

MINERALOGY AND FLUID CHEMISTRY OF SURFICIAL SEDIMENTS IN THE NEWFOUNDLAND BASIN, TOOELE AND BOX ELDER COUNTIES, UTAH

by Blair F. Jones, William W. White III, Kathryn M. Conko, Daniel M. Webster, and James F. Kohler



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Cover photo:

Winter transient pond in the central basin topographic low of Newfoundland Basin.
View is east toward the southern end of the Newfoundland Range.



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ABSTRACT

The Bureau of Land Management (BLM) and U.S. Geological Survey (USGS) conducted a joint three-year field study of Newfoundland Basin's shallow-brine aquifer and associated playa and lacustrine sediments. This study was undertaken to characterize and classify federal mineral resources residing within the Newfoundland Basin. The joint study was concentrated in the area flooded by Great Salt Lake brine during the West Desert Pumping Project (April 1987 - June 1989). Chemical and mineralogical characterization were performed on brine and selected core samples collected from the shallow-brine aquifer and sediments intercepted by 24 boreholes and eight sets of nested monitoring wells. Aquifer tests were also conducted on specific boreholes and monitoring wells. Effects of the pumping project included altering the Newfoundland Basin shallow-brine aquifer by mixing two chemically different brines, and depositing halite crust where none was previously reported.

Within the uppermost 5 feet (1.5 meters) of basin-center sediments, potassium (K), magnesium (Mg), and sulfate (SO₄) pore-fluid concentrations were as much as 0.9, 2.6, and 4.6%, respectively, essentially matching Great Salt Lake brine values. Below 5 feet (1.5 meters), pore-fluid concentrations decreased to <0.7% for K and Mg, and <2% for SO₄, presumably matching evaporated remnants from Lake Bonneville waters. Core mineralogy showed that gypsum occurrences (below halite) increased up to 75% toward the basin center at depths greater than 3.28 feet (1 meter). Conversely, aragonite generally became more abundant with depth toward the basin periphery. Borehole and monitoring well stratigraphic logs showed that basin-center halite deposits that precipitated from the ponded West Desert pumping-project brine were as much as 2-feet (0.6 meters) thick.

Model-predicted mineral sequence plots from simulated step-wise evaporation of pore-fluid brines from peripheral and central-basin core samples demonstrated that near surface pore-fluid brines (<5-foot/1.5-meter depth) were a mixture of pre-pumping ground water and Great Salt Lake brine. Conversely, pore fluids from core depths ranging from 5 to nearly 7 feet (1.5 to 2.1 meters) below ground level had predicted mineral sequence plots similar to the pre-pumping ground-water brine.

Ground-water-brine transport in sediments of the shallow-brine aquifer occurred mainly in the permeable sedimentary facies, and possibly in vertical fissures observed in mudflat-clay facies. Aquifer tests were performed in six of the 24 boreholes. Hydraulic conductivities ranged from 47 to 88 feet (14 to 27 meters)/day for five boreholes; however, a maximum hydraulic

conductivity of 536 feet (63 meters)/day was measured from a sixth borehole. Hydraulic-conductivity values from aquifer tests conducted in the monitoring wells ranged from 0.4 to 77 feet (0.1 to 23 meters)/day, and from 0.05 to 30 feet (0.02 to 9 meters)/day, respectively. The higher hydraulic conductivity values from these ranges were typically from the upper 10 feet (3 meters) of the lacustrine sediments comprising the shallow-brine aquifer.

INTRODUCTION

Background

The Great Salt Lake Desert (figure 1) of western Utah is underlain by a shallow-brine aquifer from which potentially economic quantities of sodium (Na), potassium (K), and magnesium (Mg) salts can be produced. This brine is for the most part presumed to be a remnant of freshwater Lake Bonneville, which occupied the basin from about 32,000 to 14,000 years ago (Oviatt 1987, 1997; Oviatt and others 1994). A similar origin is suggested for Great Salt Lake. However, historic comparisons of Great Salt Lake North Arm brine and shallow-aquifer brine (Kohler and White 2004) indicate that they differed chemically prior to the 1987-1989 West Desert Pumping Project, which transferred Great Salt Lake North Arm brine into the Newfoundland Basin (Wold and Waddell, 1993). The objective of the West Desert Pumping Project was to lower the pond level of Great Salt Lake, which had risen to historic heights due to abnormal runoff during the 1980's (Utah Division of Water Resources, 2009). Analyses of recent brine samples from Newfoundland Basin boreholes drilled by the Bureau of Land Management (BLM) (figure 2a) indicate that the shallow-brine aquifer chemistry of the Newfoundland Basin has been modified as a result of this pumping project.

Purpose and Scope

This study was undertaken as part of the U.S. Geological Survey (USGS) and BLM's responsibility to classify and characterize federal-mineral resources on federal lands (U.S. Department of Interior, 2000). Information gained from the study could be used by BLM to further delineate the known potassium resource area (U.S. Department of Interior, 2006). Consequently, the purpose of this paper is to 1) geochemically characterize the ground water contained in the Newfoundland Basin shallow-brine aquifer, 2) describe the lacustrine-sediment sequence that comprises the shallow-brine aquifer,

