeS_2	xa	xa

Table 4. Minerals of interest in core samples, Great Bay National Wildlife Refuge.—Continued

[Listed in alphabetical order; x, phase is present; a, phase is arsenic-bearing]

Mineral/material	Chemical formula	Kittery Formation	Eliot Formation
Pyrrhotite[2]	$Fe_{(1-x)}S$	xa	xa
Quartz	SiO_2	x	x
Rutile	TiO_2	x	x
Smithsonite	$ZnCO_3$		x
Sphalerite[2]	(Zn,Fe,Cd)S	x	x
Tellurides	e.g., PbTe, $AuTe_2$, Ag_2Te		x
Tennantite[2]	$(Cu,Ag,Zn,Fe)_{12}(As,Sb)_4S_{13}$		xa
Tetrahedrite[2]	$(Cu,Fe)_{12}Sb_4S_{13}$		xa
Wollastonite[1]	$CaSiO_3$		x
Zircon	$ZrSiO_4$	x	x

[1] Acid-consuming material.

[2] Acid-generating material (Foley and others, 2005).

Pyrite and pyrrhotite, the primary iron-sulfide minerals, are subordinate in core from AP1 (fig. 7), whereas pyrite is dominant in NR1 (fig. 8). The type of pyrite is also variable throughout both formations. Pyrite types include disseminated fine-cubic bed-parallel pyrite, massive and coarsely-crystalline bed-parallel pyrite, and massive and coarsely-crystalline pyrite in crosscutting veins. Fracture surfaces, both bed-parallel and those that cut across the rock fabric, also have some thin films of fine-grained pyrite. Several varieties of deformed pyrite occur in veins, including metamorphosed or remobilized fine-grained pyrite in veins and offsets, coarse aggregates and annealed pyrite porphyroclasts, and porphyroblastic pyrite. Some anisotropic forms of bed-parallel, vein, and overgrowth pyrite were also found. Pyrrhotite occurs mainly as small stringers in unfractured rocks and as smears along fractures surfaces.

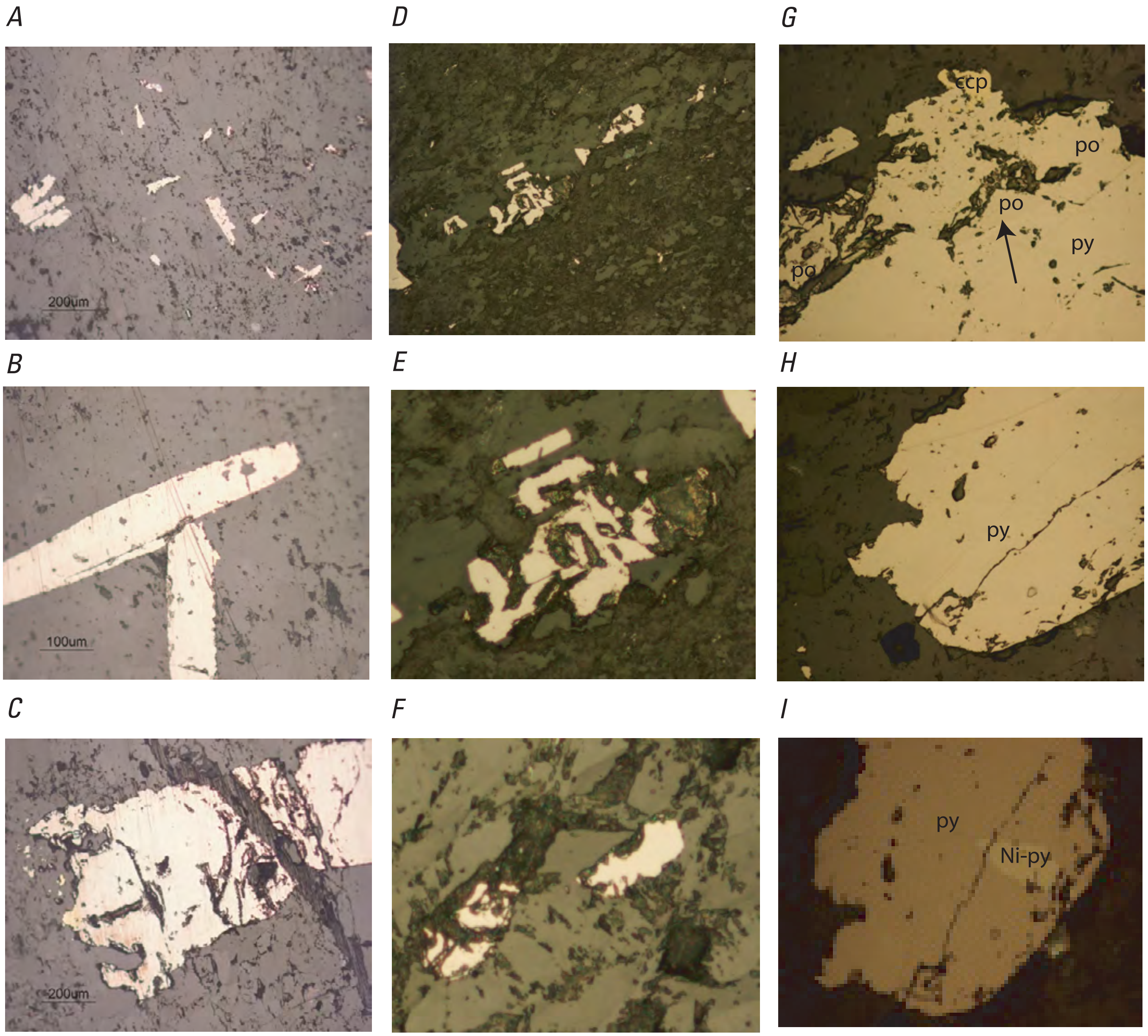

Figure 7. Reflected light photomicrographs of iron-sulfide minerals in core samples extracted from borehole AP1. Near the zone of highest transmissivity (~70-ft depth) pyrite (bright color) occurs in the groundmass as (*A*) ragged laths, field of view (f.o.v.) = 1 mm, and larger grains that have (*B*) relatively unaltered contacts in unfractured groundmass, f.o.v. = 0.5 mm, or (*C*) eroded, irregular edges where cut by fractures filled with iron-oxide minerals, f.o.v. = 1 mm. (*D*) Bed-parallel veins, f.o.v., = 2.7 mm, contain (*E*) skeletal pyrite replaced by quartz and iron-oxide, (*F*) ragged grains of pyrite with quartz and chlorite, f.o.v. = 1.6 mm. (*G*) Large pyrite (py) grains are rimmed with pyrrhotite (po) and chalcopyrite (ccp), f.o.v. = 0.4 mm. Some pyrite is enriched nickel (*H*) uncrossed and (*I*) crossed nicols, f.o.v. = 0.2 mm.

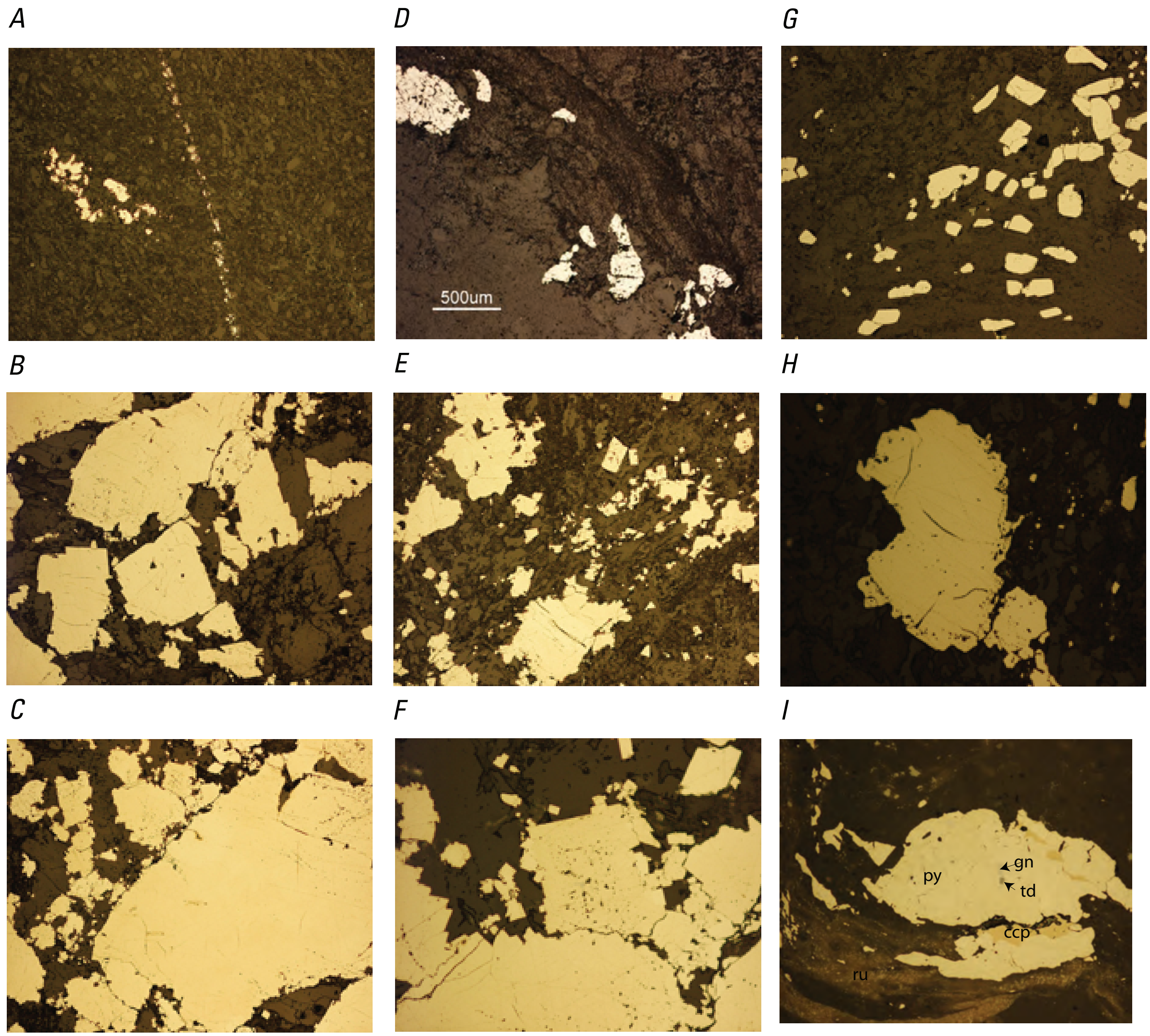

Figure 8. Reflected light photomicrographs of iron-sulfide minerals in core samples extracted from borehole NR1. At shallow depths (NR1-1, NR1-2), pyrite (bright) occurs as (*A*) patches in the groundmass and in fine sulfide veinlets, field of view (f.o.v.) = 5.3 mm, and (*B*, *C*) as fractures, and relatively unaltered, coarse aggregates in vugs, f.o.v. = 1.4 mm. At great depths (NR1-15) irregular veins with aggregates of pyrite occur (*D*) sub-parallel to bedding, f.o.v. = 2.7 m, (*E*) in chlorite veins that cut bedding, and (*F*) in isolated vugs where aggregates of pyrite contain various sulfide and silicate inclusions, f.o.v. = 1.4 mm. In the zone of high transmissivity (NR1-17, at a depth ~95 ft), pyrite (*G*) is more abundant in the bedrock, f.o.v. = 2.7 mm, and may contain numerous other sulfides (chalcopyrite; galena, gn, and tetrahedrite, td) as rims on pyrites in veins, f.o.v. = 1.4 mm, and (*H*) intergrown with trails of rutile (ru), which give the rock a pronounced red hue, f.o.v. = 0.4 mm.

Other sulfide minerals, including arsenic-bearing minerals, also occur in core samples, especially along fractures, both narrow sealed breaks in relatively unfractured bedrock and open permeable fractures comprising zones of high transmissivity (fig. 9). Closed and open fractures throughout both cores contain a variety of base-metal sulfide, oxy-hydroxide, clay, and carbonate minerals (fig. 10).

In AP1, sulfide minerals present at the 70-ft depth interval of 100 percent transmissivity include multiple forms of pyrite, and trace amounts of pyrrhotite, sphalerite, galena, chalcopyrite, cobaltite (CoAsS, containing ~45 percent As by weight), and arsenopyrite (FeAsS, containing ~46 percent As by weight). Arsenic-rich mineral phases are most visible in massive and coarsely-crystalline bed-parallel pyrites and in massive and coarsely-crystalline vein pyrites. Quartz, calcite, and chlorite (clinochlore) are the dominant gangue minerals in veins and vuggy areas. Pyrite and calcite occur in some fractures without alteration halos. Undifferentiated clay minerals and iron oxides, primarily goethite, occur in the visibly altered zone at the ~70-ft depth interval. Relatively unfractured bedrock above the zone of high transmissivity also contains sulfide minerals including pyrrhotite and pyrite, with trace arsenopyrite and cobaltite, but no other base-metal sulfides were found.

In NR1, base-metal sulfide minerals occurring at the 65- and 28-percent transmissivity depth intervals include pyrite and pyrrhotite, and a minor but diverse array of other sulfide and sulfosalt minerals including arsenopyrite, bismuthinite, cassiterite, chalcopyrite, cobaltite, galena, sphalerite, and tetrahedrite. Trace amounts of precious-metal minerals and sulfides in the core intervals include electrum, Ag-tennantite, and Au-Ag-telluride (fig. 9).

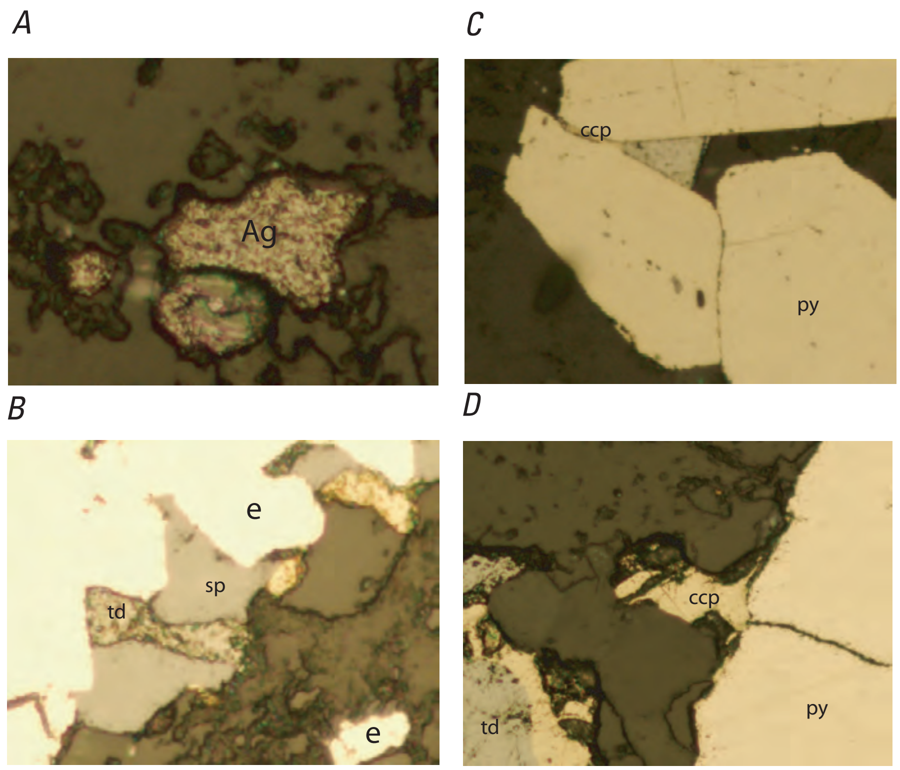

Figure 9. The Eliot Formation, at depth in NR1, contains a variety of base and precious-metal minerals, including arsenic-bearing sulfide minerals in pyrite lenses: (*A*) silver minerals (Ag) are predominantly tetrahedrite and tellurides, field of view (f.o.v.) = 0.2 mm, (*B*) electrum (e), sphalerite (sp), tetrahedrite (td), f.o.v. = 0.16 mm, and (*C*, *D*) arsenic-bearing tetrahedrite (td) grains intergrown with stringers of chalcopyrite (ccp) and larger grains of pyrite (py), f.o.v. = 0.16 mm.