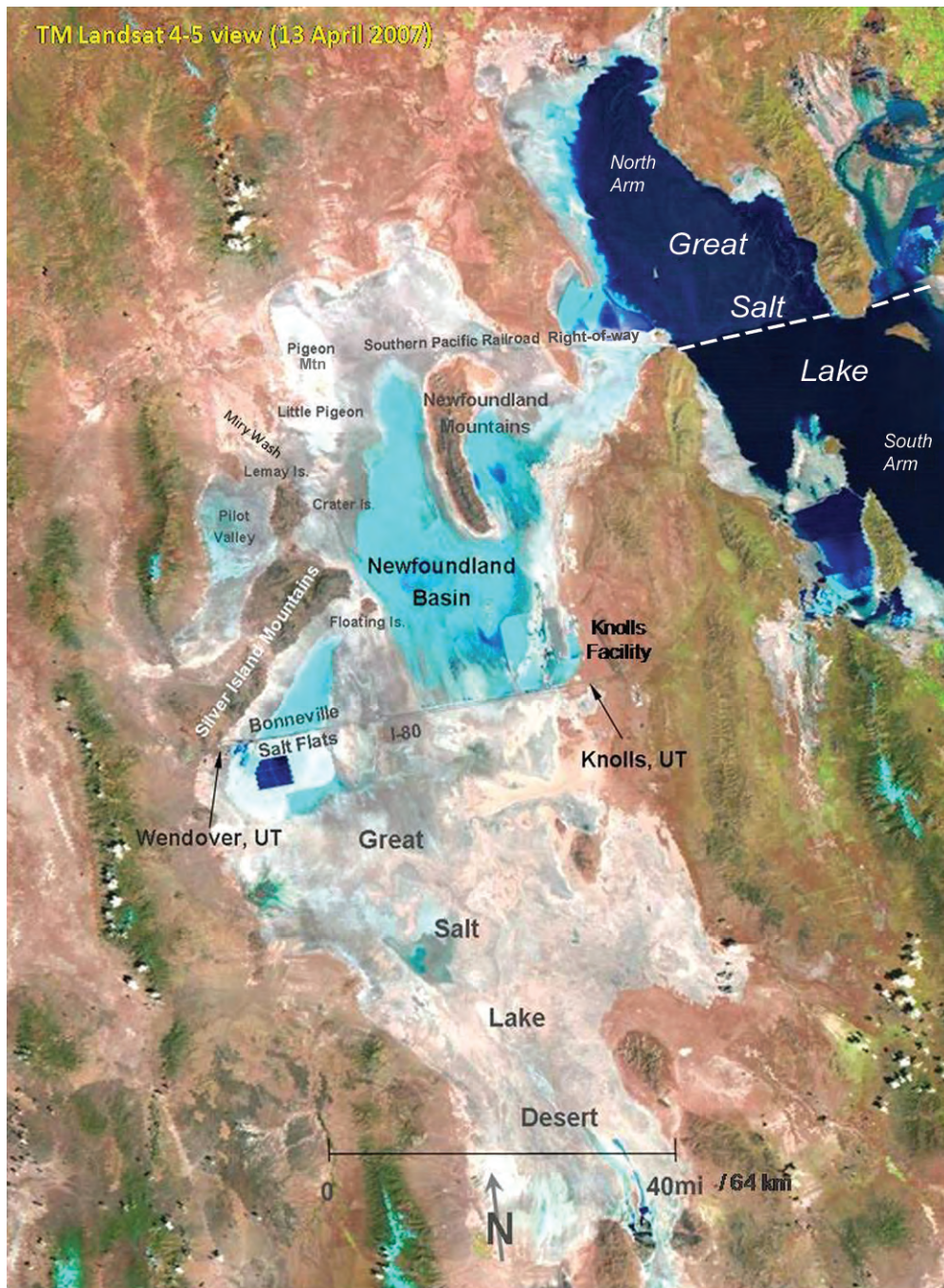


Figure 1. TM Landsat 4-5 view (13 April 2007, path 39, rows 31 and 32) showing orientation of Newfoundland Basin with respect to other subbasins within the Great Salt Lake Desert (Bonneville Salt Flats and Pilot Valley). Other topographic landmarks and cultural features (e.g., I-80 and Wendover, UT) that bound the Newfoundland Basin are also shown. Scale bar is approximate. (Dashed line shows causeway.) Imagery source is the U.S. Geological Survey Web site <http://edcsns17.cr.usgs.gov/Earth-Explorer/>.

and 3) evaluate the relationship and interaction between the mineralogy of the lacustrine sediments and the chemistry of the pore water entrained in these sediments.

The scope of the study included 1) drilling 24 reconnaissance boreholes and installing eight sets of nested monitoring wells to collect samples of lacustrine sediments and ground-water brines, 2) determining hydraulic conductivities of ground-water-bearing zones in the shallow-brine aquifer through aquifer tests of selected boreholes and monitoring wells, and 3) correlating key stratigraphic elements within sediments of the shallow-brine aquifer with pore-fluid chemistry and lacustrine-sediment mineralogy. Details of specific sample-site locations, dates of collection, stratigraphy, chemical analyses, and x-ray-diffraction (XRD) mineralogy are given in the appendices.

Description of Study Area

The Newfoundland Basin is a closed hydrologic basin in the northern part of the Great Salt Lake Desert of western Utah. The Great Salt Lake Desert is part of the Basin and Range physiographic province west of Great Salt Lake, and is underlain by a shallow-brine aquifer system developed in playa and lacustrine sediments composed of clays, carbonates, and gypsiferous evaporites. These salts and sediments are remnants of Pleistocene Lake Bonneville, which once occupied the western half of Utah and reached considerable depth (1000 feet/305 meters, Oviatt, 1997). The Newfoundland Basin is also a large playa that occupies one of three enclosed subbasins that comprise the Great Salt Lake Desert

(figure 1). These subbasins, which are separated by very low topographic divides, include the Bonneville Salt Flats (BSF), Pilot Valley, and the Newfoundland Basin. They are closed basins, with all drainage discharging toward their respective basin centers.

This report focuses on the subbasin immediately west of the Newfoundland Mountains. Although not formally named, this subbasin, which includes the topographic depression west of the Newfoundland Mountains, has been previously referred to as the Newfoundland Basin (Kohler and White 2004, White 2002, 2004). This terminology will be retained in this report. The Newfoundland Basin is bounded

on the east by the Newfoundland Mountains, and on the west by Little and Big Pigeon Mountains, Lemay, Crater, and Floating Islands (figure 1). A topographic divide that extends south-southeast from Floating Island separates Bonneville Salt Flats from Newfoundland Basin and forms its southwest boundary. Newfoundland Basin's southern boundary coincides approximately with east-west trending Interstate 80 (I-80). With exception of the "checkerboard estate" (alternating private and public sections) adjacent to the Southern Pacific Railroad right-of-way, which crosses the northern portion of the basin, most of the basin is public land administered by BLM.

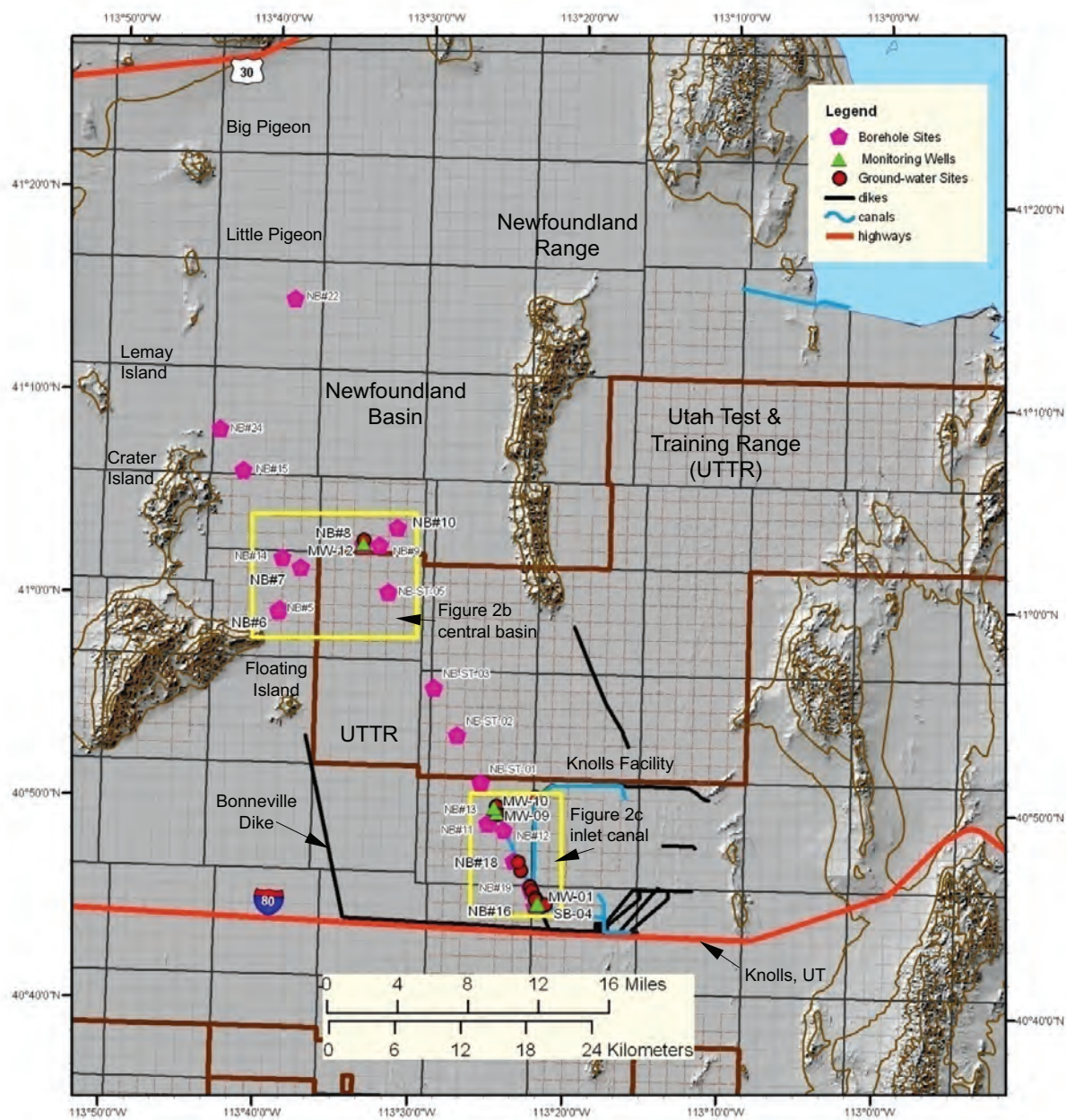


Figure 2a. Topographic map showing locations of boreholes, monitoring wells, and ground-water seeps that comprise the sources of brine, pore-water, and solid-phase samples. Specific topographic landmarks and cultural features (Bonneville Dike, UTTR, Knolls Facility, inlet canal, and Knolls, UT) are also included to aid orientation. Central-basin and inlet-canal details (indicated by yellow-border rectangles) are shown in figures 2b and 2c. Base data sources: U.S. Geological Survey National Elevation Dataset (NED) 10 meter-30 meter, 1999-2003; U.S. Geological Survey NED Shaded Relief from Geography Network, <http://www.geographynetwork.com>; and Utah Automated Geographic Reference Center TownshipsPLSS_24kTopo 1:24,000, 2001.

Recent maps of the Newfoundland Basin identify a portion of it as the Newfoundland Evaporation Basin. This is an anthropogenic feature covering about 500 square miles (1,295 square kilometers) (Wold and Waddell 1993), and bounded on the south and west by an artificial dike (Bonneville Dike - figure 2a). This area was subsequently filled with Great Salt Lake brine during the 1987-1989 West Desert Pumping Project conducted by the State of Utah. The term "West Pond" refers to the brine pond that formed in the Newfoundland Evaporation Basin as a result of the pumping project. During the pumping project and for some time after its termination, brine from the West Pond was transferred to a series of evaporation ponds via a 6-mile (9.6-kilometer) long inlet canal (figure 2a). This brine-processing facility was constructed by a mineral-extraction company within a non-exclusive right-of-way administered by BLM. Approximately 55,000 acres (22,258 hectares) of land encompassed by the right-of-way was federally owned, and about 2,000 acres (809 hectares) of Utah School and Institutional Trust Land was also involved (Mike Nelson, Supervisory Realty Specialist, BLM Salt Lake Field Office, personal communication, 7 May 2008). The brine-processing facility, which was situated adjacent to Knolls, Utah, is informally referred to in this paper as the Knolls Facility (figures 1 and 2a).

Approximately one-third (about 170 square miles/440 square kilometers) of the Newfoundland Basin is occupied by the U.S. Air Force (USAF) Utah Test and Training Range (UTTR - figure 2a). The UTTR surface and airspace are administered by the USAF through Hill Air Force Base, Ogden, Utah. The surface and subsurface minerals are administered by BLM.

Previous Work

Chemical Characterization of the Shallow-Brine Aquifer

Chemical analyses of brines from the Great Salt Lake Desert shallow-brine aquifer were reported by Nolan (1927), Nackowski (1967), Turk (1969), Lindenburg (1974), Lines (1978), Mason and others (1995), Kohler (2002), Kohler and White (2004), and White (2002, 2004). Nolan, Nackowski, and Lindenburg conducted large-scale studies that also included portions of the Newfoundland Basin, while Turk, Lines, Mason and others, and White confined their studies mainly to the Bonneville Salt Flats (Pilot Valley was included in Lines, and Mason and others). Kohler and Kohler and White summarized brine chemistry from brine samples obtained from recent and historic boreholes drilled in the Newfoundland Basin.

The objective of Nolan's study was to identify mode of occurrence, distribution, and general characteristics of K-bearing brines in the Great Salt Lake Desert (Nolan, 1927, p. 4). Nolan examined the shallow-brine aquifer in the Great Salt Lake Desert by drilling 405 boreholes on transects adjacent to existing highways, railroads, and accessible township lines. The boreholes were drilled with a 5-inch (13-centimeter) diameter auger to depths of up to 10 feet (3 meters), and were spaced on 1-mile (1.6-kilometer) centers (commonly at section corners). A brine sample was collected from each borehole and analyzed for K, Mg, chloride (Cl), and SO₄. Based on these analyses, the positions of 60 and 100 g/L Cl-

ion contours could be mapped and K and Mg values could be assigned to specific borehole locations. The 100 g/L Cl- contour encompassed a 1,424 square-mile (3,688 square-kilometer) area of the Great Salt Lake Desert, of which 449 square miles (1,163 square-kilometers), or about 32% of the total area, are within the Newfoundland Basin. Nolan also mapped the extent of the Bonneville and Pilot Valley salt crusts (Nolan, 1927, pp. 28, 35-39, and Plate 3). The results of Nolan's investigation were used by the USGS to classify much of the Great Salt Lake Desert as a known potassium resource area (Pera and others, 1978).

During 1964, the Utah Geological and Mineralogical Survey (now Utah Geological Survey) (Lindenburg, 1974, pp. 1, 9, 15, 21) drilled 85 core holes along and north of the Salt Lake Base and Meridian from BSF to Knolls, UT, to sample the brines and sediments of the Great Salt Lake Desert. Thirteen of the 85 core holes were within the bounds of the Newfoundland Evaporation Basin and distributed on 1-mile (1.6 kilometer) centers along the Salt Lake Base and Meridian. They extended from the north-trending portion of the Bonneville Dike on the west to Knolls on the east. The primary objective of Lindenburg's (1974) study was to understand the cause of compositional differences between brine chemistries of Great Salt Lake and the Great Salt Lake Desert. Lindenburg (1974, pp. 61-62) concluded that the major difference between the two brine systems was the higher sulfate content of Great Salt Lake, which was due to annual sulfate contribution from the discharge of the Jordan and Bear Rivers into the lake. He further concluded that Great Salt Lake Desert brines reflected post-Bonneville brines, and were confined to closed basins without measurable sulfate input from existing surface drainages.

Nackowski (1967) drilled 42 boreholes in the shallow-brine aquifer of Pilot Valley and Newfoundland Basin. The boreholes ranged from 12 to 16-feet (3.7 to 4.9 meters) deep, and seven of the 42 holes were drilled on 2-mile (3.2 kilometer) centers and extended east for 11 miles (17.6 kilometers) from north of Crater Island (in the Silver Island Mountains) to the center of the Newfoundland Basin. Brine samples were collected from each borehole and analyzed for Na, K, lithium (Li), Mg, calcium (Ca), SO₄ and Cl. Water table levels and sediment lithology (reported at 1-foot/0.3 meter intervals) were recorded for each borehole. The objective of Nackowski's (1967) study was to calculate the total brine supply and brine reserves contained in Pilot Valley (designated by Nackowski as the "Northwest Bonneville brine area"), as well as the depletion rate and production life for a specific brine cutoff grade (0.5% potassium chloride - KCl).

Turk (1969, pp.272-284), Lindenburg (1974, pp. 22-27), Lines (1978, p. 14), and Mason and others (1995, pp. 46-51) reported major ion compositions from chemical analyses of brine samples collected from 255 monitoring wells, 30 core holes, and 52 auger holes drilled in the BSF portion of the shallow-brine aquifer. The completed wells, core holes, and auger holes ranged in depth from 1 to 25 feet (0.3 to 7.6 meters), and were drilled or hand augered into the BSF playa between 1964 and 1993 (Turk 1969, pp. 64-65-70 wells; Lindenburg 1974, pp. 1-21-30 core holes; Lines 1979, p. 5-133 wells; White 2003, p. 4, U.S. Geological Survey Conservation Division [USGS-CD]- 52 auger holes; Mason and others 1995, p. 1-52 wells). Turk, Lines, and Mason and others performed multiple-year sampling, while sampling by

Lindenburg and USGS-CD was only once.

Brine analyses from 18 auger holes drilled on or adjacent to BSF by Nolan (1927) were used as baseline values for an historical comparison by White (2002, pp. 449-450) with more recent chemical analyses of BSF brines by Lines (1978), Mason and others (1995), and BLM (White, 2002).

In the mid-1960s, much of the Newfoundland Basin was explored for K by Reynolds Metals Company under a prospecting permit from the federal government. During this exploration program, 92 shallow boreholes were completed within the area flooded by the West Desert Pumping Project, 72 of which were in the Newfoundland Basin. Brine samples from these boreholes were analyzed for K, Mg, Cl, and SO₄. More recently, Kohler and White (2004) used chemical analyses from the Reynolds brine samples and published brine analyses from the Great Salt Lake North Arm as the two compositional extremes possible for mixtures used to simulate effects of brine mixing as a result of the Pumping Project. The mixing simulation was performed using the TEQUIL model, which is based on Pitzer electrolyte equations, and calculates liquid-solid-gas equilibria in complex brine systems (Moller and others 1997). Results of the TEQUIL modeling showed that a simulated 50-50 artificial mixture of pre-Pumping Project shallow-aquifer brine (Reynolds brine), and Great Salt Lake brine was very similar to Newfoundland Basin brines collected 10 years after the completion of the Pumping Project. Furthermore, the modeling suggests that current Newfoundland Basin brine chemistry reflects mixing of Great Salt Lake and original Newfoundland Basin shallow-aquifer brines.