In the upper part of NR1, just above the 65 percent transmissivity interval, is a zone consisting of fractures lined with iron-stained crusts of quartz, clinochlore, muscovite, and remnants of pyrite, loosely cemented by calcite. The iron-oxide material is amorphous. Unaltered pyrite and sphalerite also occur in more massive bedrock in this interval. Deeper in the borehole, beginning at ~45 ft and continuing to ~65 ft, iron-oxide minerals, including goethite and hematite, chlorite, and sericite, likely formed by alteration of the sulfides, feldspars, biotite, and muscovite, are interspersed with pyrite, galena, sphalerite and chalcopyrite, as well as trace amounts of arsenopyrite and tetrahedrite in irregular veins and fractures. Much of the cubic pyrite occurs in coarse aggregates with minor disaggregation and little apparent alteration. Blebs and stringers of bismuth and lead-bismuth-sulfide and sulfosalt minerals and sphalerite (cadmium-bearing), galena, tetrahedrite, and locally, silver-tennantite, occur in masses of aggregated pyrite. Surface alteration minerals on pyrite include anglesite, a stable lead-sulfate, and melanterite, an efflorescent iron-sulfate mineral. In some samples, pyrite shows incipient alteration to pyrrhotite, with development of iron-oxide staining. Altered biotite contains blebs of a bismuth-telluride mineral. White coatings in fractures consist of quartz, scorodite, nontronite, calcite, and locally alunite; tan crusts also contain other iron-oxide minerals (such as rozenite) and biotite. Grains of an silver-telluride mineral (~10 µm wide) are found intermixed with silver-tennantite, galena and pyrite. Monazite is abundant in some samples and is commonly found within zones of coarse pyrite. Small subhedral barite crystals occur widely dispersed within the dominantly silicate gangue matrix of the core samples.

Lower in the core, below ~94 ft, is a narrow (<5 ft) interval with high permeability—the 28 percent transmissivity zone. Pyrite, pyrrhotite, sphalerite, galena, chalcopyrite, and a variety of other base-, and some precious-metal, sulfide and sulfosalt minerals are found in trace amounts. Electrum and Ag-telluride minerals (possibly sylvanite and nagyagite) occur as small grains in pyrite. Accessory sulfide and sulfosalt phases include arsenopyrite (with ~46 percent arsenic by weight), tetrahedrite, bismuthinite, lead-bismuth-sulfosalt minerals and cobaltite-gersdorffite (~45 percent arsenic by weight). Base-metal oxide minerals include cassiterite (tin oxide) and hematite. Pyrites contain grains of chalcopyrite, sphalerite (with high cadmium), and galena (with included bismuthinite), in inclusion-rich zones. The pyrite and chalcopyrite also contain included tetrahedrite with significant arsenic Chalcopyrite contains a bismuth-tellurium phase. Tetrahedrite can contain up to ~10 percent arsenic by weight. Some pyrite is zoned with nickel contents that approach bravoite. Barite, quartz, albite, microcline, chlorite, sericite, calcite, and wollastonite occur in some fracture fillings.

Alteration minerals associated with the zone of high transmissivity include chalcocite and covellite, goethite and other mixed iron-oxyhydroxide minerals, and kaolinite and chlorites (fig. 10). Green coatings on fracture surfaces contain pyrite, quartz, chlorite and calcite; pyrite, which contains blebs and stringers of arsenopyrite, galena, chalcopyrite, sphalerite (cadmium-bearing), and gold in electrum, is often rimmed by goethite and more rarely scorodite and/or rozenite. Trace accessory phases found in coatings composed mainly of quartz, feldspar, muscovite, biotite, and calcite, include apatite, cassiterite, monazite, rutile, and sphene. Beige-green coatings on fracture surfaces consist of quartz, chlorite, some white mica (illite), and calcite. Fracture fillings include calcite, quartz, plagioclase, with accessory rutile, barite, smithsonite, and celestite. Fracture walls are lined with pyrite rimmed by lepidocrocite, rozenite, and arsenopyrite (fig. 10).

Sulfide minerals in core samples from both boreholes contain variable and generally low amounts of trace elements. In general, pyrites in core samples from AP1 and NR1 have similar average trace element contents of arsenic, copper nickel, lead, selenium and zinc (table 5), although the ranges vary. Measured contents of arsenic, nickel, selenium, and zinc in pyrite from NR1 are five to 20 times the point values for AP1 (Appendix 5). Bulk mineral separates of pyrite (massive and coarsely crystalline) from fractures contain contents for minerals in the range of <3,000 ppm arsenic, <3,500 ppm cobalt, and <2,000 ppm nickel. Galena contains less than 1,000 ppm selenium and sphalerite contains up to 2 weight percent cadmium.

Trace-element contents increase with depth for NR1. At the 67 percent transmissivity depth interval (~25 ft) pyrite separates contain <200 ppm arsenic, <1,000 ppm cobalt and <1,000 ppm nickel. Further down the drill hole, in the zone of 27 percent transmissivity (~94 ft), pyrite contains <4,500 ppm arsenic, <2,700 ppm cobalt, and <5,300 ppm nickel.

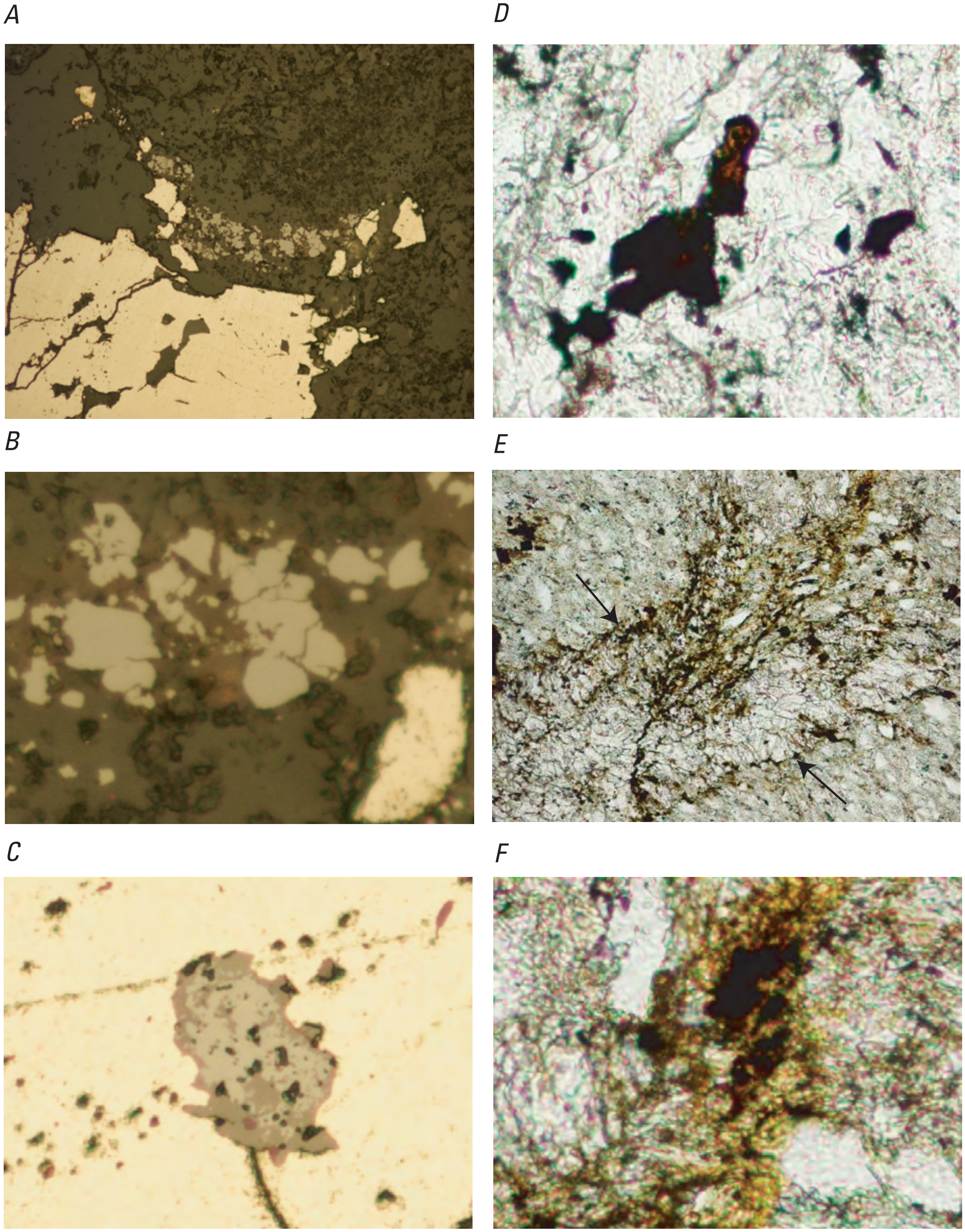

Figure 10. Alteration types and mineral coatings in core samples, Eliot and Kittery Formations, show evidence for pyrite oxidation: (*A*) Pyrite (bright) in fracture altered to hematite (gray) at contact with bedrock (dark material), field of view (f.o.v.) = 1.4 mm, (*B*) close-up view shows goethite and lepidocrosite rims (reddish hue) on altering hematite (gray) adjacent to relatively unaltered pyrite, f.o.v. = 0.16 mm, (*C*) pyrite grains containing patches of hematite and other iron oxyhydroxide minerals formed by in-situ weathering, possibly fracture-controlled, f.o.v. = 0.16 mm, (*D*) transmitted light view of isolated pyrite grains in bedrock altering to iron-oxides in a groundmass of quartz, chlorite, and clay minerals, f.o.v. = 1.4 mm, (*E*) 1-mm-wide veins of calcite contain iron-hydroxide (black) minerals at contacts with groundmass and in veins, f.o.v. = 2.7 mm. Some calcite veins contain (*F*) partially altered pyrite grains (black) and iron-stained carbonate minerals (reddish hue), f.o.v. = 0.16 mm.

Table 5. Summary of trace element contents of pyrites from rocks of the Great Bay National Wildlife Refuge

[wt. %; weight percent; As, arsenic; Co, cobalt; Ni, nickel; Pb, lead; Se, selenium; Zn, zinc]

Drill core site	Formation	As (wt. %)	Co (wt. %)	Ni (wt. %)	Pb (wt. %)	Se (wt. %)	Zn (wt. %)
AP1, average	Eliot	0.005	0.12	0.06	0.38	0.002	0.01
AP1, range	Eliot	0-0.03	0.07-0.34	0-0.2	0–11.68†	0–0.02	0–.03
NP1, average	Kittery	0.02	0.12	0.08	0.02	0.002	0.01
NP1, range	Kittery	0–0.65	0.04–0.39	0–0.53	0–11.69†	0–0.28	0–0.2

† High values in range likely indicate presence of inclusions of galena or Pb-sulfate in pyrite.

Discussion and Summary

The geological characterization of metasedimentary rocks obtained from cores extracted from the Kittery and Eliot Formations shows that they contain sparse arsenian pyrite, pyrrhotite, and chalcopyrite (plus carbonate, chlorite, and quartz) in fine fractures in aquifer rocks. Small amounts of iron and other base-metal sulfide minerals are also contained in unfractured bedrock dissected by the cores. Notably, neither the bulk rocks, which contain <40 ppm arsenic and <400 ppm zinc, nor the minerals (for example, pyrite contains < 3,000 ppm arsenic and < 200 ppm zinc) in either borehole are exceedingly high in arsenic or zinc.

The primary geologic sources of arsenic and zinc in waters extracted from boreholes AP1 and NR1 are most likely arsenic-bearing iron-sulfide minerals and sphalerite, which occur as trace to minor components of the rocks. Sulfide minerals are predominantly pyrite, with lesser amounts of chalcopyrite, galena, and sphalerite. Pyrite contains the bulk of the arsenic present in the rocks, either as low amounts of structural arsenic or as trace amounts of included arsenian sulfide and sulfosalt minerals, including arsenopyrite, arsenian tetrahedrite, and cobaltite. Sphalerite contains most of the zinc and all of the cadmium; some zinc is present as smithsonite. The base-metal sulfide minerals are concentrated primarily in veins and stringers, and also in vuggy, partially silicified, and in some cases calcite-bearing, open zones that are generally parallel to bedding in the sediments (Appendix 2). Much lower amounts of arsenic-bearing sulfides and sphalerite are disseminated within the rock; coarse sulfide aggregates of pyrite contain most of the visible primary arsenic source minerals. The predominant gangue minerals include calcite, quartz, and chlorite, which rim and armor many sulfides. Gold and silver-telluride minerals and higher amounts of base-metal sulfides such as pyrite, sphalerite, tetrahedrite, galena, lead-bismuth-sulfosalts, and chalcopyrite, relative to the rest of the core, are found in the most significant alteration zone (containing clay minerals, iron-oxide and iron-sulfate minerals) at depth in the Eliot core. The minor amounts of sub-economic polymetallic mineralization coincide with one zone of high transmissivity.

Oxidation of sulfides, and the release of acid, arsenic, and other trace metals, is most prevalent in open fractures that cut bedding and in vuggy zones that parallel bedding in the vicinity of the zones of high transmissivity. The presence of significant calcite and lesser amounts of other acid-neutralizing carbonate and silicate minerals likely acted as a natural buffer to reduce acidity, force precipitation of iron-oxyhydroxide minerals, and remove some amount of trace elements, including arsenic and lead, from ground waters in the refuge. The higher values of arsenic measured in unfiltered waters compared to filtered samples (table 2B) suggest that the arsenic is carried on fine iron-oxyhydroxide particulate matter carried in suspension in the well water flow. Zinc may remain in solution to a larger extent because of complexing with carbonate and its solubility in near-neutral ground and surface waters.

Metamorphic rocks sampled in the Great Bay area that contain the sulfide minerals described above are at biotite-grade and consist of phyllitic rocks (Kittery Formation) that grade upward into somewhat finer grained rocks (Eliot Formation); all are intensely folded and multiply fractured. The felsic and siliceous metasedimentary and metavolcanic rocks had limited acid-neutralizing capacity because they are composed primarily of feldspars, quartz, and minor mafic minerals. Feldspars in many of the rocks are altered to micas and clay minerals, which has further reduced any natural acid-neutralizing capability. Albite and microcline are relatively fast weathering compared to stable clay mineral forms, so typically their ability to neutralize acid generated by the oxidation of pyrite may exceed those of some micas and clays. The acid-consuming potential of micas and clay minerals also varies by composition (Foley and others, 2005). The presence of calcite, most of which is probably of metamorphic or hydrothermal derivation, may have exerted the greatest influence on the arsenic contents of ground water within the Great Bay National Wildlife Refuge. Carbonate minerals having high acid-neutralizing capacity occur in veins, vugs, and permeable layers in most zones of high transmissivity in the bedrock. In addition, the most base-metal-sulfide-rich segment of the core, which also corresponds to a zone of high transmissivity, contains metamorphic and(or) hydrothermal silicate minerals that weather at an intermediate rate and have a moderate capacity to consume acid. The presence of wollastonite and some sheet-silicates (clinochlore, chlorite-chamosite, kaolinite) served to enhance the overall acid-neutralizing potential of the bedrock within the fracture zones. Taken together, these minerals have the potential to counteract the acid-generating consequence of weathering iron-sulfide minerals. Note that the pH values of ground water in the region are near-neutral (table 2; Ayotte and others, 2003) and that both bedrock cores contain minor amounts of relatively pristine sulfide minerals (fig. 11). Because the bedrock does contain a significant amount of unoxidized disseminated sulfides, primarily pyrite and sphalerite in layers and as fine disseminations, the potential remains for bedrock in the Great Bay National Wildlife Refuge to continue to contribute minor arsenic and zinc to the ground water aquifer.