Origins of Salt Crust and Shallow-Brine Aquifer

Salt crust and associated near-surface deposits of the Great Salt Lake Desert resulted from the desiccation of Lake Bonneville (Mason and Kipp 1998, p. 10). For example, as the drying of Lake Bonneville progressed, salt crust was originally deposited in the center of the basin. Once the weight of the lake water on the basin floor was eliminated, upward isostatic rebound raised the east side of the Lake Bonneville Basin more than the west side. Consequently, the salt crust position was shifted west to its current location as the Bonneville Salt Flats near the base of the Silver Island Mountains (Eardley, 1962, p. 9-10, 22-23; Turk and others, 1973, p. 66-67). This shifting was an iterative process involving dissolution of the salt crust from meteoric precipitation coupled with gradual westward shifting of the resulting brine pool and re-precipitated salt crust as the basin floor slowly rebounded. Recent and historical areal extent, thickness, and volume of Bonneville Salt Flats salt crust was analyzed and described by White and Terrazas, (2006).

It should be noted that the existing salt crust in the Newfoundland Basin is not related to the Bonneville Salt Flats and is due mainly to the 1987-1989 West Desert Pumping Project. Of the 695 million tons of salt estimated by the USGS (Wold and Waddell, 1993) to have been pumped into the Newfoundland Evaporation Basin, 10 million tons are estimated to be in a salt crust that developed on the floor of the West Pond (see Wold and Waddell, 1993 for details of the estimated salt budget from the Pumping Project). Further-

more, no salt crust was mentioned in the stratigraphic logs from the Reynolds borehole program that predated the Pumping Project.

Dissolved solids in the shallow-brine aquifer of the Great Salt Lake Desert probably were derived from multiple sources. Nolan (1927, p. 41-42) suggested a combination of dissolved solids transported by waters draining into a closed basin and those leached from clay-bearing lacustrine sediments containing entrained brine that resulted from multiple desiccation episodes of Lake Bonneville. He also concluded that quantitatively, the latter source was more important, as it supplied the sodium chloride (NaCl) that makes up the bulk of dissolved solids in the brine. Data presented by Turk and others (1973, p. 75) substantiated Nolan's conclusion.

Other investigators suggested that the ultimate source of dissolved solids in the shallow-brine aquifer was the same as the source of the salts in the Great Salt Lake. Specifically, Feth (1959, p. 638) believed that pre-Lake Bonneville bedded evaporite deposits provided most of the salt load to the Lake Bonneville Basin (e.g., bedded halite deposits in the Jurassic Arapien Shale have been documented to extend for tens of square miles in Juab, Sanpete, and Sevier Valleys). Jones (1966, p. 198) concluded that, in general, the distribution of Cl, bicarbonate (HCO₃), and SO₄ anions in highly concentrated lake or playa waters is a direct function of existing lithology and associated weathering processes within the contributing drainage areas (e.g., high percentages of Cl indicate sedimentary rocks of marine origin and solution processes; carbonate (CO₃) reflects igneous lithologies and the hydrolysis of primary silicates; predominance of SO₄ suggests ore mineralization and acid alteration). All of the lithologic environments mentioned by Jones are present in the Lake Bonneville Basin.

In summary, major sources for ions comprising the solid and liquid phases of the salt crust and shallow-brine aquifer have been identified as 1) clayey lacustrine sediments, 2) evaporite deposits in the catchment, and 3) existing lithologies within the drainage basin.

Characterization of Great Salt Lake Desert Lacustrine Sediments

Early characterization of Great Salt Lake Desert lacustrine sediments deposited in Lake Bonneville was by G. K. Gilbert (1890) in his monograph "Lake Bonneville." Gilbert divided Lake Bonneville sediments into two groups: white marl and yellow clay (Nolan 1927, p. 32). These units have now been identified as facies of the Bonneville alloformation, deposited in late Pleistocene Lake Bonneville, and studied in specific sedimentologic detail by Oviatt (1987, 1997), and Oviatt and others (1994). The Bonneville sediments have been attributed to shallow offshore to deep-water deposition in the last deep-lake cycle lasting from about 35 to 10 thousand years (ky) (Scott and others, 1983; Spencer and others, 1984; Currey and Oviatt, 1985; Oviatt and others, 1992).

The most recent sediments of the Newfoundland Basin were described by Eardley (1962) from shallow cores taken across the basin in the vicinity of I-80. He concluded that the last carbonate (lacustrine) sediments were deposited at least

10 ky ago, and since that time have undergone variable ablation up to depths of 15 feet (4.6 meters). Eardley also suggested that in the course of evaporation, gypsum was formed through capillary action at the sediment surface, and in places was subsequently mobilized and accumulated in dunes. Turk and others (1973) described the recent surficial sediments of the Bonneville Salt Flats subbasin (adjacent to and southwest of Newfoundland Basin) and related them to the shallow aquifer hydrology. Sediments were characterized as primarily silt and clay-sized materials, with sand-sized particles composed mainly of brine shrimp fecal pellets in thin discontinuous lenses. Nodular layers of sand-sized aragonite were observed to be commonly associated with the fecal-pellet facies. Additionally, the overall mineralogy was summarized as dominantly aragonite in all size fractions, with quartz, smectite, minor gypsum, illite, and calcite. Graf and others (1959) reported dolomite, and perhaps magnesite, in a shallow carbonate layer, but this has not been confirmed. Jones and Spencer (1999) reported on the ubiquitous greenish to olive clay beneath the salt crust in the lowest area of the Bonneville Salt Flats and equated it to diagenetic Mg-smectite identified in the saline bottom sediments of Great Salt Lake.

FIELD METHODS AND SAMPLE COLLECTION

Boreholes

Twenty-four boreholes were hand augered in undisturbed Newfoundland Basin lacustrine sediments between September 1998 and August 2001. Twenty of the boreholes were labeled with an alpha-numeric identifier starting with NB (Newfoundland Basin), followed by the pound sign and a sequential numeral (e.g., NB#5). Some boreholes were twinned at or near the same site and consequently assigned lowercase alpha suffixes to their respective borehole labels (e.g., NB#11a and NB#11b). Boreholes were generally located in either the central or peripheral portions of the basin. The central portion represents the southern end of the topographic low point of the basin and is the site of three boreholes (NB#8, 9, and 10 – see figure 2b). The peripheral portion includes seven boreholes distributed along the basin's west margin (NB#5, 6, 7, 14, 15, 22, and 24 – see figures 2a & 2b), and ten boreholes sited in the basin's southeastern quarter, which includes the inlet canal near Knolls, UT (NB#2, 3, 11a, 11b, 12, 13, 16-19 – see figure 2c). An additional four boreholes (identified as NB-ST-01 through NB-ST-05; "ST" = salt-crust transect) were located along a 15-mile (24-kilometer)