The general association of anomalous arsenic content in ground water to a consolidated bedrock geologic unit (in this case, the Kittery and Eliot Formations) as suggested by Ayotte and others (1999, 2003) and Montgomery and others (2003) is verified by the presence of arsenic-bearing minerals in bedrock underlying the Great Bay National Wildlife Refuge. However, the low contents of arsenic and other metals in filtered local ground waters in the two boreholes drilled in the Great Bay National Wildlife Refuge (table 2; Appendix 2), are likely controlled by reactions with dominantly carbonate and secondarily silicate gangue minerals that partially fill fractures, fissures, and permeable zones within the bedrock formations. If rocks from the Kittery and Eliot Formations examined in this study are representative of the formations, then sources of arsenic other than geologic reservoirs may be needed to account for the anomalous arsenic levels found in private bedrock aquifer wells of Rockingham County and adjacent counties in southeastern New Hampshire, as established by Boudette and others (1985) and Montgomery and others (2003). Data for the Great Bay area suggest that other sources for arsenic may need to be considered for ground water aquifers comprised of the Kittery and Eliot Formations. This study supports conclusions by Montgomery and others (2003) and Ayotte and others (2003) that individual testing of private bedrock wells may be necessary to establish the arsenic contents of drinking water, because the concentration of arsenic in ground water cannot be accurately accounted for and modeled based solely on the available hydrochemical and geological data.

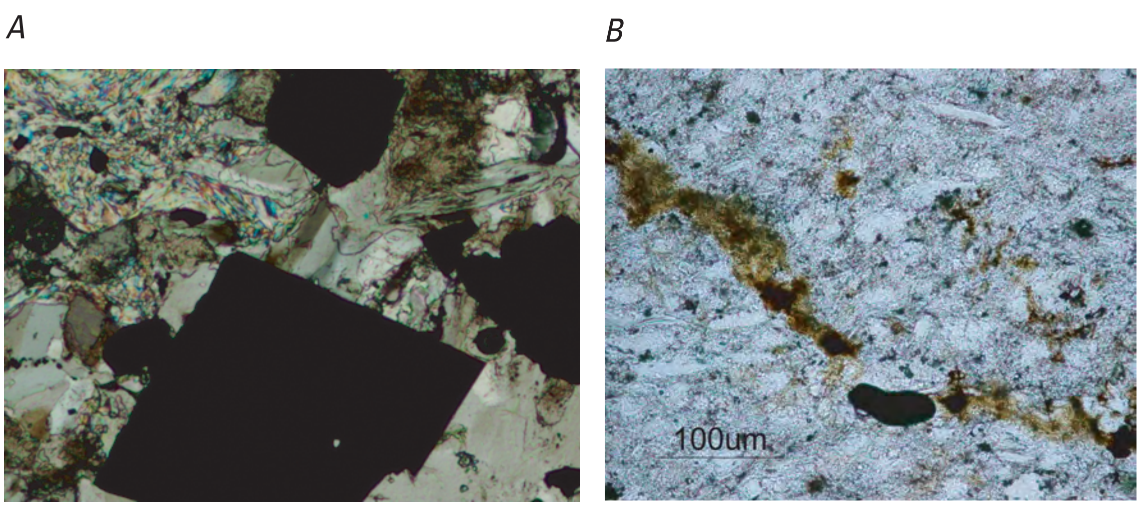

Figure 11. Unaltered and altered pyrites from borehole NR1: near the zone of highest transmissivity (~70-ft depth) pyrite associated with quartz and carbonate in fine fractures forms (*A*) relatively pristine unoxidized cubes in sharp contact with gangue minerals, field of view = 0.199 mm, and (*B*) irregular grains that are oxidized and partially altered to iron-oxyhydroxide material, field of view = 5.3 mm.

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Appendixes

Appendix 1. Analytical methods

Rock geochemistry

USGS Analytical Laboratories were used for sample preparation and analyses. Major elements were analyzed by wavelength dispersive, X-ray fluorescence spectroscopy (WD-XRF), and neutron activation (INAA) (USGS Laboratories in Denver, Colo.). Sample preparation, analytical methods, and detection limits are reported in Taggart (2002). Other analyses were done at XRAL or ACT Laboratories under contract to the USGS. Forty-two major, minor, and trace elements were determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES) and inductively coupled plasma-mass spectrometry (ICP-MS).

Mineral identification and analysis

Rocks were cut and prepared as polished thin sections and grain mounts for optical microscopy and petrographic study, scanning electron microscopy (SEM), and electron probe microanalysis (EPMA). Hand-picked mineral concentrates were analyzed by powder X-ray diffraction (XRD) as smear mounts on quartz plates. Powder patterns were collected on a Scintag X1 automated diffractometer equipped with a Peltier detector using CuKá radiation. Patterns were interpreted with the aid of Scintag and MDI Applications JADE search/match software and compared with reference patterns in the Powder Diffraction File (International Center for Diffraction Data, 2002). Mineral separates and polished thin sections were carbon-coated and examined with a JEOL JSM-840 scanning electron microscope (SEM) equipped with a back-scattered electron (BSE) detector, a secondary electron (SE) detector, and a PGT X-ray energy-dispersive system (EDS). EDS spectra were collected to obtain a qualitative analysis of mineral compositions to refine XRD identifications. The SEM typically was operated at an accelerating voltage of 15 kV (kilovolts) and a specimen current of 1 to 2 nA (nanoamperes). Sulfide minerals were analyzed for 13 elements by EPMA using a JEOL electron microprobe optimized for determining trace-element concentrations in sulfide minerals by operating at 20 kV, 50 nA, and using long (60-120 second) peak count times. Detection limits based on counting statistics are on the order of 200 ppm or less. Standards included a variety of natural and synthetic sulfide minerals. The SEM and EPMA instruments are in USGS laboratories in Reston, Va.

Appendix 2. Sample selection data from the Great Bay National Wildlife Refuge Well Site Adam's Point (AP1): Core segment descriptions

[ft, feet; cm, centimeter; ~, approximately; ?, probable]

Segment number	Length, in feet[1]	Description
Surface to bedrock	3.2	Soil and till, gray marine clay
AP1-1	1.7	Bedrock, iron-stained fractures, mineralized vertical fractures.
AP1-2	5	Iron-staining throughout, low-angle fractures, breaks with low angle fractures.
AP1-3	4.6	Broken up during drilling, few true fractures.
AP1-4	5.25	No information.
AP1-5	5	No information.
AP1-6	5.1	Tone varies from light to dark, vertical white veins, top and bottom breaks with 30-degree dip.
AP1-7	5	Bedding on top, dark coloration at bottom, chlorite and pyrite in fractures, graphite material in muds, near-vertical bedding at top, grading to brecciated at bottom, pyrite and calcite fill closed veins; lower in segment brecciation changes to foliation, calcite-filled fractures, pyrite, chlorite, and calcite in fractures at base of segment.
AP1-8	5.25	Foliated rock, with fracture fillings of calcite, chlorite, and pyrite throughout, some calcite, calcite+pyrite, chlorite, calcite+pyrite+chlorite.
AP1-9	4.9	Near-vertical bedding.
AP1-10	5.3	Many sub-segments in core.
AP1-11	4.75	No information.
AP1-12	4	Light coloration, dark red beds (3 drilling breaks), vertical and 45-degree dip calcite-filled fractures, near-vertical bedding shows convolutions, pyrite in vertical fractures, vertical calcite-filled fracture with pyrite, at bottom 45-degree dip fracture with calcite and pyrite.
AP1-13	4.9	Water data interval (66- to 72-ft depth), brittle, many drilling breaks, flat, vertical and 45-degree dip calcite-filled fractures, calcite and pyrite on fracture surface, calcite, calcite parallel +pyrite, slicken-sides in fracture fills, dark matrix rock.
AP1-14A	0.45	Water data interval (66- to 72-ft depth).
AP1-14B	4.5	Water data interval (66- to 72-ft depth), calcite and chlorite slickenslides, open fractures, calcite filled fractures, calcite and pyrite on top and bottom breaks and fractures, lower in segment rock is significantly lighter in color calcite and pyrite in fractures, calcite coatings on fracture faces.
AP1-15	5.1	Couple of main fractures, dip breaks on many pieces, calcite and pyrite in fracture faces.
AP1-16	4	Fracture with calcite, and possibly quartz on face, calcite and pyrite on fracture faces, discoloration along fracture faces, near-vertical bedding, discoloration and weathering along near-vertical calcite and quartz-filled parallel fractures.
AP1-17	~5	Highly broken and many fractures.
AP1-18	~5	Highly broken and many fractures.
AP1-19	~2	Highly broken and many fractures.
AP1-20	4.85	Lighter color rock, calcite and pyrite top fracture face, calcite on bottom fracture face, calcite on top and bottom fracture faces, weathered calcite-filled fractures, pyrite near vertical fracture/break face at base.

[1] Footage provided is length of core described by segment number. The total length of the core is 104.75 feet below casing and 102.75 feet below ground surface.

Notes describing selected AP1 samples:

AP1-13-1

- Veins at top of section running parallel and perpendicular to bedding (calcite) ~5 cm long
- Fine-grained pyrite visible throughout entire section in white material (calcite mostly, with some quartz)
- Several concentrated areas of pyrite in white and gray areas (calcite/quartz?), pyrites range from mm to cm in diameter
- Bedding consists of banded white (quartz/barite?)/light gray and then darker gray to black (quartz?).

AP1-13-2a

- Bedding same as above; calcite veins running parallel to bedding; 2.5- to 7.5-cm long,
- 1 calcite vein going perpendicular to bedding
- Very fine-grained dispersed pyrite spread throughout section in white mineral (quartz + calcite).

AP1-13-2c

- Bedding same as above; bands a little bit thicker (3 mm wide) in this section
- Area of cross-bedding; light gray bands of quartz; running perpendicular to rest of bedding
- 5 parallel veins of calcite
- 1 perpendicular vein of calcite running entire length of this section; cutting across both parallel veins described above as well as the 2.5-cm-wide vein from above
- Pyrite same as above; in gray/white (quartz); very fine-grained, widely spread out with no concentrated areas.

AP1-13-2cA

- Bedding same as above; light gray/white bands (quartz mostly; maybe some calcite) followed by darker gray to black bands (1 to 2 millimeters wide)
- Perpendicular vein calcite
- Parallel vein around entire width of core present at beginning of this section
- Fine-grained sulfides (pyrite) seen in section, mostly in light-gray/white (quartz); no concentrations; widely dispersed throughout section.

AP1-13-3a

- Bedding same as above, bands are < 1 millimeter
- Numerous calcite veins:
  - Veins parallel to bedding cut all but the smallest perpendicular veins
  - 4 veins perpendicular to bedding
- Pyrite same as above, no concentration seen, very widely dispersed.

AP1-13-4a

- Bedding same as above; narrow bands
- Larger parallel calcite veins present
- Light gray bands perpendicular to bedding; ~5 cm each
- Numerous pyrite concentration ranging from cm wide patches to less than a millimeter in width
  - All associated with either dark gray (quartz?) or calcite clots.

AP1-13-4b

- Bedding same as above with narrow bands
- 7 small veins (calcite),
  - Parallel to bedding
  - Diagonally to bedding
- Pyrite: 5 small areas of concentration; largest is 1 cm wide, smallest the size of a pencil tip
  - Found in dark gray (quartz?) and some in calcite deposits in inner core; broken chunk revealed concentrations of pyrite below surface of core
  - Pyrite also seen; fine-grained; spread throughout section; in lighter gray (quartz); in darker gray/black (quartz).

AP1-13-5a

- Bedding same as above with small bands and fewer dark gray/black bands
- 10 calcite veins overlapped; diagonal (~2.0 to 4.0 cm), large perpendicular to bedding (~5 cm); bed-parallel vein
- Altered, dark-colored, material at end of perpendicular calcite vein, black altered chunks of material; 2.5 to 5.0 cm stringers
- Very fine grained sulfide (probably pyrite), widely dispersed in section, no concentrations seen.

AP1-13-6

- Bedding same as above with small 2 millimeter bands
- Calcite veins: 2.5–7.5 cm wide
- Several small concentrations of pyrite seen on inside of core in this section; none very large (fine disseminated to 2 millimeter clots)
- Fe staining close to pyrite concentrations.

AP1-14-1

- Bedding is banded white/light gray band (quartz/calcite?) followed by dark gray/black band (quartz); bands ~same width; ~2.5 cm
- Bag of core chunks; not labeled as what core or part of core but similar banding
    - No veins readily apparent but has calcite deposits in chunks
    - Small orange-colored colored dots ~1 to 2 millimeters, seen throughout; (iron staining; oxidized sulfide)
- Calcite veins in core; four 1 to 2 millimeters wide and perpendicular to bedding
- Sulfides; fine-grained pyrite located in both calcite and quartz (dark and light gray); no concentrations
- Iron-oxides and staining; orange-colored staining visible in several spots; oxidized sulfides; calcite in piece; reddish-brown colored bands visible (oxidation or Fe staining); biggest is ~5 cm long.
- 3 concentrations of pyrite visible along inside of break in core; 1 cm wide.

AP1-14-7

- Bedding same as above; several circular reddish-brown patches visible
- 12 calcite veins;
    - 5 parallel veins
        - 3 overlap; 2 large veins parallel and 1 small running parallel to bottom large parallel
        - 1 medium; offset in areas; ~7.5 cm long
        - 1 large; branching off new large diagonal; ~2 to 8 cm long
    - 3 diagonal veins
        - 2 overlap- diagonal veins running parallel to one another 1 large and one small
- 1 new diagonal; branches off large bottom parallel vein overlap; runs through entire section and into next
    - 4 perpendicular veins
        - 2 continue form last section- large ending in V and small one branching off of top large parallel vein
        - 1 medium intersecting offset parallel vein; ~8 cm long
        - 1 small intersecting offset parallel vein ~1.5 cm inch above medium vein; continues to next section.
- Very fine-grained sulfides visible throughout.
- Many large areas of reddish-brown discoloration; iron staining and sulfide oxidation visible along edges of fracture.

Appendix 3. Sample selection data from the Great Bay National Wildlife Refuge Well Site National Refuge (NR2): Core segment descriptions

[ft, feet; cm, centimeter; mm, millimeter; ~, approximately; ?, probable; +, plus]

Segment number	Length, in feet[1]	Description
Surface to bedrock	19	Soil and tills, gray marine clay, with pebbles.
NR1-1	2.8	Green schist, foliated, bedding at 45 degree dip, calcite veins with quartz, iron staining throughout bedrock, iron-stained fractures on upper surface, steeper (75-degree dip) vein of calcite and quartz at end of segment, sulfur smell noted (zinc sulfate, ZnS?).
NR1-2	4.65	Green schist, quartz and calcite veins paralleling bedding, small pyrite cubes in rock, AB fracture is iron-stained, bottom fracture contains iron-staining, pyrite and quartz, lots of fine pyrite in fractures and along core walls .
NR1-3	4.7	Two parallel, high angle fractures, little iron-staining on top fracture, bottom fracture has pyrite and iron staining. Some fractures have calcite coatings, and folded quartz bedding planes.
NR1-4	5.1	Graphite in drill, sulfur smell in core, hard breaks in core, folded quartz veins, graphite + pyrite, and iron stains on some fracture surfaces, calcite on vein faces, pyrite + graphite (?), light or no iron-staining, pyrites rimmed with dark green mineral in bedrock.
NR1-5	5	Segments have 45-degree dip breaks, fractures are mostly bedding parallel with calcite, and some have graphite also. Near-bottom fractures with calcite and cubic pyrite crystals on top face.
NR1-6	3.65	Top break (40-degree dip parallel to bedding) has pyrite crystals, also light yellow-green and dark-green minerals. Quartz, calcite, and chlorite in fracture. Pyrite in core wall shows reaction rims around concentrated zones of medium to small disseminated crystals. Closed, but permeable fractures. Quartz lenses throughout core and soft, yellow-green mineral.
NR1-7	1.25	Cross-cutting quartz and calcite fractures, graphite in drill, sharp and irregular surface breaks, graphite + pyrite on surfaces, bottom fractures are calcite coated.
NR1-8	4.85	Bedding and foliation are unclear. Solution cavities (sub-mm) in quartz and calcite veins, several partially open fractures, variable dips on fractures.
NR1-9	5.1	Highly fractured and weathered zone (saprolite?). Pyrite and calcite on surfaces.
NR1-10	5	Two feet of bedrock, then continuation of fractured, weathered zone. Vuggy quartz.
NR1-11	4.8	No information.
NR1-12	4.6	Fractures. Small solution cavities in core wall. Fractures with slickenslides.
NR1-13	4.95	Break at top and bottom contain calcite and quartz, small solution vugs, medium solution vugs at bottom of segment with quartz lenses in bedrock.
NR1-14	5.1	Top break has pyrite on surface, slickenslides with calcite, Breccia zone between A-B, below, calcite slickenslides with pyrite, pyrite and graphite in fractures, quartz and calcite lenses.
NR1-15	5	Large quartz lenses, pyrite and graphite, top break has pyrite and green minerals, bottom break has slickensides with graphite coating. Large quartz lenses, breaks near bottom of segment.
NR1-16	4.7	Breaks in core length, wax plug trial conducted on December 2, 1999.
NR1-17	5.15	Top and bottom breaks, pyrite in bedding, calcite layering parallel to bedding; some breaks have pyrite+graphite, near vertical calcite veining, quartz throughout. Breaks continue throughout length of core. Gneissic grain texture with quartz grains at bottom of hole, possibly quartz diorite rock.

[1] Footage provided is length of core described by segment number. The total length of the core is 96.85 feet below casing and 94.85 feet below ground surface.

Notes describing selected NR1 samples:

NR1-1-1

- Plastic bags full of top soil; no rock to examine or describe
- NR1-0-2.3 ft-dark brown soil.

NR1-1-2

- Consists of 2 plastic bags of soil and core
  - 2.3 ft to 10 ft; light brown chunky soil; clay-like texture
  - 10 ft to 17 ft; light brown to light gray soil with sandy texture
- Bedding gray; almost uniform with light gray bands at infrequent intervals
- 4 calcite layers; 1 vein parallel to bedding and 3 more circular clots
- Pyrite; fine-grained; visible throughout section but no concentrations visible
- Minor staining (iron oxidation) visible along surface and major staining visible at fracture surface.

NR1-1-3

- Bedding gray almost uniform with light gray bands at infrequent intervals
- One calcite vein; large horseshoe shape vein near left edge of section continued into next section; narrow U-shaped calcite veins
- Pyrite visible throughout but no concentrations.
- Major staining along all 3 fracture zones (iron sulfide oxidation?); some areas of deep red colorations.

NR1-1-4

- Bedding same as above
- 4 calcite veins; 1 offset medium U-shaped vein; 3 small diagonal veins a left edge of section; each ~1 mm wide
- Fine-grained pyrite visible throughout section; most notably along the edge of core
- Minor staining (iron sulfide oxidation?) visible along surface and edge of core.

NR1-2-1

- Bedding parallel to width of core; bands of light gray (quartz?) followed by smaller, darker gray/black bands
- 5 major calcite veins; 2 horseshoe or U-shaped; 2 diagonal vein; 2 parallel veins; all appear to be 4 to 5 cm wide calcite veins
- Fine-grained sulfides (pyrite?) visible throughout section; no concentrations present
- Major staining (iron or sulfide oxidation?) especially along fracture surface; ~5 cm area with iron staining.

NR1-2-2

- Bedding; light-gray bands (quartz?) ~5-cm-wide followed by dark-gray bands (also quartz?) ~8 cm-wide; dark-gray band has patchy light gray areas but no banding
- Calcite veins all are curved parallel to bedding –1 large and the others are small –all appear to be calcite
  - Large calcite vein has fine-grained pyrite visible in and around edges
- Fine-grained pyrite visible throughout in light/dark gray quartz banding and in calcite veins; no concentrations visible
- Minor orange-red staining visible along core surface; major staining visible at fracture surfaces.

NR1-2-3 core

- Bedding; light-gray bands (quartz?) ~5-cm-wide followed by dark-gray bands (also quartz?) ~8 cm-wide; dark-gray band has patchy light gray areas but no banding
- Calcite vein are parallel to bedding; narrow and discontinuous
- Coarser-grained pyrite (1 to 2 mm cubes); no major concentrations visible; several small concentrations of pyrite visible
- No iron staining visible.

NR1-2-4

- Bedding same as above
- Calcite veins and clots
- Coarse-grained pyrite (2 to 3 mm cubes) visible throughout; several areas with small concentrations.
- Minor staining (Fe or oxidation?) along fracture surfaces.

NR1-15-1

- Bedding; major banding; light gray/tan bands followed by dark gray bands; bands at 10 degrees from horizontal and ~1.5 cm wide
- Three 3-cm-wide white veins (probably quartz) running parallel to bedding;
- Major deposits of calcite along fracture zones
- Reddish-brown band ~2.5 cm long, perpendicular to bedding in right center of section
- Pyrite visible throughout entire section
    - A couple of minor concentrations along surface of core visible
    - Pyrite, fine-grained, visible throughout section; no concentrations; pyrite visible, especially along fracture surfaces
- Minor staining in vicinity of small pyrite grains along fracture zone; almost no staining visible.

NR1-15-2 [note: missing at least a 10 cm section]

- Bedding; major banding; light gray/tan bands followed by dark gray bands; bands at 10 degrees from horizontal and ~1.5 cm wide
- Several small to medium concentrations of pyrite along section; mostly in and around large white band of quartz
- No iron staining visible.

NR1-15-3

- Bedding; ~8-cm-wide light gray bands (quartz?) followed by large white band (~5 cm thick quartz layer)
- Calcite; fizzes along fracture but not seen on surface
- Fine-grained pyrite visible throughout section; no concentrations or staining visible.

NR1-15-4

- Bedding; banding with large light gray bands followed by dark gray bands; bands horizontal
- 3 calcite veins; small; 1 perpendicular to bedding; 3 to 5 cm wide
- 3 white bands parallel to bedding; quartz
- Fine-grained pyrite visible especially along fracture and within dark gray bands
- Minor staining along fracture (iron or sulfide oxidation?).

NR1-15-5

- Bedding same as above except for light gray band to dark gray banding
- 3 calcite veins running parallel; small discontinuous stringers of carbonate material
- Pyrite visible
- No iron staining visible.

NR1-15-6 core

- Bedding same as above
- 2 small dark gray veins cutting diagonally through section—
    - Concentrations of pyrite in and around these dark gray bands
    - Small concentrations of pyrite throughout section.

NR1-16-1

- Bedding; banding consists of cm-wide light gray bands followed by thinner dark gray band; band is horizontal
    - 3 calcite veins; small; 1 perpendicular to bedding; 3 to 5 cm wide
    - 3 white bands parallel to bedding; quartz
- Pyrite, fine-grained, visible throughout entire section; several areas of small pyrite concentrations visible; mainly in and around the calcite veins.
    - No iron staining visible.

NR1-16-2

- Bedding; banding consists of cm-wide light gray bands followed by thinner dark gray band; band is horizontal
    - 3 calcite veins; small; 1 perpendicular to bedding; 3 to 5 cm wide
    - 3 white bands parallel to bedding; quartz
- Pyrite, fine-grained, visible throughout entire section; no areas of pyrite concentrations visible
- No iron staining visible.

NR1-16-3

- Bedding; banding consists of cm-wide light gray bands followed by thinner dark gray band; band is horizontal
    - 3 calcite veins; small; 1 perpendicular to bedding; 3 to 5 cm wide
    - 3 white bands parallel to bedding; quartz
- Pyrite visible throughout; no concentrations or staining; more sulfides (pyrite) along fracture zone.

NR1-16-4

- Bedding; banding consists of cm-wide light gray bands followed by thinner dark gray band; band is horizontal
  - 4 calcite veins; small; 1 perpendicular to bedding; 3 to 5 cm wide
  - 3 white bands parallel to bedding; quartz
- Small pyrite concentrations visible in and around calcite veins.

NR1-16-5

- Bedding; banding consists of cm-wide light gray bands followed by thinner dark gray band; band is horizontal
  - 7 calcite veins; 1 large bed-parallel vein runs entire width of core; 1 perpendicular to bedding; 3 to 5 cm wide
  - 3 white bands parallel to bedding; quartz
- Several small pyrite concentrations.

NR1-16-6

- Bedding same as above
- 3 calcite veins; each ~2 cm wide
- Small pyrite concentrations visible mainly along fracture zones.

NR1-17-1

- Bedding; mostly uniform gray; light gray; horizontal with respect to vertical core orientation
  - 3 small bed-parallel dark-gray/black veins; each ~5 cm long and each have sulfides (pyrite?) in and around them
- 5 calcite veins and 1 small deposit
  - Calcite clots; oval shaped in right edge center of core
  - 4 parallel veins; 1 to 3 cm in width
  - 2 perpendicular –4 to 10 cm in width
- Several small sulfide concentrations visible throughout section; most in or around black sulfide-bearing veins
- Minor staining (iron or sulfide oxidation?) visible on surface; 3 very small patchy areas
- Fine-grained pyrite visible throughout section; few visible concentrations.

NR1-17-3

- Sample crushed and in plastic bag
  - Bedding, sulfides and staining appear to be the same as NR1-17-1
  - Calcite veins not possible to determine with sample available.

NR1-17-4

- Sample crushed and in plastic bag
  - Bedding, sulfides and staining appear to be the same as NR1-17-1
  - Calcite veins not possible to determine with sample available
- Fine-grained pyrite visible throughout section; few visible concentrations.

NR1-17-5

- Bedding same as NR1-17-1
- Small network of calcite veins in center of section
- Fine-grained pyrite visible throughout section; few visible concentrations
- Minor staining (iron sulfide oxidation?).

NR1-17-6

- Bedding; mostly uniform gray; light gray; horizontal with respect to vertical core orientation
- 6 large perpendicular calcite veins cutting across section; each ~5 cm wide
- 2 parallel veins; each small; 1 goes entire width of section; ~5 cm wide
- Fine-grained pyrite visible throughout section; visible small concentrations of pyrite; 2 to 3 cm wide
- No staining visible.

NR1-17-8B

- Bedding; mostly uniform gray; light gray; horizontal with respect to vertical core orientation
- 10 large perpendicular calcite veins cutting across section; each ~1 to 5 cm wide
- 2 parallel veins; each small; 1 goes entire width of section; ~5 cm wide
- Fine-grained pyrite visible throughout section; no concentrations of sulfides
- Major staining (iron-sulfide oxidation?) visible.

NR1-17-9A

- Bedding; mostly uniform gray; light gray; horizontal with respect to vertical core orientation
- 5 perpendicular calcite veins cutting across section; each ~1 to 3 cm wide
- 2 parallel veins; each small; 1 goes entire width of section; ~5 cm wide
- Fine-grained pyrite visible throughout section; no concentrations of sulfides
- No iron staining visible

NR1-17-9A1

- Plastic bag of sample
- Bedding; mostly uniform gray; light gray; horizontal with respect to vertical core orientation
- 6 large perpendicular calcite veins cutting across section; each ~5 cm wide
- 2 parallel veins; each small; 1 goes entire width of section; ~5 cm wide
- Fine-grained pyrite visible throughout section; visible small concentrations of pyrite; 2 to 3 cm wide
- No staining visible.

Appendix 4. Ground water chemistry data from boreholes AP1 and NR1, Great Bay National Wildlife Refuge (U.S. Geological Survey Water Resources Data, 2005)

[AP1, Adams Point borehole; NR1, National Refuge borehole; flt, filtered; unflt, unfiltered; pH scale, a reverse logarithmic representation of relative hydrogen proton concentration; T, temperature; ºC, degrees Centigrade; NTU, nephalometric turbitity units; S.C., specific conductance; µS/cm, microsiemens per centimeter; mg/L, milligram per liter; µg/L, micrograms per liter; E, estimated value; ft, feet; %, percent; <, less than; ~, approximately; As^T, total arsenic; As^3, trivalent arsenic; As^5, pentavalent arsenic; sax, sample passed through a syringe packed with 500 milligrams of a strong anion exchanger]

A. Site information, anions, major elements

Data type	Type of analysis	Unit	NR1	NR1	NR1	NR1	NR1	AP1	AP1
Sampling date			1/10/00	7/26/00	7/26/00	7/26/00	7/27/00	2/16/00	8/1/00
T (water)	field	ºC	9.7	12.8	13.0	17.5	10.8	9.4	13.2
T (air)	field	ºC		22.0	22.0	22.0	22.0		20.0
Turbidity	field	NTU		50	73	74	60		4.1
S.C. (at 25ºC)	unflt	µS/cm	290	336	256	290	274		574
S.C. (at 25ºC)	unflt, lab	µS/cm		348	276	300	284		612
Alkalinity (as $CaCO_3$)	flt, field	mg/L		142	E 97	111	99		148
D.O.	field	mg/L	2.5	.2	.4	2.5	.2	3.0	.2
pH	unflt, field	units	8.4	9.0	7.6	7.7	7.5	9.2	7.7
pH	unflt, lab	units		8.8	7.4	7.7	7.5		7.4
Carbonate	flt, field	mg/L		15	0	0	0		0
Bicarbonate	flt, field	mg/L		143	118	136	121		181
NO_3 (as N)	flt	mg/L		< .010	< .010	.016	< .010		< .010
PO_4 (as P)	flt	mg/L		.034	< .006	< .006	.007		< .006
Mg	flt	mg/L		1.92	6.10	6.24	6.43		8.86
Na	flt	mg/L		64.3	7.82	18.8	10.3		44.5
K	flt	mg/L		2.11	1.66	2.42	1.94		5.05
Cl	flt	mg/L		4.69	3.66	3.72	3.66		87.0
SO4	flt	mg/L		25.6	31.9	31.0	32.3		27.2
Si	flt	mg/L		11.3	9.42	9.83	10.0		12.0
Al	flt	µg/L		7	24	2	2		6
Ca	flt	mg/L		8.68	34.4	30.0	33.8		55.6
Fe	unflt	µg/L	5600					1500	
Fe	flt	µg/L		< 10	136	22	123		109
Fe-(II)	unflt	µg/L		.0	M	M	M		M
Mn	unflt	µg/L	227					36.2	
Mn	flt	µg/L		12.1	109	114	96.1		47.8

Appendix 4. Ground water chemistry data from boreholes AP1 and NR1, Great Bay National Wildlife Refuge. —Continued