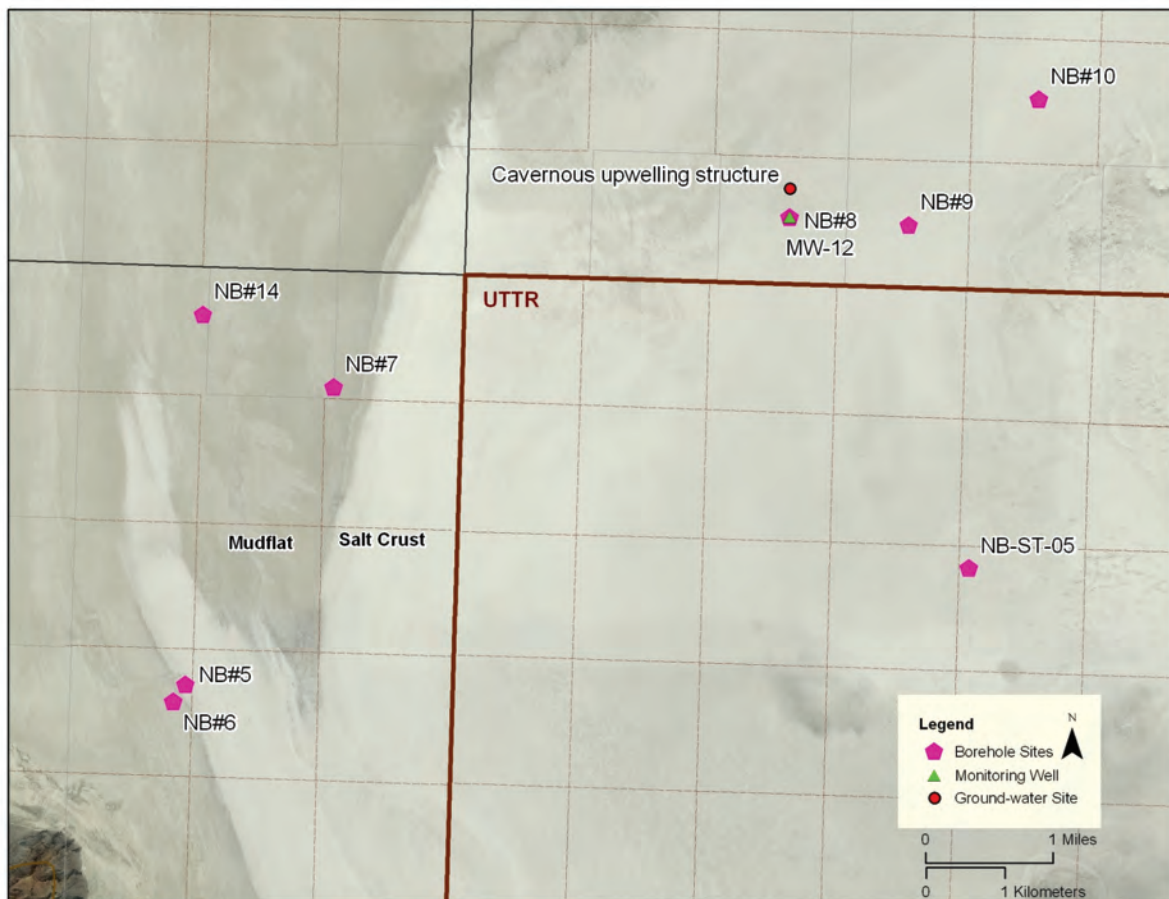


Figure 2b. Orthophoto map showing locations of boreholes and monitoring wells that comprise the sources of brine, pore-water, and solid-phase samples from the central basin (NB#8, NB#9, NB#10, MW-12, and NB-ST-05), and western periphery (NB#5, NB#6, NB#7, and NB#14). Mudflat and salt-crust areas and a ground-water site labeled "cavernous upwelling structure" (see figure 4) are also identified. Base data sources: U.S. Department of Agriculture, National Agriculture Imagery Program (NAIP) Preliminary Compressed County Mosaics, 2006; U.S. Geological Survey National Elevation Dataset (NED) 10 meter-30 meter, 1999-2003; Utah Automated Geographic Reference Center TownshipsPLSS_24kTopo 1:24,000, 2001.

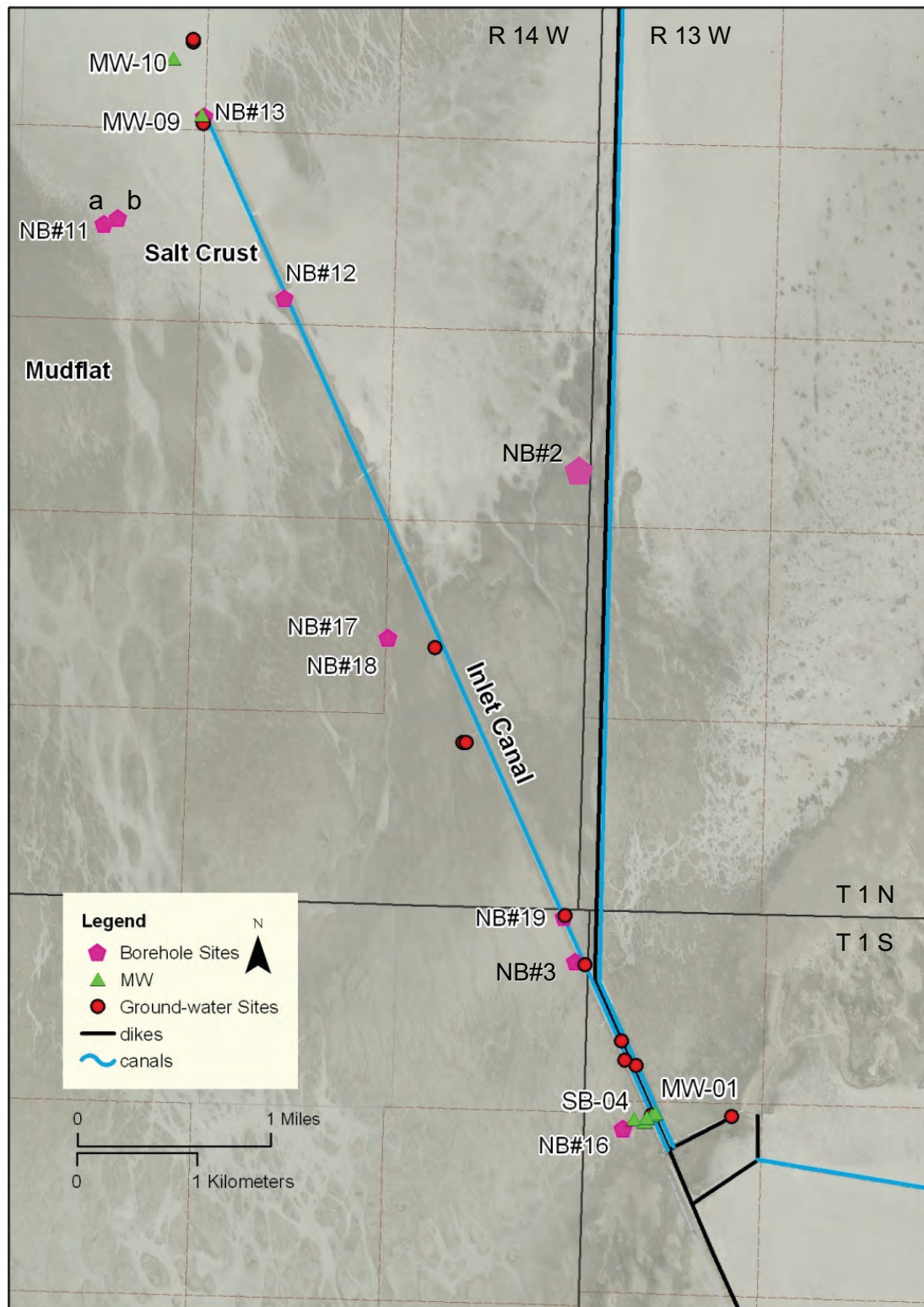


Figure 2c. Orthophoto map of the inlet canal showing locations of boreholes and monitoring wells that comprise the sources of brine, pore-water, and solid-phase samples from the southern periphery (SB-04, MW-01, NB#2, NB#3, NB#16–NB#19) and intermediate sites (NB#11a, NB#11b–NB#13, MW-09, and MW-10). Mudflat and salt-crust areas are also identified. Base data sources: U.S. Department of Agriculture, National Agriculture Imagery Program (NAIP) Preliminary Compressed County Mosaics, 2006; U.S. Geological Survey National Elevation Dataset (NED) 10 meter-30 meter, 1999-2003; Utah Automated Geographic Reference Center Township-sPLSS_24kTopo 1:24,000, 2001.

transect that extends from the north end of the inlet canal through the UTTR (see figure 2a). This transect, along with boreholes distributed along the inlet canal represents a transition from the basin's peripheral margin to its central topographic low. Borehole depths ranged from 3 to 9 feet (0.9 to 2.8 meters) deep. Two different types of hand auger were used to drill the boreholes: 1) a 4.6-inch (11.7-centimeter) outside diameter (O.D.) mud auger was used to record sediment stratigraphy and ground-water levels, and 2) either a 3.0-inch (7.6-centimeter) inside diameter (I.D.) Soil Recovery Auger (SRA), or a 2.0-inch (5-centimeter) I.D. split-core sampler were used to collect core samples from specific borehole locations. Each hole was logged to record changes in the sediment stratigraphy and to describe the sediment composition of ground-water-bearing strata (appendix A1).