[AP1, Adams Point borehole; NR1, National Refuge borehole; flt, filtered; unflt, unfiltered; pH scale, a reverse logarithmic representation of relative hydrogen proton concentration; T, temperature; ºC, degrees Centigrade; NTU, nephalometric turbitity units; S.C., specific conductance; µS/cm, microsiemens per centimeter; mg/L, milligram per liter; µg/L, micrograms per liter; E, estimated value; ft, feet; %, percent; <, less than; ~, approximately; As^T, total arsenic; As^3, trivalent arsenic; As^5, pentavalent arsenic; sax, sample passed through a syringe packed with 500 milligrams of a strong anion exchanger]

B. Trace elements

Data type	Type of analysis	Units	NR1	NR1	NR1	NR1	NR1	AP1	AP1
Sampling date			1/10/00	7/26/00	7/26/00	7/26/00	7/27/00	2/16/00	8/1/00
As	flt	µg/L		6.1	< .9	E .7	E .9		5.2
As	unflt	µg/L	14					4	
Ba	flt	µg/L		20	12	37	21		17
B	flt	µg/L		36	22	24	23		30
Mo	flt	µg/L		3.1	11.2	9.7	11.4		18.1
Zn	flt	µg/L		12	311	214	363		238
Li	flt	µg/L		3.5	6.5	4.6	4.6		5.2
U	flt	µg/L		1.02	< 1.00	< 1.00	< 1.00		1.53

C. Arsenic speciation in water samples as a function of depth

Data type	Analysis/ Unit	NR1	NR1	NR1	NR1	AP1
Depth	ft	20–23	53–63.5	82–95	20–82	66.5–72
Transmissivity	%	0	0	~ 28	100	100
As^T	flt	0.25	0.51	5.19	0.58	3.88
As^3	flt	0.25	0.51	1.74	0.58	2.97
As^5	flt	-0.2	-0.2	3.45	-0.2	0.91
As^3	sax	0.25	0.69	7.25	0.59	2.89
As^5	sax	0.05	0.09	1	0.09	0.45
As^T	sax	0.3	0.78	8.25	0.68	3.34

Appendix 5. Bedrock geochemistry data from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; -, upper limit of detection; ppm, parts per million; ppb, parts per billion; <, less than; ~, approximately]

A. Major element data

Data type	Unit	AP1-13-3A	AP1-13-4A	AP1-13-6 A-C	AP1-14-4	AP1-14-6	NR1-1-1A	NR1-1-2
SiO_2	Percent	65.07	66.25	61.96	67.10	67.22	62.27	63.15
Al_2O_3	Percent	14.37	13.89	14.36	9.92	8.75	11.90	12.78
Fe_2O_3	Percent	5.70	5.54	5.78	3.66	3.16	4.75	5.26
FeO	Percent			4.51	3.07	2.73	3.62	3.94
MnO	Percent	0.058	0.057	0.069	0.074	0.082	0.081	0.058
MgO	Percent	3.95	3.82	3.88	2.55	2.18	3.41	3.66
CaO	Percent	2.34	2.43	3.79	6.33	7.82	5.94	4.31
Na_2O	Percent	2.13	1.95	2.17	2.04	2.15	1.71	1.71
K_2O	Percent	3.48	3.41	2.98	1.55	1.01	2.03	2.33
TiO_2	Percent	0.708	0.677	0.716	0.585	0.571	0.624	0.656
P_2O_5	Percent	0.14	0.14	0.14	0.14	0.14	0.14	0.14
LOI	Percent	2.46	2.24	4.48	6.26	7.38	7.36	6.21
TOTAL	Percent	100.410	100.400	100.320	100.210	100.440	100.210	100.270
H_2O-	Percent			0.016	0.134	0.143	0.060	0.168
H_2O+	Percent			1.954	1.451	1.363	2.116	2.385
Fe	Percent	4.10	3.77					
Na	Percent	1.47	1.32					
F	Percent			0.066	0.032	0.028	0.059	0.072
Cl	Percent			-0.010	0.020	0.010	0.010	0.010
C	Percent			0.71	1.36	1.71	1.39	0.99
C org	Percent			0.07	0.05	0.05	0.06	0.05
CO_2	Percent			2.35	4.80	6.10	4.90	3.45
SO_4	Percent			0.06	-0.05	0.06	-0.05	-0.05
S	Percent			0.17	0.08	0.06	0.15	0.21

Appendix 5. Bedrock geochemistry data from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; -, upper limit of detection; ppm, parts per million; ppb, parts per billion; <, less than; ~, approximately]

A. Major element data—Continued								
Data type	**Unit**	**NR1-15-3**	**NR1-15-2**	**NR1-16-4**	**NR1-17-4A**	**NR1-17-4**	**NR1-17-5C**	**NR1-17-6A**
SiO_2	Percent	61.99	67.48	67.28	59.85	59.47	69.89	62.70
Al_2O_3	Percent	12.60	10.29	11.29	13.97	13.95	10.89	10.83
Fe_2O_3	Percent	4.74	3.58	3.95	5.88	6.08	3.58	3.68
FeO	Percent						2.27	
MnO	Percent	0.067	0.098	0.061	0.080	0.080	0.064	0.098
MgO	Percent	3.40	2.59	3.10	4.56	4.56	2.98	4.01
CaO	Percent	3.62	3.52	3.14	3.32	3.31	3.20	5.70
Na_2O	Percent	1.03	2.31	1.00	1.00	1.01	0.61	1.59
K_2O	Percent	3.56	2.37	2.95	3.55	3.50	2.82	2.23
TiO_2	Percent	0.599	0.657	0.766	0.674	0.677	0.700	0.677
P_2O_5	Percent	0.08	0.16	0.18	0.12	0.12	0.17	0.16
LOI	Percent	8.40	7.39	5.40	6.65	6.75	5.39	7.610
TOTAL	Percent	100.10	100.44	99.11	99.65	99.52	100.30	99.30
H_2O-	Percent						0.187	
H_2O+	Percent						1.934	
Fe	Percent	3.62	2.88	2.84	4.65	4.73		3.19
Na	Percent	0.71	1.52	0.64	0.66	0.68		1.08
F	Percent						0.128	
Cl	Percent						-0.01	
C	Percent						0.72	
C org	Percent						0.10	
CO_2	Percent						2.25	
SO_4	Percent						-0.05	
S	Percent						0.92	

Appendix 5. Bedrock geochemistry data from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; -, upper limit of detection; ppm, parts per million; ppb, parts per billion; <, less than; ~, approximately]

B. Trace element chemistry								
Data type	Unit	AP1-14-6	NR1-17-5C	AP1-13-6 A-C	AP1-14-4	NR1-1-2	NR1-1-1A	NR1-16-4
Ba	ppm	149	360	507	253	383	340	
Sr	ppm	221	61	174	196	121	147	
Y	ppm	27	34	27	27	27	27	
Sc	ppm	9	12	16	10	13	13	11
Zr	ppm	299	354	171	262	194	193	
Be	ppm	1	2	2	1	2	2	
V	ppm	47	72	98	61	78	74	
V	ppm	52.92	69.07	99.69	64.29	86.94	77.16	70.37
Cr	ppm	75.18	51.69	77.88	67.99	51.70	49.91	296.00
Co	ppm	6.94	6.28	18.99	9.70	15.86	12.66	13.00
Ni	ppm	46.68	42.92	93.18	58.74	81.89	73.23	-20.00
Cu	ppm	14.20	16.01	26.88	16.65	23.19	23.11	-10.00
Zn	ppm	36.81	113.21	77.05	52.49	77.69	72.53	186.13
Ga	ppm	10.57	12.93	18.62	12.52	16.59	15.29	13.42
Ge	ppm	1.35	1.81	1.84	1.45	1.79	1.83	1.21
As	ppm	15.87	-5.00	38.84	25.40	-5.00	-5.00	3.00
Rb	ppm	42.77	166.21	111.11	59.35	96.46	85.74	163.00
Sr	ppm	228.50	62.38	169.48	206.51	127.04	153.57	69.74
Y	ppm	27.00	32.75	25.65	28.30	28.61	27.77	33.57
Zr	ppm	313.50	349.28	167.21	275.28	194.22	195.46	436.84
Nb	ppm	11.36	12.53	13.05	11.01	12.86	11.75	13.41
Mo	ppm	-2	-2	-2	-2	-2	2	-2
Ag	ppm	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
In	ppm	-0.1	-0.1	-0.1	-0.10	-0.1	-0.1	-0.1
Sn	ppm	1.30	1.63	2.19	17.41	3.47	2.63	3.22
Sb	ppm	0.64	3.59	0.66	0.66	2.12	2.17	7.20

Appendix 5. Bedrock geochemistry data from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; -, upper limit of detection; ppm, parts per million; ppb, parts per billion; <, less than; ~, approximately]

B. Trace element chemistry—Continued								
Data type	Units	AP1-14-6	NR1-17-5C	AP1-13-6 A-C	AP1-14-4	NR1-1-2	NR1-1-1A	NR1-16-4
Cs	ppm	2.11	7.95	4.16	1.82	3.64	3.35	6.75
Ba	ppm	155.79	355.10	490.97	263.07	389.94	348.92	373.30
Hf	ppm	8.03	9.59	4.67	7.11	5.24	5.21	10.04
Ta	ppm	0.81	0.97	0.95	0.82	1.44	0.87	0.96
W	ppm	0.88	5.50	1.08	0.91	1.10	0.99	7.29
Tl	ppm	0.22	1.79	0.72	0.31	0.60	0.58	1.62
Pb	ppm	-5.00	7.68	7.90	5.52	11.11	12.47	13.12
Bi	ppm	-0.10	0.26	-0.10	-0.10	-0.10	-0.10	2.66
Th	ppm	8.00	10.68	9.43	8.72	9.06	8.70	14.35
U	ppm	2.28	2.86	2.74	2.78	2.53	2.54	3.12
Ge	ppm	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	0.11
Se	ppm	0.65	0.88	0.55	0.71	0.42	0.46	0.52
Te	ppm	-0.10	0.25	-0.10	-0.10	0.11	-0.10	0.54
Bi	ppm	-0.10	0.64	0.13	-0.10	0.14	0.10	7.30
Au	ppb	1	3	1	1	1	1	1.6
Ag	ppm	0.26	0.25	-0.20	0.29	-0.20	-0.20	-0.20
Hg	ppb	-5	-5	-5	-5	-5	-5	-5
Ba	ppm	155.79	355.10	490.97	263.07	389.94	348.92	373.30
Hf	ppm	8.03	9.59	4.67	7.11	5.24	5.21	10.04
Ta	ppm	0.81	0.97	0.95	0.82	1.44	0.87	0.96
W	ppm	0.88	5.50	1.08	0.91	1.10	0.99	7.29
Tl	ppm	0.22	1.79	0.72	0.31	0.60	0.58	1.62
Pb	ppm	-5.00	7.68	7.90	5.52	11.11	12.47	13.12
Bi	ppm	-0.10	0.26	-0.10	-0.10	-0.10	-0.10	2.66
Th	ppm	8.00	10.68	9.43	8.72	9.06	8.70	14.35
U	ppm	2.28	2.86	2.74	2.78	2.53	2.54	3.12

Appendix 5. Bedrock geochemistry data from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; -, upper limit of detection; ppm, parts per million; ppb, parts per billion; <, less than; ~, approximately]

B. Trace element chemistry—Continued

Sample ID	Units	AP1-13-3A	NR1-17-6A	NR1-15-3	NR1-15-2	AP1-13-4A	NR1-17-4A	NR1-17-4A Dup
Sc	ppm	14.0	12.2	13.5	9.3	12.8	14.2	14.2
V	ppm	99.26	84.07	89.97	64.55	91.54	89.64	92.76
Cr	ppm	227	326	138	219	151	140	141
Co	ppm	20	13	18	12	19	19	19
Ni	ppm	68.86	-20.00	-20.00	-20.00	56.22	39.46	53.26
Cu	ppm	26.35	55.17	-10.00	39.28	26.20	55.63	85.64
Zn	ppm	84.65	152.73	53.44	399.40	69.07	180.42	141.71
Ga	ppm	19.47	14.27	16.56	12.83	18.19	19.44	19.71
Ge	ppm	1.39	1.61	1.12	1.50	1.28	1.38	1.13
As	ppm	28.0	2.8	9.2	6.3	24.9	2.5	3.1
Rb	ppm	141.58	131.55	180.57	157.52	134.25	218.87	214.47
Sr	ppm	180.32	193.59	92.15	91.31	178.21	75.61	76.53
Y	ppm	26.72	29.10	23.14	30.00	25.77	27.03	27.47
Zr	ppm	216.62	352.79	152.31	451.56	190.80	160.19	165.50
Nb	ppm	13.98	11.70	11.32	12.15	13.04	13.23	13.64
Mo	ppm	-2	-2	-2	-2	-2	-2	-2
Ag	ppm	-0.50	0.94	-0.50	4.56	-0.50	-0.50	-0.50
In	ppm	-0.10	0.91	-0.10	0.67	-0.10	-0.10	-0.10
Sn	ppm	2.02	4.28	1.14	4.97	1.63	1.70	1.41
Sb	ppm	0.80	11.50	15.60	50.40	0.80	6.90	7.00

Appendix 5. Bedrock geochemistry data from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; -, upper limit of detection; ppm, parts per million; ppb, parts per billion; <, less than; ~, approximately]

B. Trace element chemistry—Continued								
Sample ID	**Units**	**AP1-13-3A**	**NR1-17-6A**	**NR1-15-3**	**NR1-15-2**	**AP1-13-4A**	**NR1-17-4A**	**NR1-17-4A Dup**
Cs	ppm	5.96	5.46	6.97	8.86	5.57	8.95	8.78
Ba	ppm	556.79	182.52	429.14	263.57	532.58	518.97	529.29
Hf	ppm	4.82	8.09	3.73	10.12	4.69	4.28	4.45
Ta	ppm	0.92	0.82	0.78	0.86	0.92	0.92	0.96
W	ppm	0.90	11.16	7.96	84.77	1.71	5.31	5.36
Tl	ppm	1.05	1.52	0.63	1.54	0.89	2.00	1.80
Pb	ppm	7.45	218.28	-5.00	394.25	8.71	-5.00	-5.00
Bi	ppm	-0.10	4.78	0.13	20.59	0.36	0.29	0.20
Th	ppm	11.98	11.27	10.63	12.47	11.80	10.48	10.88
U	ppm	2.78	2.82	2.75	2.95	2.75	2.80	2.93
Ge	ppm	0.23	0.16	0.12	0.10	0.20	0.14	0.20
Se	ppm	0.41	1.48	0.67	1.15	0.33	0.97	0.91
Se	ppm	-3	-3	-3	-3	-3	-3	-3
Te	ppm	-0.10	0.89	0.46	1.83	-0.10	0.36	0.33
Bi	ppm	0.28	13.09	2.70	57.03	0.68	1.13	1.11
Au	ppb	2	4	5	28	-2	-2	-2
Au	ppb	0.70	0.90	8.80	18.80	0.80	3.30	
Ag	ppm	-0.20	4.03	0.27	10.45	-0.20	-0.20	-0.20
Hg	ppb	-5.00	-5.00	-5.00	14.75	-5.00	-5.00	-5.00
Hg	ppm	-1	-1	-1	-1	-1	-1	-1
Ir	ppb	-5	-5	-5	-5	-5	-5	-5
Br	ppm	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5

Appendix 5. Bedrock geochemistry data from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; -, upper limit of detection; ppm, parts per million; <, less than; ~, approximately]