Borehole total depths, ground-water interception depths and subsequent static water levels were measured and recorded as feet below ground level (BGL). Ground-water samples were collected from each of the boreholes and submitted for chemical analyses. Core samples of the lacustrine sediments were collected from 13 of 24 boreholes to extract pore fluids for chemical analyses and to determine solid-phase composition of the cored sediments by X-ray diffraction (XRD). Core samples and their pore fluids were analyzed by USGS, Reston Research Laboratory (see appendix A2 for analytical methods and quality-assurance details).

Aquifer tests were performed with an impeller pump on six of the boreholes to measure ground-water drawdown and recovery. Measured pump rates in the field ranged from 1 to 2 gallons (3.8 to 7.6 liters) per minute (gpm/Lpm). The change in pump rate was a function of head difference in static water levels. These measurements were subsequently used to calculate specific capacities of ground-water-bearing strata encountered in individual boreholes. Resulting specific capacities were then used as input to TGUESS version 1.2 to estimate the hydraulic conductivities of the respective ground-water-bearing strata. The TGUESS program estimates transmissivity (T) and hydraulic conductivity (K) from specific capacity (Q/s) using an iterative technique described by Bradbury and Rothchild (1985, 1993). Because its computational routine requires a guessing value for transmissivity, the program was named TGUESS.

Ground-water samples were collected from each borehole with a peristaltic pump using 0.25-inch O.D. polyethylene tubing. Collected samples were stored in 8-ounce (237 mL), low-density polyethylene (LDPE) sample bottles. Sample-density measurements using a CLUSA no. 458438 hydrometer were determined in the field for each sample. Confirmation density measurements and chemical analyses for specific ions were performed by Chemical and Mineralogical Services (CMS), Salt Lake City, UT. Sodium and potassium concentrations were determined by flame photometry using an Instrumentation Laboratories Model 343. Calcium and magnesium were determined by di-sodium ethylenediaminetetraacetate (EDTA) titration (EPA methods 311C and 314B). Sulfate was determined gravimetrically by barium chloride precipitation (EPA method 426A), and chloride was determined by silver nitrate titration using the Mohr method. Sample densities were determined with a density meter and verified with a hydrometer (EPA method 210B). Total dissolved solids (TDS) were calculated by summation of cation and anion concentrations. To check the accuracy of the analyses, the mole-balance method described by Sturm and others (1980, p. 175) was used.

Monitoring Wells

Eight sets of monitoring wells were completed in the Newfoundland Basin shallow-brine aquifer during 1999 and were designated as MW-01 through MW-05, MW-09, MW-10, and MW-12. The wells were installed by S. S. Papadopoulos and Associates, and were 1-inch I.D. PVC with 0.010-inch (0.025-centimeter) slotted screens. Screened intervals typically ranged from 2 to 5 feet (0.6 to 1.5 meters). The length of the screened interval plus a distance of 1 foot (0.3 meters) above the screen was gravel packed with 20–40 Colorado Silica Sand. A 1-foot thick barrier sand (screened to 70 mesh/0.2 millimeter) was placed above the gravel pack to prevent infiltration of cement grout. Each well was then grouted with Type V Portland cement from the surface of the barrier sand to ground level. Because the shallow-brine aquifer was reported to extend to depths of about 25 feet (7.6 meters) BGL (Lines, 1979; Mason and Kipp, 1998), monitoring-well sets were comprised of two to three wells (table 1). Shallow water-table wells 7 to 9-feet (2.1 to 2.7-meters) deep were identified by an "A" suffix, and wells from 10 to 20 and 21 to 28-feet (3 to 6 and 6.4 to 8.5-meters) deep were designated with "B" and "C" suffixes, respectively.

Wells MW-01 through MW-05 were located at the south end of the Knolls Facility inlet canal on a line perpendicular to the trend of the canal. Wells MW-09 and MW-10 were located at the north end of the inlet canal (about 6 miles/9.6 kilometers from MW-01 through MW-05), and separated from each other by a distance of about 0.3 miles (0.5 kilometers) along a north-west-trending line extending from the inlet canal (figure 2c). The MW-12 set of wells is located in the deep portion of the Newfoundland Basin about 17 miles (27 kilometers) northwest of the end of the inlet canal (figure 2a).

Ground-Water Seeps

Horizontal seepage zones in the side walls of the Knolls Facility inlet canal, and ground-water discharge from vertical fissures observed in mudflat clays and from cavernous upwelling structures in salt-crust settings comprise the ground water-seep sample category (figures 3a, 3b, and 4). Samples were collected with a peristaltic pump using 0.25-inch O.D. polyethylene tubing and stored in 8-ounce (237 mL), low density polyethylene (LDPE) sample bottles. Density measurements and chemical analysis for specific ions were determined by Chemical and Mineralogical Services (CMS), Salt Lake City, UT, as described above. Some sample splits were also submitted to USGS, Reston Research Laboratory for analyses.

Surface Water

Brine samples from the transient pond covering both mudflat and salt-crust floors comprise the surface-water sample category (figure 5). The transient pond is more typically a winter occurrence and results from ponding of both ground-water discharge and accumulation of meteoric precipitation on the playa surface. The ground-water component of this ponding is due to reduction of evaporation rate during the late fall and winter months (commonly November through March). However, some additional ponding also occurs as a result of summer thunderstorms. Surface-water samples were collected and analyzed as described under "Ground-Water Seeps."

Table 1. Listing of Newfoundland Basin monitoring-well construction data (Bryan Grigsby, Hydrogeologist, S.S. Papadopoulos, written communication, January 7, 2008).

Location	Construction Date	Ground Elev., ft	TOC ¹ Elev., ft	Total Depth, ft (BGL) ²	Screen Interval, ft (BGL) ²	Screen Midpoint Elev., ft (BGL) ²	Well Seal Interval, ft (BGL) ²	TOC ¹ , ft (AGL) ³
MW01A	10/28/1999	4218.3	4222.52	7	2.5 - 6.9	4213.6	NA	4.2
MW01B	10/29/1999	4218.2	4221.35	11	9.2 - 10.7	4208.2	2 - 7.6	3.1
MW01C	10/29/1999	4218.1	4221.14	16.5	14.7 - 16.4	4202.5	3 - 13.1	3.1
MW02A	3/8/2000	4224.4	4227.21	14.8	10.2 - 14.2	4212.2	2 - 6.8	
MW02C	11/4/1999	4224.5	4227.25	24	21.5 - 24	4201.7	2 - 20.5	2.7
MW02D	3/7/2000	4224.6	4227.11	57	52.5 - 56.5	4170.1	2 - 49	
MW03A	11/3/1999	4217.2	4220.99	7	1.5 - 6.5	4213.2	NA	3.8
MW03B	11/3/1999	4217.2	4221.17	20.5	18 - 20.5	4197.9	1.5 - 15.6	3.9
MW03C	11/3/1999	4217.2	4221.05	26	23.4 - 25.9	4192.5	1.5 - 22.8	3.8
MW03D	3/18/2000	4217.1	4220.15	61	53 - 57	4162.1	2 - 49	
MW04A	11/5/1999	4220.6	4223.44	9	4.2 - 8.7	4214.1	2 - 3.1	2.6
MW04B	11/5/1999	4221.3	4223.88	20	17.5 - 20	4202.5	2 - 16.5	2.4
MW04C	11/5/1999	4221.3	4224.14	24.5	22 - 24.4	4198.1	2 - 21.1	2.6
MW05A	11/5/1999	4223.8	4226.21	11.3	8.6 - 11	4214.0	2 - 5.2	2.4
MW05B	11/5/1999	4224.0	4226.64	17	14.8 - 17	4208.1	2 - 13.8	2.6
MW05C	11/5/1999	4223.4	4226.21	27.5	25.3 - 27.4	4197.0	2 - 24	2.8
MW05D	3/14/2000	4223.7	4227.08	57.5	52.5 - 56.5	4169.2	2 - 50	
MW09A	11/16/1999	4215.2	4218.27	7	2.1 - 6.5	4210.9	NA	3.1
MW09B	11/18/1999	4215.3	4217.72	23	17.2 - 19.7	4196.8	1 - 13	2.4
MW10A	11/20/1999	4215.3	4218.03	7	2.2 - 7	4210.7	NA	2.7
MW10B	11/20/1999	4215.4	4219.01	18	15 - 17.5	4199.1	1 - 12	3.6
MW12A (salt)	11/13/1999	4213.2	4216.17	1.6	0.3 - 1.6	4212.2	NA	3.0
MW12B	11/15/1999	4213.2	4216.38	6.5	4.5 - 6.5	4207.7	1.5 - 4	3.3
MW12C	11/15/1999	4213.2	4216.01	18	15 - 17.5	4196.9	1.5 - 13.8	3.0

¹TOC = Top of casing²BGL = Below ground level³AGL = Above ground level

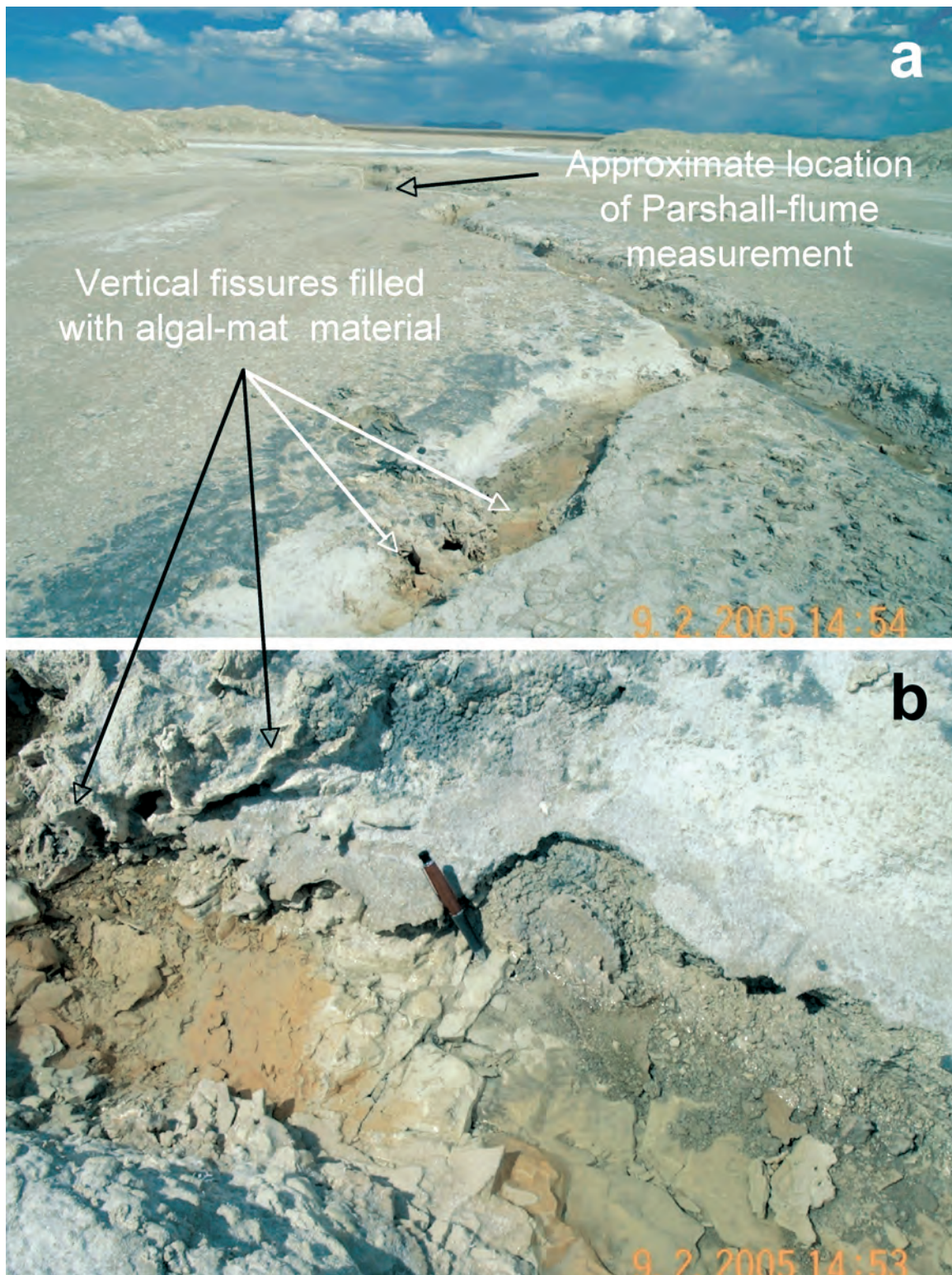


Figure 3. Example of ground-water discharge from vertical fissures present in the floor of dendritic drainages adjacent to west-side breaches in the inlet canal berm (3a). Location is near the south end of the inlet canal adjacent to NB#19 (see figure 2c). Vertical fissures occur both as open fractures that discharge ground-water brine (marked by ball-point pen in 3b), and as fissure-filled algal-mat material (3a and 3b). During July 2001, a discharge flow rate was measured with a Parshall flume just east of this location where branches of the dendritic drainage converged into a single channel (3a). Photographs by W. White, BLM, 2 September, 2005.



Figure 4. Example of ground-water discharge from a cavernous upwelling structure in the Newfoundland Basin salt crust. Location is 282 feet (86 meters) northwest of borehole NB#8 (UTM 284,620 E., and 4, 547,108 N.) Photograph by W. White, BLM, 16 September, 1999.



Figure 5. Example of the winter transient pond in the central basin topographic low of Newfoundland Basin. View is east toward the southern end of the Newfoundland Range, and location is 3.5 miles (5.6 kilometers) south of monitoring well MW-12. A 1.0-inch (2.5-centimeter) pond depth was measured at this location. Photograph by W. White, BLM, 25 April, 2000.

Data Archival

Borehole and monitoring-well locations, and their respective surface elevations, total depths, static ground-water levels, and brine-sample chemical analyses were archived in the USGS National Water Information System (NWIS). Ground-water seep and surface-water locations and their respective brine-sample chemical analyses were also entered into NWIS.

Chemical analyses of pore-water recovered from borehole cores are listed in appendix A3. Chemical analyses of brine samples collected from ground-water seeps, surface water, and open boreholes are listed in appendices A2 and A4.

RESULTS AND DISCUSSION

Sedimentology

Lacustrine Sediments of the Shallow-Brine Aquifer

The focus of this study is the upper 25 feet (7.6 meters) of lacustrine sediments that comprise the shallow-brine aquifer, which occupies an area of about 449 square miles (1,163 square-kilometers) within the Newfoundland Basin. This area of the Newfoundland Basin lies within the 100 g/L Cl contour identified by Nolan (1927, Plate 3). Sediment types in the Newfoundland Basin include clay and silt, sand-size material (oolites and brine-shrimp fecal pellets), algal-mat material, gypsum crystals, and halite crust.

The clay and silt-size material dominates the bulk of the lacustrine sediments and forms near-horizontal beds that can be traced along the 6-mile (9.6-kilometer) length of the inlet canal at Knolls (figure 2c). Typical clay mineralogy observed in the sediment beneath Great Salt Lake and nearby Bonneville Salt Flats includes smectite, illite, and a small amount of kaolinite. The remainder of clay-sized material is composed of carbonate, largely aragonite, with lesser calcite and dolomite (Gwynn and Murphy, 1980, p. 88; Turk, 1969, p. 27-32). Quantitative X-ray diffraction (XRD) mineralogy determined from Newfoundland Basin core samples from this study includes halite, quartz, aragonite, calcite, dolomite, gypsum, and a summation of the clay minerals.

Interbedded with clay and silt are alternating facies of sand-size oolites and brine-shrimp fecal pellets. When encountered in recovered core, these oolite/fecal-pellet facies are typically saturated with brine and range in thickness from 1 to 5 inches (2.5 to 13 centimeters). This facies is an important conduit for ground-water transport in the shallow-brine aquifer. Commonly associated with the oolite/fecal-pellet facies is algal-mat material that either forms a wavy carbonate cement cap on top of, or wavy cemented interbeds within the oolite/fecal-pellet facies. In addition to association with the oolite/fecal-pellet facies, the algal-mat material has been observed both as fillings in vertical fissures developed in the clay and silt-size material and as individual low-relief mounds protruding from the present mudflat surface.