C. Rare element chemistry								
Data type	**Unit**	**AP1-14-6**	**NR1-17-5 C**	**AP1-13-6 A-C**	**AP1-14-4**	**NR1-1-2**	**NR1-1-1 A**	**NR1-16-4**
La	ppm	30.920	39.681	35.328	31.379	32.003	32.115	48.873
Ce	ppm	61.016	78.671	67.010	61.223	61.304	61.922	102.044
Pr	ppm	7.467	9.538	8.027	7.481	7.254	7.510	11.142
Nd	ppm	27.891	35.647	29.714	28.865	27.799	28.044	39.165
Sm	ppm	5.378	6.907	5.707	5.436	5.393	5.483	7.353
Eu	ppm	1.196	1.525	1.282	1.210	1.267	1.266	1.582
Gd	ppm	4.999	6.248	5.207	5.125	5.183	5.033	5.760
Tb	ppm	0.809	1.020	0.802	0.837	0.867	0.829	0.965
Dy	ppm	4.627	5.943	4.776	4.878	4.912	4.742	5.388
Ho	ppm	0.910	1.154	0.933	0.962	0.962	0.933	1.098
Er	ppm	2.597	3.337	2.659	2.756	2.788	2.646	3.092
Tm	ppm	0.402	0.528	0.413	0.439	0.438	0.417	0.481
Yb	ppm	2.679	3.210	2.648	2.667	2.712	2.568	3.119
Lu	ppm	0.391	0.480	0.384	0.395	0.393	0.383	0.462

Appendix 5. Bedrock geochemistry data from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; -, upper limit of detection; ppm, parts per million; <, less than; ~, approximately]

C. Rare element chemistry—Continued								
Data type	**Unit**	**AP1-13-3A**	**NR1-17-6A**	**NR1-15-3**	**NR1-15-2**	**AP1-13-4A**	**NR1-17-4A**	**NR1-17-4A Dup**
La	ppm	41.127	43.219	38.176	43.017	40.937	32.524	33.446
Ce	ppm	85.996	88.282	78.737	92.383	85.684	68.795	69.894
Pr	ppm	9.386	9.554	8.565	10.004	9.203	7.670	7.786
Nd	ppm	32.073	34.138	29.913	35.252	32.261	28.438	29.121
Sm	ppm	5.959	6.390	5.499	6.599	6.176	5.404	5.620
Eu	ppm	1.310	1.433	1.185	1.383	1.283	1.338	1.400
Gd	ppm	4.657	5.167	4.318	5.259	4.684	4.727	4.813
Tb	ppm	0.764	0.848	0.677	0.871	0.758	0.795	0.816
Dy	ppm	4.196	4.741	3.850	4.839	4.266	4.494	4.596
Ho	ppm	0.851	0.941	0.778	0.965	0.850	0.884	0.912
Er	ppm	2.367	2.613	2.234	2.864	2.445	2.481	2.539
Tm	ppm	0.366	0.390	0.329	0.427	0.355	0.391	0.384
Yb	ppm	2.373	2.546	2.113	2.720	2.307	2.476	2.493
Lu	ppm	0.344	0.388	0.309	0.419	0.346	0.357	0.365

Appendix 6. Electron microprobe analytical data for pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR1175Cb	Pyrite	0.093	0.085	0.009	0.000	0.000	0.012	0.001
NR1153mpy	Pyrite	0.079	0.010	0.009	0.000	0.000	0.023	0.001
NR1175Cb	Pyrite	0.136	0.178	0.018	0.015	0.000	0.024	0.001
NR1175Cb	Pyrite	0.132	0.056	0.009	0.000	0.000	0.024	0.009
NR1175Cb	Pyrite	0.200	0.229	0.009	0.000	0.000	0.024	0.001
NR1175Cb	Pyrite	0.317	0.173	0.011	0.000	0.000	0.022	0.001
NR1175Cb	Pyrite	0.167	0.164	0.009	0.000	0.000	0.021	0.001
NR1175Cb	Pyrite	0.131	0.118	0.009	0.000	0.000	0.021	0.001
NR1175Cb	Pyrite	0.110	0.061	0.019	0.000	0.000	0.021	0.001
NR1175Cb	Pyrite	0.087	0.112	0.009	0.000	0.000	0.021	0.001
NR1175Cb	Pyrite	0.089	0.137	0.009	0.000	0.000	0.020	0.001
NR1175Cb	Pyrite	0.079	0.136	0.009	0.000	0.000	0.020	0.001
NR1175Cb	Pyrite	0.094	0.148	0.014	0.000	0.000	0.020	0.001
NR1175Cb	Pyrite	0.065	0.010	0.014	0.000	0.000	0.020	0.007
NR1175Cb	Pyrite	0.099	0.036	0.009	0.000	0.000	0.019	0.001
NR1175Cb	Pyrite	0.093	0.035	0.010	0.000	0.000	0.019	0.001
NR1175Cb	Pyrite	0.088	0.010	0.009	0.000	0.000	0.019	0.004
NR1175Cb	Pyrite	0.144	0.162	0.011	0.000	0.000	0.019	0.001
NR1175Cb	Pyrite	0.168	0.138	0.021	0.000	0.000	0.013	0.007
NR1175Cb	Pyrite	0.070	0.017	0.009	0.000	0.000	0.012	0.001
NR1175Cb	Pyrite	0.104	0.079	0.011	0.000	0.000	0.012	0.001
NR1175Cb	Pyrite	0.082	0.061	0.013	0.000	0.000	0.012	0.001
NR1175Cb	Pyrite	0.095	0.032	0.011	0.000	0.000	0.012	0.001
NR1175Cb	Pyrite	0.100	0.040	0.009	0.000	0.000	0.012	0.001
NR1175Cb	Pyrite	0.115	0.012	0.009	0.000	0.000	0.012	0.008
NR1175Cb	Pyrite	0.114	0.081	0.009	0.000	0.000	0.012	0.001
NR1175Cb	Pyrite	0.133	0.134	0.012	0.000	0.000	0.012	0.001
NR1175Cb	Pyrite	0.097	0.045	0.009	0.000	0.000	0.011	0.003
NR1175Cb	Pyrite	0.082	0.010	0.010	0.000	0.000	0.011	0.001

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR1175Cb	Pyrite	0.103	0.014	0.016	0.000	0.000	0.011	0.001
NR1175Cb	Pyrite	0.118	0.061	0.017	0.000	0.000	0.011	0.001
NR1175Cb	Pyrite	0.091	0.040	0.012	0.000	0.000	0.010	0.005
NR1175Cb	Pyrite	0.135	0.090	0.027	0.000	0.000	0.010	0.001
NR1175Cb	Pyrite	0.089	0.022	0.015	0.000	0.000	0.010	0.001
NR1175Cb	Pyrite	0.094	0.025	0.015	0.000	0.000	0.010	0.001
NR1175Cb	Pyrite	0.090	0.040	0.028	0.000	0.000	0.010	0.001
NR1175Cb	Pyrite	0.089	0.010	0.029	0.000	0.000	0.010	0.001
NR1175Cb	Pyrite	0.075	0.030	0.010	0.000	0.000	0.009	0.007
NR1175Cb	Pyrite	0.105	0.023	0.022	0.000	0.000	0.009	0.001
NR1175Cb	Pyrite	0.105	0.134	0.019	0.000	0.000	0.009	0.001
NR1175Cb	Pyrite	0.078	0.010	0.024	0.000	0.000	0.009	0.001
NR1175Cb	Pyrite	0.154	0.061	0.009	0.000	0.000	0.009	0.001
NR1175Cb	Pyrite	0.078	0.019	0.009	0.000	0.000	0.009	0.001
NR1175Cb	Pyrite	0.079	0.039	0.009	0.000	0.000	0.008	0.001
NR1175Cb	Pyrite	0.088	0.052	0.009	0.000	0.000	0.008	0.001
NR1175Cb	Pyrite	0.093	0.071	0.009	0.000	0.000	0.008	0.006
NR1175Cb	Pyrite	0.086	0.028	0.022	0.000	0.000	0.008	0.001
NR1175Cb	Pyrite	0.090	0.056	0.009	0.000	0.000	0.008	0.001
NR1175Cb	Pyrite	0.077	0.013	0.009	0.000	0.000	0.008	0.001
NR1175Cb	Pyrite	0.082	0.054	0.018	0.000	0.000	0.008	0.018
NR1175Cb	Pyrite	0.257	0.131	0.009	0.000	0.000	0.007	0.005
NR1175Cb	Pyrite	0.083	0.012	0.009	0.000	0.000	0.007	0.001
NR1175Cb	Pyrite	0.302	0.140	0.009	0.000	0.000	0.007	0.010
NR1175Cb	Pyrite	0.079	0.023	0.009	0.000	0.000	0.007	0.006
NR1175Cb	Pyrite	0.081	0.022	0.031	0.000	0.000	0.007	0.001
NR1175Cb	Pyrite	0.074	0.079	0.009	0.000	0.000	0.007	0.001
NR1175Cb	Pyrite	0.178	0.103	0.009	0.000	0.000	0.007	0.001
NR1175Cb	Pyrite	0.230	0.155	0.009	0.000	0.000	0.007	0.009
NR1175Cb	Pyrite	0.136	0.056	0.022	0.000	0.000	0.007	0.001
NR1175Ca	Pyrite	0.174	0.112	0.068	0.000	0.000	0.648	0.002
NR1175Ca	Pyrite	0.160	0.076	0.011	0.000	0.000	0.234	0.001

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR1175Ca	Pyrite	0.117	0.090	0.035	0.000	0.000	0.211	0.001
NR1175Ca	Pyrite	0.128	0.054	0.044	0.000	0.000	0.176	0.001
NR1175Ca	Pyrite	0.106	0.092	0.010	0.000	0.000	0.130	0.001
NR1175Ca	Pyrite	0.117	0.209	0.104	0.000	0.000	0.058	0.012
NR1175Ca	Pyrite	0.045	0.210	0.198	0.000	0.000	0.055	0.011
NR1175Ca	Pyrite	0.102	0.255	0.091	0.000	0.000	0.050	0.010
NR1175Ca	Pyrite	0.113	0.160	0.017	0.000	0.000	0.047	0.002
NR1175Ca	Pyrite	0.084	0.072	0.009	0.000	0.000	0.043	0.014
NR1175Ca	Pyrite	0.084	0.031	0.014	0.000	0.000	0.039	0.001
NR1175Ca	Pyrite	0.387	0.332	0.009	0.000	0.000	0.037	0.001
NR1175Ca	Pyrite	0.090	0.043	0.015	0.000	0.000	0.033	0.004
NR1175Ca	Pyrite	0.077	0.010	0.023	0.000	0.000	0.033	0.001
NR1175Ca	Pyrite	0.092	0.070	0.016	0.000	0.000	0.032	0.001
NR1175Ca	Pyrite	0.191	0.317	0.013	0.000	0.000	0.032	0.001
NR1175Ca	Pyrite	0.081	0.032	0.011	0.000	0.000	0.031	0.009
NR1175Ca	Pyrite	0.111	0.185	0.015	0.000	0.000	0.031	0.007
NR1175Ca	Pyrite	0.088	0.010	0.013	0.000	0.000	0.030	0.001
NR1175Ca	Pyrite	0.097	0.088	0.030	0.000	0.000	0.030	0.001
NR1175Ca	Pyrite	0.098	0.052	0.018	0.000	0.000	0.030	0.001
NR1175Ca	Pyrite	0.116	0.144	0.009	0.000	0.000	0.029	0.001
NR1175Ca	Pyrite	0.228	0.157	0.014	0.000	0.000	0.029	0.001
NR1175Ca	Pyrite	0.143	0.018	0.009	0.000	0.000	0.028	0.001
NR1175Ca	Pyrite	0.104	0.018	0.000	0.000	0.000	0.021	0.000
NR1175Ca	Pyrite	0.106	0.158	0.093	0.000	0.000	0.021	0.004
NR1175Ca	Pyrite	0.119	0.055	0.049	0.000	0.000	0.015	0.003
NR1175Ca	Pyrite	0.083	0.013	0.000	0.000	0.000	0.014	0.005
NR1175Ca	Pyrite	0.084	0.000	0.000	0.000	0.000	0.010	0.016
NR1175Ca	Pyrite	0.147	0.154	0.002	0.000	0.000	0.008	0.006
NR1175Ca	Pyrite	0.081	0.010	0.011	0.000	0.000	0.007	0.001
NR1175Ca	Pyrite	0.078	0.010	0.009	0.000	0.000	0.007	0.001
NR1175Ca	Pyrite	0.142	0.105	0.013	0.000	0.000	0.007	0.001
NR1175Ca	Pyrite	0.095	0.096	0.020	0.000	0.000	0.007	0.001

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR1175Ca	Pyrite	0.082	0.010	0.009	0.000	0.000	0.006	0.001
NR1175Ca	Pyrite	0.083	0.030	0.020	0.000	0.000	0.006	0.008
NR1175Ca	Pyrite	0.335	0.206	0.019	0.000	0.000	0.006	0.001
NR1175Ca	Pyrite	0.084	0.021	0.014	0.000	0.000	0.006	0.001
NR1175Ca	Pyrite	0.086	0.040	0.009	0.000	0.000	0.006	0.001
NR1175Ca	Pyrite	0.089	0.121	0.009	0.000	0.000	0.006	0.002
NR1175Ca	Pyrite	0.124	0.025	0.010	0.000	0.000	0.006	0.009
NR1175Ca	Pyrite	0.079	0.048	0.026	0.000	0.000	0.005	0.009
NR1175Ca	Pyrite	0.082	0.085	0.009	0.000	0.000	0.005	0.002
NR1175Ca	Pyrite	0.076	0.017	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.082	0.010	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.110	0.075	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.078	0.010	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.077	0.020	0.009	0.000	0.000	0.005	0.002
NR1175Ca	Pyrite	0.100	0.040	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.084	0.137	0.022	0.020	0.000	0.005	0.001
NR1175Ca	Pyrite	0.110	0.083	0.009	0.000	0.000	0.005	0.010
NR1175Ca	Pyrite	0.081	0.010	0.014	0.000	0.000	0.005	0.002
NR1175Ca	Pyrite	0.086	0.010	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.160	0.168	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.190	0.128	0.010	0.000	0.000	0.005	0.002
NR1175Ca	Pyrite	0.111	0.180	0.009	0.000	0.000	0.005	0.002
NR1175Ca	Pyrite	0.083	0.010	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.104	0.022	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.104	0.030	0.012	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.095	0.096	0.024	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.108	0.121	0.025	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.084	0.010	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.082	0.050	0.023	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.115	0.026	0.009	0.000	0.000	0.005	0.013
NR1175Ca	Pyrite	0.082	0.027	0.019	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.077	0.013	0.009	0.000	0.000	0.005	0.001

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR1175Ca	Pyrite	0.271	0.155	0.010	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.099	0.024	0.009	0.040	0.000	0.005	0.001
NR1175Ca	Pyrite	0.094	0.025	0.009	0.000	0.000	0.005	0.004
NR1175Ca	Pyrite	0.078	0.014	0.010	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.084	0.014	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.095	0.025	0.012	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.125	0.167	0.009	0.000	0.000	0.005	0.004
NR1175Ca	Pyrite	0.079	0.020	0.012	0.000	0.000	0.005	0.007
NR1175Ca	Pyrite	0.102	0.107	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.086	0.022	0.009	0.000	0.000	0.005	0.004
NR1175Ca	Pyrite	0.078	0.050	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.147	0.064	0.012	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.283	0.129	0.013	0.000	0.000	0.005	0.014
NR1175Ca	Pyrite	0.072	0.014	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.089	0.012	0.011	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.089	0.057	0.016	0.002	0.000	0.005	0.001
NR1175Ca	Pyrite	0.249	0.196	0.015	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.102	0.104	0.015	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.099	0.047	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.123	0.250	0.009	0.000	0.000	0.005	0.002
NR1175Ca	Pyrite	0.085	0.095	0.029	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.093	0.025	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.082	0.010	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.119	0.301	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.127	0.080	0.018	0.000	0.000	0.005	0.008
NR1175Ca	Pyrite	0.209	0.062	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.123	0.071	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.080	0.037	0.016	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.142	0.032	0.029	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.080	0.052	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.092	0.295	0.009	0.000	0.000	0.005	0.003
NR1175Ca	Pyrite	0.082	0.089	0.035	0.000	0.000	0.005	0.014

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR1175Ca	Pyrite	0.102	0.275	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.112	0.022	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.147	0.108	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.093	0.047	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.278	0.379	0.009	0.000	0.000	0.005	0.003
NR1175Ca	Pyrite	0.177	0.210	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.082	0.018	0.009	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.166	0.133	0.011	0.000	0.000	0.005	0.003
NR1175Ca	Pyrite	0.070	0.010	0.016	0.000	0.000	0.005	0.010
NR1175Ca	Pyrite	0.079	0.010	0.017	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.097	0.075	0.010	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.225	0.165	0.032	0.000	0.000	0.005	0.015
NR1175Ca	Pyrite	0.079	0.010	0.011	0.000	0.000	0.005	0.001
NR1175Ca	Pyrite	0.088	0.124	0.013	0.000	0.000	0.000	0.000
NR1175Ca	Pyrite	0.163	0.155	0.000	0.000	0.000	0.000	0.000
NR1175Ca	Pyrite	0.108	0.012	0.000	0.000	0.000	0.000	0.000
NR116B	Pyrite	0.165	0.063	0.000	0.000	0.000	0.226	0.000
NR116B	Pyrite	0.122	0.076	0.024	0.000	0.000	0.203	0.000
NR116B	Pyrite	0.088	0.061	0.000	0.000	0.000	0.038	0.013
NR116B	Pyrite	0.096	0.059	0.007	0.000	0.000	0.027	0.000
NR116B	Pyrite	0.101	0.076	0.021	0.000	0.000	0.025	0.000
NR116B	Pyrite	0.102	0.041	0.009	0.000	0.000	0.025	0.000
NR116B	Pyrite	0.123	0.068	0.000	0.000	0.000	0.020	0.000
NR116B	Pyrite	0.124	0.047	0.000	0.000	0.000	0.020	0.000
NR116B	Pyrite	0.112	0.005	0.000	0.006	0.000	0.018	0.000
NR116B	Pyrite	0.089	0.033	0.011	0.000	0.000	0.018	0.002
NR116B	Pyrite	0.118	0.017	0.000	0.000	0.000	0.017	0.000
NR116B	Pyrite	0.103	0.116	0.000	0.000	0.000	0.017	0.000
NR116B	Pyrite	0.114	0.050	0.010	0.000	0.000	0.016	0.000
NR116B	Pyrite	0.124	0.071	0.002	0.000	0.000	0.013	0.000
NR116B	Pyrite	0.090	0.089	0.000	0.000	0.000	0.013	0.005
NR116B	Pyrite	0.229	0.038	0.003	0.000	0.000	0.013	0.000

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR116B	Pyrite	0.092	0.043	0.000	0.000	0.000	0.008	0.003
NR116B	Pyrite	0.087	0.050	0.004	0.000	0.000	0.007	0.000
NR116B	Pyrite	0.099	0.022	0.002	0.000	0.000	0.007	0.000
NR116B	Pyrite	0.101	0.035	0.000	0.000	0.000	0.006	0.002
NR116B	Pyrite	0.139	0.078	0.018	0.000	0.000	0.005	0.000
NR116B	Pyrite	0.098	0.015	0.006	0.000	0.000	0.005	0.000
NR116B	Pyrite	0.094	0.045	0.000	0.000	0.000	0.003	0.000
NR116B	Pyrite	0.104	0.030	0.000	0.000	0.000	0.000	0.000
NR116B	Pyrite	0.086	0.017	0.010	0.000	0.000	0.000	0.000
NR116B	Pyrite	0.099	0.015	0.003	0.000	0.000	0.000	0.000
NR116B	Pyrite	0.106	0.095	0.000	0.000	0.000	0.000	0.000
NR116B	Pyrite	0.082	0.040	0.000	0.000	0.000	0.000	0.000
NR116B	Pyrite	0.131	0.068	0.009	0.000	0.000	0.000	0.007
NR116B	Pyrite	0.086	0.077	0.026	0.000	0.000	0.000	0.013
NR116B	Pyrite	0.101	0.063	0.000	0.000	0.000	0.000	0.000
NR116A	Pyrite	0.132	0.041	0.033	0.000	0.000	0.169	0.000
NR116A	Pyrite	0.111	0.079	0.000	0.000	0.000	0.123	0.000
NR116A	Pyrite	0.116	0.147	0.008	0.000	0.000	0.042	0.001
NR116A	Pyrite	0.088	0.021	0.005	0.000	0.000	0.034	0.000
NR116A	Pyrite	0.094	0.033	0.006	0.000	0.000	0.028	0.003
NR116A	Pyrite	0.081	0.000	0.014	0.000	0.000	0.028	0.000
NR116A	Pyrite	0.146	0.008	0.000	0.000	0.000	0.023	0.000
NR116A	Pyrite	0.114	0.008	0.000	0.002	0.000	0.023	0.003
NR116A	Pyrite	0.103	0.063	0.000	0.000	0.000	0.022	0.000
NR116A	Pyrite	0.117	0.012	0.000	0.000	0.000	0.021	0.000
NR116A	Pyrite	0.083	0.071	0.000	0.003	0.000	0.020	0.000
NR116A	Pyrite	0.096	0.031	0.000	0.000	0.000	0.019	0.000
NR116A	Pyrite	0.077	0.015	0.009	0.000	0.000	0.018	0.002
NR116A	Pyrite	0.086	0.024	0.005	0.000	0.000	0.017	0.004
NR116A	Pyrite	0.100	0.092	0.006	0.000	0.000	0.017	0.000
NR116A	Pyrite	0.112	0.053	0.000	0.000	0.000	0.017	0.000
NR116A	Pyrite	0.083	0.124	0.000	0.002	0.000	0.015	0.000

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR116A	Pyrite	0.103	0.026	0.000	0.000	0.000	0.014	0.000
NR116A	Pyrite	0.097	0.025	0.001	0.000	0.000	0.014	0.000
NR116A	Pyrite	0.108	0.023	0.000	0.000	0.000	0.013	0.000
NR116A	Pyrite	0.127	0.017	0.003	0.000	0.000	0.012	0.000
NR116A	Pyrite	0.084	0.007	0.000	0.000	0.000	0.012	0.000
NR116A	Pyrite	0.088	0.055	0.017	0.000	0.000	0.012	0.006
NR116A	Pyrite	0.087	0.027	0.014	0.000	0.000	0.012	0.000
NR116A	Pyrite	0.126	0.015	0.000	0.000	0.000	0.011	0.006
NR116A	Pyrite	0.086	0.029	0.000	0.000	0.000	0.011	0.013
NR116A	Pyrite	0.086	0.098	0.000	0.000	0.000	0.010	0.000
NR116A	Pyrite	0.088	0.003	0.016	0.000	0.000	0.010	0.011
NR116A	Pyrite	0.090	0.011	0.000	0.000	0.000	0.009	0.005
NR116A	Pyrite	0.083	0.016	0.000	0.000	0.000	0.009	0.012
NR116A	Pyrite	0.085	0.025	0.000	0.000	0.000	0.008	0.000
NR116A	Pyrite	0.104	0.264	0.000	0.000	0.000	0.008	0.001
NR116A	Pyrite	0.097	0.074	0.000	0.000	0.000	0.007	0.000
NR116A	Pyrite	0.103	0.030	0.000	0.000	0.000	0.007	0.000
NR116A	Pyrite	0.118	0.002	0.000	0.000	0.000	0.007	0.007
NR116A	Pyrite	0.118	0.070	0.000	0.000	0.000	0.007	0.000
NR116A	Pyrite	0.121	0.050	0.008	0.000	0.000	0.006	0.000
NR116A	Pyrite	0.079	0.020	0.001	0.014	0.000	0.004	0.006
NR116A	Pyrite	0.109	0.013	0.013	0.000	0.000	0.004	0.000
NR116A	Pyrite	0.158	0.050	0.000	0.000	0.000	0.004	0.000
NR116A	Pyrite	0.082	0.009	0.000	0.000	0.000	0.004	0.000
NR116A	Pyrite	0.092	0.042	0.000	0.000	0.000	0.003	0.000
NR116A	Pyrite	0.091	0.018	0.013	0.000	0.000	0.003	0.000
NR116A	Pyrite	0.081	0.003	0.000	0.000	0.000	0.003	0.000
NR116A	Pyrite	0.085	0.012	0.022	0.000	0.000	0.002	0.000
NR116A	Pyrite	0.078	0.067	0.000	0.000	0.000	0.002	0.000
NR116A	Pyrite	0.087	0.043	0.009	0.000	0.000	0.002	0.017
NR116A	Pyrite	0.090	0.029	0.000	0.000	0.000	0.001	0.000
NR116A	Pyrite	0.108	0.020	0.003	0.000	0.000	0.000	0.000

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR116A	Pyrite	0.119	0.016	0.000	0.000	0.000	0.000	0.012
NR116A	Pyrite	0.083	0.010	0.003	0.000	0.000	0.000	0.006
NR116A	Pyrite	0.103	0.037	0.000	0.000	0.000	0.000	0.000
NR116A	Pyrite	0.127	0.235	0.000	0.000	0.000	0.000	0.001
NR116A	Pyrite	0.089	0.083	0.020	0.000	0.000	0.000	0.000
NR116A	Pyrite	0.097	0.015	0.000	0.000	0.000	0.000	0.000
NR116A	Pyrite	0.212	0.051	0.000	0.000	0.000	0.000	0.000
NR116A	Pyrite	0.127	0.060	0.000	0.000	0.000	0.000	0.000
NR116A	Pyrite	0.084	0.027	0.007	0.000	0.000	0.000	0.000
NR116A	Pyrite	0.145	0.022	0.020	0.000	0.000	0.000	0.000
NR116A	Pyrite	0.084	0.041	0.000	0.000	0.000	0.000	0.000
NR116A	Pyrite	0.096	0.279	0.000	0.024	0.000	0.000	0.002
NR116A	Pyrite	0.106	0.260	0.000	0.000	0.000	0.000	0.000
NR116A	Pyrite	0.115	0.012	0.000	0.000	0.000	0.000	0.000
NR116A	Pyrite	0.102	0.080	0.007	0.004	0.000	0.000	0.000
NR1153mpy	Pyrite	0.120	0.085	0.009	0.000	0.000	0.028	0.001
NR1153mpy	Pyrite	0.234	0.531	0.013	0.000	0.000	0.028	0.001
NR1153mpy	Pyrite	0.110	0.018	0.009	0.000	0.000	0.028	0.004
NR1153mpy	Pyrite	0.099	0.075	0.009	0.000	0.000	0.027	0.001
NR1153mpy	Pyrite	0.101	0.091	0.017	0.000	0.000	0.027	0.001
NR1153mpy	Pyrite	0.113	0.022	0.009	0.000	0.000	0.026	0.001
NR1153mpy	Pyrite	0.100	0.028	0.009	0.000	0.000	0.026	0.001
NR1153mpy	Pyrite	0.206	0.332	0.018	0.000	0.000	0.026	0.001
NR1153mpy	Pyrite	0.330	0.128	0.019	0.000	0.000	0.026	0.001
NR1153mpy	Pyrite	0.120	0.058	0.010	0.000	0.000	0.026	0.001
NR1153mpy	Pyrite	0.078	0.084	0.010	0.000	0.000	0.026	0.001
NR1153mpy	Pyrite	0.119	0.080	0.009	0.000	0.000	0.025	0.001
NR1153mpy	Pyrite	0.285	0.225	0.021	0.000	0.000	0.025	0.003
NR1153mpy	Pyrite	0.092	0.042	0.009	0.000	0.000	0.024	0.001
NR1153mpy	Pyrite	0.157	0.091	0.009	0.000	0.000	0.024	0.001
NR1153mpy	Pyrite	0.085	0.044	0.020	0.000	0.000	0.024	0.003
NR1153mpy	Pyrite	0.217	0.110	0.009	0.000	0.000	0.024	0.009

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR1153mpy	Pyrite	0.108	0.015	0.009	0.000	0.000	0.023	0.001
NR1153mpy	Pyrite	0.081	0.011	0.009	0.000	0.000	0.023	0.001
NR1153mpy	Pyrite	0.072	0.025	0.018	0.000	0.000	0.023	0.003
NR1153mpy	Pyrite	0.114	0.027	0.009	0.000	0.000	0.022	0.001
NR1153mpy	Pyrite	0.099	0.128	0.009	0.000	0.000	0.022	0.001
NR1153mpy	Pyrite	0.104	0.014	0.009	0.000	0.000	0.022	0.004
NR1153mpy	Pyrite	0.082	0.034	0.014	0.000	0.000	0.022	0.005
NR1153mpy	Pyrite	0.096	0.104	0.015	0.000	0.000	0.022	0.001
NR1153mpy	Pyrite	0.109	0.064	0.009	0.000	0.000	0.022	0.001
NR1153mpy	Pyrite	0.124	0.027	0.012	0.000	0.000	0.017	0.001
NR1153mpy	Pyrite	0.079	0.010	0.009	0.018	0.000	0.017	0.006
NR1153mpy	Pyrite	0.153	0.187	0.009	0.000	0.000	0.017	0.001
NR1153mpy	Pyrite	0.080	0.017	0.009	0.000	0.000	0.017	0.001
NR1153mpy	Pyrite	0.084	0.066	0.026	0.000	0.000	0.017	0.007
NR1153mpy	Pyrite	0.083	0.038	0.023	0.000	0.000	0.017	0.001
NR1153mpy	Pyrite	0.087	0.039	0.009	0.000	0.000	0.016	0.001
NR1153mpy	Pyrite	0.122	0.025	0.009	0.000	0.000	0.016	0.007
NR1153mpy	Pyrite	0.082	0.040	0.009	0.000	0.000	0.016	0.014
NR1153mpy	Pyrite	0.080	0.010	0.009	0.000	0.000	0.015	0.017
NR1153mpy	Pyrite	0.082	0.110	0.009	0.000	0.000	0.015	0.001
NR1153mpy	Pyrite	0.097	0.036	0.009	0.000	0.000	0.015	0.001
NR1153mpy	Pyrite	0.103	0.128	0.018	0.000	0.000	0.015	0.001
NR1153mpy	Pyrite	0.084	0.013	0.025	0.000	0.000	0.015	0.012
NR1153mpy	Pyrite	0.112	0.162	0.010	0.000	0.000	0.015	0.006
NR1153mpy	Pyrite	0.086	0.021	0.009	0.000	0.000	0.014	0.006
NR1153mpy	Pyrite	0.078	0.026	0.009	0.000	0.000	0.014	0.013
NR1153mpy	Pyrite	0.092	0.066	0.009	0.000	0.000	0.014	0.017
NR1153mpy	Pyrite	0.081	0.024	0.009	0.000	0.000	0.014	0.001
NR1153mpy	Pyrite	0.287	0.113	0.016	0.000	0.000	0.014	0.006
NR1153mpy	Pyrite	0.119	0.090	0.009	0.000	0.000	0.013	0.001
NR1153mpy	Pyrite	0.144	0.167	0.011	0.000	0.000	0.013	0.007
NR1153mpy	Pyrite	0.122	0.143	0.009	0.000	0.000	0.013	0.028

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR1153mpy	Pyrite	0.081	0.035	0.009	0.000	0.000	0.013	0.001
NR1153mpy	Pyrite	0.088	0.054	0.009	0.000	0.000	0.013	0.004
NR1153mpy	Pyrite	0.118	0.057	0.037	0.000	0.000	0.013	0.001
NR1153mpy	Pyrite	0.100	0.279	0.009	0.000	0.000	0.013	0.002
NR1152	Pyrite	0.182	0.090	0.049	0.374	0.000	0.630	0.000
NR1152	Pyrite	0.388	0.315	0.000	0.000	0.000	0.032	0.000
NR1152	Pyrite	0.194	0.301	0.004	0.000	0.000	0.027	0.000
NR1152	Pyrite	0.114	0.172	0.006	0.000	0.000	0.026	0.006
NR1152	Pyrite	0.119	0.131	0.000	0.000	0.000	0.024	0.000
NR1152	Pyrite	0.123	0.074	0.000	0.000	0.000	0.023	0.000
NR1152	Pyrite	0.237	0.511	0.004	0.000	0.000	0.023	0.000
NR1152	Pyrite	0.209	0.316	0.009	0.000	0.000	0.021	0.000
NR1152	Pyrite	0.332	0.116	0.010	0.000	0.000	0.021	0.000
NR1152	Pyrite	0.287	0.210	0.011	0.000	0.000	0.020	0.002
NR1152	Pyrite	0.139	0.165	0.009	0.000	0.000	0.019	0.000
NR1152	Pyrite	0.135	0.045	0.000	0.016	0.000	0.019	0.008
NR1152	Pyrite	0.203	0.215	0.000	0.000	0.000	0.019	0.000
NR1152	Pyrite	0.083	0.000	0.000	0.000	0.000	0.018	0.000
NR1152	Pyrite	0.085	0.001	0.000	0.000	0.000	0.018	0.000
NR1152	Pyrite	0.160	0.079	0.000	0.000	0.000	0.018	0.000
NR1152	Pyrite	0.220	0.097	0.000	0.000	0.000	0.018	0.008
NR1152	Pyrite	0.108	0.004	0.000	0.000	0.000	0.017	0.003
NR1152	Pyrite	0.171	0.151	0.000	0.000	0.000	0.016	0.000
NR1152	Pyrite	0.134	0.106	0.000	0.000	0.000	0.016	0.000
NR1152	Pyrite	0.319	0.159	0.002	0.000	0.000	0.016	0.000
NR1152	Pyrite	0.093	0.125	0.000	0.000	0.000	0.015	0.000
NR1152	Pyrite	0.098	0.135	0.005	0.000	0.000	0.015	0.000
NR1152	Pyrite	0.087	0.021	0.000	0.000	0.000	0.014	0.000
NR1152	Pyrite	0.092	0.000	0.000	0.000	0.000	0.014	0.003
NR1152	Pyrite	0.147	0.149	0.002	0.000	0.000	0.014	0.000
NR1152	Pyrite	0.303	0.110	0.000	0.000	0.000	0.013	0.000
NR1152	Pyrite	0.083	0.000	0.000	0.000	0.000	0.012	0.005

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR1152	Pyrite	0.156	0.174	0.000	0.000	0.000	0.012	0.000
NR1152	Pyrite	0.091	0.029	0.000	0.000	0.000	0.011	0.000
NR1152	Pyrite	0.101	0.026	0.000	0.000	0.000	0.010	0.000
NR1152	Pyrite	0.116	0.149	0.001	0.000	0.000	0.010	0.005
NR1152	Pyrite	0.085	0.014	0.000	0.000	0.000	0.009	0.000
NR1152	Pyrite	0.289	0.101	0.007	0.000	0.000	0.009	0.005
NR1152	Pyrite	0.122	0.079	0.000	0.000	0.000	0.008	0.000
NR1152	Pyrite	0.126	0.131	0.000	0.000	0.000	0.008	0.027
NR1152	Pyrite	0.074	0.007	0.000	0.000	0.000	0.007	0.000
NR1152	Pyrite	0.137	0.122	0.003	0.000	0.000	0.007	0.000
NR1152	Pyrite	0.171	0.125	0.011	0.000	0.000	0.007	0.006
NR1152	Pyrite	0.086	0.000	0.001	0.000	0.000	0.006	0.000
NR1152	Pyrite	0.106	0.004	0.007	0.000	0.000	0.006	0.000
NR1152	Pyrite	0.095	0.030	0.003	0.000	0.000	0.005	0.004
NR1152	Pyrite	0.093	0.012	0.006	0.000	0.000	0.005	0.000
NR1152	Pyrite	0.109	0.122	0.010	0.000	0.000	0.004	0.000
NR1152	Pyrite	0.083	0.029	0.000	0.000	0.000	0.003	0.000
NR1152	Pyrite	0.097	0.060	0.000	0.000	0.000	0.003	0.005
NR1152	Pyrite	0.085	0.000	0.002	0.000	0.000	0.002	0.000
NR1152	Pyrite	0.082	0.000	0.000	0.000	0.000	0.002	0.000
NR1152	Pyrite	0.260	0.118	0.000	0.000	0.000	0.002	0.004
NR1152	Pyrite	0.087	0.002	0.000	0.000	0.000	0.002	0.000
NR1152	Pyrite	0.304	0.127	0.000	0.000	0.000	0.002	0.009
NR1152	Pyrite	0.086	0.000	0.000	0.000	0.000	0.001	0.000
NR1152	Pyrite	0.087	0.020	0.011	0.000	0.000	0.001	0.007
NR1152	Pyrite	0.093	0.109	0.000	0.000	0.000	0.001	0.001
NR1152	Pyrite	0.086	0.000	0.000	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.081	0.010	0.000	0.000	0.000	0.000	0.001
NR1152	Pyrite	0.113	0.072	0.000	0.000	0.000	0.000	0.009
NR1152	Pyrite	0.085	0.000	0.005	0.000	0.000	0.000	0.001
NR1152	Pyrite	0.090	0.000	0.000	0.006	0.000	0.000	0.000
NR1152	Pyrite	0.193	0.116	0.001	0.000	0.000	0.000	0.001

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR1152	Pyrite	0.115	0.167	0.000	0.000	0.000	0.000	0.001
NR1152	Pyrite	0.112	0.109	0.016	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.088	0.000	0.000	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.086	0.040	0.014	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.081	0.003	0.000	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.273	0.142	0.001	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.103	0.014	0.000	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.098	0.015	0.000	0.000	0.000	0.000	0.003
NR1152	Pyrite	0.082	0.004	0.001	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.088	0.004	0.000	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.129	0.154	0.000	0.000	0.000	0.000	0.003
NR1152	Pyrite	0.090	0.012	0.000	0.000	0.000	0.000	0.003
NR1152	Pyrite	0.285	0.116	0.004	0.007	0.000	0.000	0.013
NR1152	Pyrite	0.076	0.004	0.000	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.094	0.002	0.002	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.093	0.047	0.007	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.106	0.092	0.006	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.123	0.285	0.000	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.280	0.362	0.000	0.000	0.000	0.000	0.002
NR1152	Pyrite	0.181	0.196	0.000	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.086	0.008	0.000	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.164	0.116	0.002	3.294	0.000	0.000	0.002
NR1152	Pyrite	0.134	0.024	0.021	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.125	0.113	0.054	1.463	0.000	0.000	0.000
NR1152	Pyrite	0.148	0.094	0.000	1.385	0.000	0.000	0.000
NR1152	Pyrite	0.152	0.152	0.000	0.061	0.000	0.000	0.000
NR1152	Pyrite	0.099	0.099	0.099	0.000	0.000	0.000	0.000
NR1152	Pyrite	0.175	0.093	0.000	0.000	0.000	0.000	0.000
NR1111A	Pyrite	0.079	0.023	0.009	0.000	0.000	0.019	0.006
NR1111A	Pyrite	0.083	0.031	0.009	0.000	0.000	0.019	0.001
NR1111A	Pyrite	0.301	0.122	0.009	0.000	0.000	0.018	0.001
NR1111A	Pyrite	0.120	0.082	0.011	0.000	0.000	0.018	0.001

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR1111A	Pyrite	0.086	0.101	0.009	0.000	0.000	0.018	0.006
NR1111A	Pyrite	0.161	0.090	0.026	0.000	0.000	0.018	0.004
NR1111A	Pyrite	0.226	0.049	0.012	0.000	0.000	0.018	0.001
NR1111A	Pyrite	0.104	0.034	0.009	0.000	0.000	0.018	0.001
AP114-6	Pyrite	0.084	0.022	0.002	0.342	0.000	0.026	0.008
AP114-6	Pyrite	0.092	0.000	0.004	0.000	0.000	0.025	0.000
AP114-6	Pyrite	0.230	0.145	0.005	0.000	0.000	0.024	0.000
AP114-6	Pyrite	0.105	0.079	0.008	0.000	0.000	0.022	0.000
AP114-6	Pyrite	0.069	0.000	0.005	0.000	0.000	0.014	0.006
AP114-6	Pyrite	0.107	0.116	0.009	0.130	0.000	0.010	0.000
AP114-6	Pyrite	0.108	0.068	0.002	0.000	0.000	0.007	0.000
AP114-6	Pyrite	0.094	0.029	0.019	0.031	0.000	0.005	0.000
AP114-6	Pyrite	0.082	0.000	0.015	0.000	0.000	0.004	0.000
AP114-6	Pyrite	0.083	0.013	0.000	0.000	0.000	0.002	0.005
AP114-6	Pyrite	0.233	0.142	0.000	0.000	0.000	0.002	0.008
AP114-6	Pyrite	0.337	0.192	0.010	0.000	0.000	0.001	0.000
AP114-6	Pyrite	0.088	0.011	0.005	0.000	0.000	0.001	0.000
AP114-6	Pyrite	0.083	0.037	0.017	0.000	0.000	0.000	0.008
AP114-6	Pyrite	0.086	0.074	0.000	0.000	0.000	0.000	0.001
AP114-6	Pyrite	0.080	0.007	0.000	0.000	0.000	0.000	0.000
AP114-6	Pyrite	0.082	0.000	0.000	0.000	0.000	0.000	0.000
AP114-6	Pyrite	0.099	0.085	0.015	0.000	0.000	0.000	0.000
AP114-6	Pyrite	0.251	0.182	0.006	0.000	0.000	0.000	0.000
AP114-6	Pyrite	0.086	0.000	0.000	0.000	0.000	0.000	0.000
AP114-6	Pyrite	0.097	0.036	0.000	0.000	0.000	0.000	0.000
AP114-6	Pyrite	0.083	0.000	0.008	0.000	0.000	0.000	0.000
AP114-6	Pyrite	0.228	0.151	0.022	0.000	0.000	0.000	0.014
AP114-6	Pyrite	0.083	0.000	0.002	0.000	0.000	0.000	0.000
AP113-4A	Pyrite	0.090	0.099	0.000	0.000	0.000	0.016	0.000
AP113-4A	Pyrite	0.165	0.079	0.017	0.000	0.000	0.013	0.003
AP113-4A	Pyrite	0.096	0.055	0.000	0.000	0.000	0.009	0.016
AP113-4A	Pyrite	0.120	0.046	0.027	1.411	0.000	0.008	0.000

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
AP113-4A	Pyrite	0.093	0.000	0.020	0.009	0.000	0.005	0.000
AP113-4A	Pyrite	0.181	0.092	0.000	0.000	0.000	0.002	0.000
AP113-4A	Pyrite	0.139	0.045	0.012	0.000	0.000	0.002	0.000
AP113-4A	Pyrite	0.145	0.091	0.002	0.479	0.000	0.001	0.000
AP113-4A	Pyrite	0.113	0.064	0.000	0.000	0.000	0.000	0.000
AP113-4A	Pyrite	0.087	0.000	0.000	0.000	0.000	0.000	0.000
AP113-4A	Pyrite	0.150	0.053	0.003	0.000	0.000	0.000	0.000
AP113-4A	Pyrite	0.075	0.000	0.007	0.015	0.000	0.000	0.009
AP113-4A	Pyrite	0.114	0.011	0.000	11.687	0.000	0.000	0.007
Average	Pyrite	0.112	0.069	0.012	0.000	0.000	0.020	0.002
Median	Pyrite	0.099	0.050	0.009	0.000	0.000	0.008	0.001
Range	Pyrite	0.045–0.388	0–0.531	0–0.198	0–11.687	0.000	0–0.648	0–0.28
NR1152	Galena	0.009	0.000	0.000	83.480	0.000	0.000	1.002
NR1152	Galena	0.006	0.000	0.000	85.504	0.000	0.000	1.190
NR1152	Galena	0.006	0.000	0.000	85.085	0.000	0.000	0.000
AP113-4A	Galena	0.009	0.004	0.012	80.988	0.000	0.000	0.000
AP113-4A	Galena	0.000	0.000	0.000	81.026	0.000	0.000	0.000
AP113-4A	Galena	0.017	0.001	0.000	84.127	0.000	0.000	0.116
AP113-4A	Galena	0.008	0.000	0.000	84.682	0.000	0.000	0.067
Average	Galena	0.008	0.001	0.002	83.556	0.000	0.000	0.339
Median	Galena	0.008	0.000	0.000	84.127	0.000	0.000	0.067
Range	Galena	0–0.01	0–0.005	0–0.012	80.99–85.50	0.000	0.000	0–1.2
NR1175Ca	Tetrahedrite	0.000	0.605	0.689	0.000	38.950	2.730	0.043
NR1175Ca	Tetrahedrite	0.000	0.671	0.333	0.000	42.370	2.799	0.037
NR1175Ca	Tetrahedrite	0.194	0.579	1.007	0.024	37.630	4.885	0.024
NR116B	Tetrahedrite	0.138	0.183	0.321	0.000	39.820	2.659	0.000
NR116B	Tetrahedrite	0.155	0.309	0.000	0.734	40.010	2.706	0.000
NR1152	Tetrahedrite	0.304	0.328	0.773	5.316	38.450	4.637	0.000
Average	Tetrahedrite	0.132	0.446	0.521	1.012	39.538	3.403	0.017
Median	Tetrahedrite	0.147	0.454	0.511	0.012	39.385	2.765	0.012
Range	Tetrahedrite	0–0.3	0.18–0.67	0–1.007	0–5.32	0–42.37	2.66–4.88	0–.04

Appendix 6. Electron microprobe analytical data for Pyrite and other sulfide minerals from selected core samples from boreholes AP1 and NR1, Great Bay National Wildlife Refuge.—Continued

[Replicate analyses, duplicate analyses, and analyses by different methods are listed individually; AP1, Adams Point borehole; NR1, National Refuge borehole; dup, duplicate; wt., weight; %, percent]

Sample number	Mineral	Co (wt. %)	Ni (wt. %)	Zn (wt. %)	Pb (wt. %)	Cu (wt. %)	As (wt. %)	Se (wt. %)
NR1175Ca	Ni-As-Pyrite	0.000	9.851	0.000	0.000	7.190	4.091	0.000
NR1175Ca	Ni-As-Pyrite	0.000	7.393	0.000	0.000	8.519	3.696	0.000
NR1175Ca	Ni-As-Pyrite	0.000	10.279	0.000	0.000	7.075	4.269	0.000
Average	Ni-As-Pyrite	0.000	9.174	0.000	0.000	7.595	4.019	0.000
Median	Ni-As-Pyrite	0.000	9.851	0.000	0.000	7.190	4.091	0.000
Range	Ni-As-Pyrite	0–0.3	7.4–10.3	0.000	0.000	7.0–8.5	3.6–4.3	0.000

Sample number	Mineral	Fe (wt. %)		Zn (wt. %)	Cd (wt. %)
NR1175Ca	Sphalerite	0.300		64.7	.18
NR1175Ca	Sphalerite	0.670		65.6	.21
NR1175Ca	Sphalerite	0.92		65.8	.39
NR1175Ca	Sphalerite	1.23		63.7	.10

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Foley, Nora K., and others—**Geological Assessment of Cores from the Great Bay National Wildlife Refuge, New Hampshire**—Scientific Investigations Report 2006–5203