Turk (1969, p.38) and Turk and others (1973, p. 76-77) suggested two possible processes for the vertical-fissure formation: osmotic desiccation and syneresis. However, determination of actual processes for vertical-fissure formation is beyond the scope of this study. Consequently, in this discussion we refer to them as "vertical fissures." We record their presence because, in

sufficient density, they have been reported as significant conduits for ground-water transport and discharge (Mason and Kipp 1998). Open vertical fissures exposed in the clay floors of dendritic drainage channels incised in the mudflat surfaces adjacent to breaches in the inlet canal have been observed as sites of ground-water discharge from the shallow-brine aquifer. Algal-mat-filled vertical fissures were also adjacent to these open fissures (see figures 3a and 3b). Brine-tolerant brown-colored algae were observed as gelatinous coatings on surfaces of some open fissures in the dendritic drainage channels, and on surfaces of brine-saturated vertical fissures contained in the clay and silt-size material comprising some borehole core samples. We believe these algae are responsible for forming the algal-mat material observed in the Newfoundland Basin.

In addition to their scattered distribution on Newfoundland Basin mudflat surfaces, several occurrences of individual low-relief mounds composed of wavy algal-mat material were also observed protruding through thin salt crust (less than 0.5 inches/1.3 centimeters thick) about 0.5 miles (0.8 kilometers) north of the end of the inlet canal. Mound length and width dimensions range from 2 by 2 to 6 by 3 feet (0.6 by 0.6 to 1.8 by 0.9 meters), and mound height is typically 1 to 2 inches (2.5 to 5.0 centimeters). These low-relief mounds are also sites of ground-water discharge from the shallow-brine aquifer, and accompanied by presence of brown-colored algae as gelatinous coatings on scattered fragments of wavy algal-mat surfaces (figures 6a and b). The wavy algal-mat material is typically made up of carbonate-cemented oolite/fecal-pellet facies mixed with fine sand-sized angular carbonate fragments. The combination of ground-water discharge and algae-coated mat surfaces from the low-relief mounds smelled like tidal-pool ocean water. Although not specifically observed during field exams, conduits of this ground-water discharge from the low-relief mounds are believed to be similar to the vertical fissures observed in the clays of the Newfoundland Basin mudflats (e.g., clays exposed in the walls of the inlet canal and in clay floors of the dendritic drainages adjacent to the inlet canal—see figure 3b). The amount of ground-water discharge from these low-relief mounds at the time of visitation was sufficient to collect several brine samples, but did not wet the salt crust beyond the borders of the mound (figures 6a and 6b).

Gypsum occurrences include an aeolian facies composed of uniform, sand-size, rounded gypsum crystals, and a diagenetic facies composed of doubly terminated lath-shaped individual gypsum crystals dispersed in a clay matrix. The rounded gypsum crystals of the aeolian facies range from about 0.03 to 0.06 inches (0.8 to 1.5 centimeters) in their longest dimension. Doubly terminated lath-shaped gypsum crystals of the diagenetic facies increase in size with depth and range in length from 0.25 to 0.5 inches (0.6 to 1.3 centimeters).

The salt crust resulting from the 1987-1989 West Desert Pumping Project is lens shaped in both its east-west and north-south cross sections. Where measured salt-crust thickness is greatest, its width is about 9 miles (14 kilometers) east-west (just north of the UTTR boundary between T. 3 and 4 N.). Measured salt-crust thickness ranges from 18 to 25 inches (45.7 to 63.5 centimeters) in three borehole sites near the basin's topographic low point in sections 26, 33, and 34, T. 4 N., R. 16 W., Salt Lake Base and Meridian. Based on satellite imagery, salt-crust length observed during this study is at least 30 miles (48 kilometers) north-south starting from the north end of the inlet canal (figure 7). Although originally precipitated from evapora-

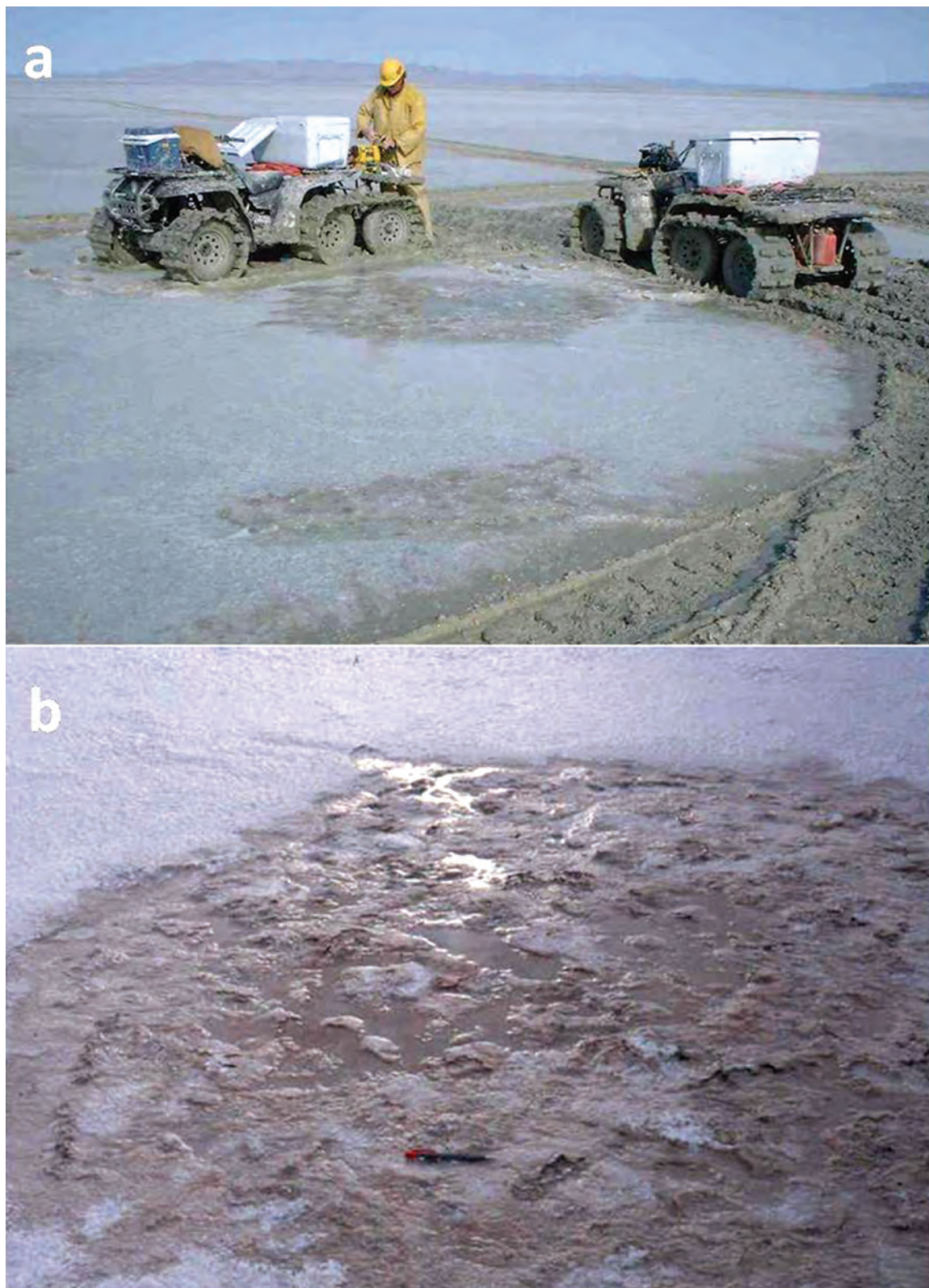


Figure 6. Example of ground-water discharge from low-relief algal-mat mounds located near the north end of the inlet canal and 680 feet (207 meters) northeast of monitoring well MW-10: 6a shows setting up to sample ground-water discharge from one of the mounds with a peristaltic pump; 6b is a close-up of a low-relief algal-mat mound showing ground-water discharge and examples of wavy algal-mat fragments (red ball-point pen). Measured mound length-width dimensions range from 2 by 2 to 3 by 6 feet (0.6 by 0.6 meters to 0.9 by 1.8 meters) with 1.0-inch (2.5-centimeter) vertical relief above the thin salt-crust-covered mudflat surface. Photographs by J. Kohler (6a) and W. White (6b), BLM, 23-24 March, 2000.

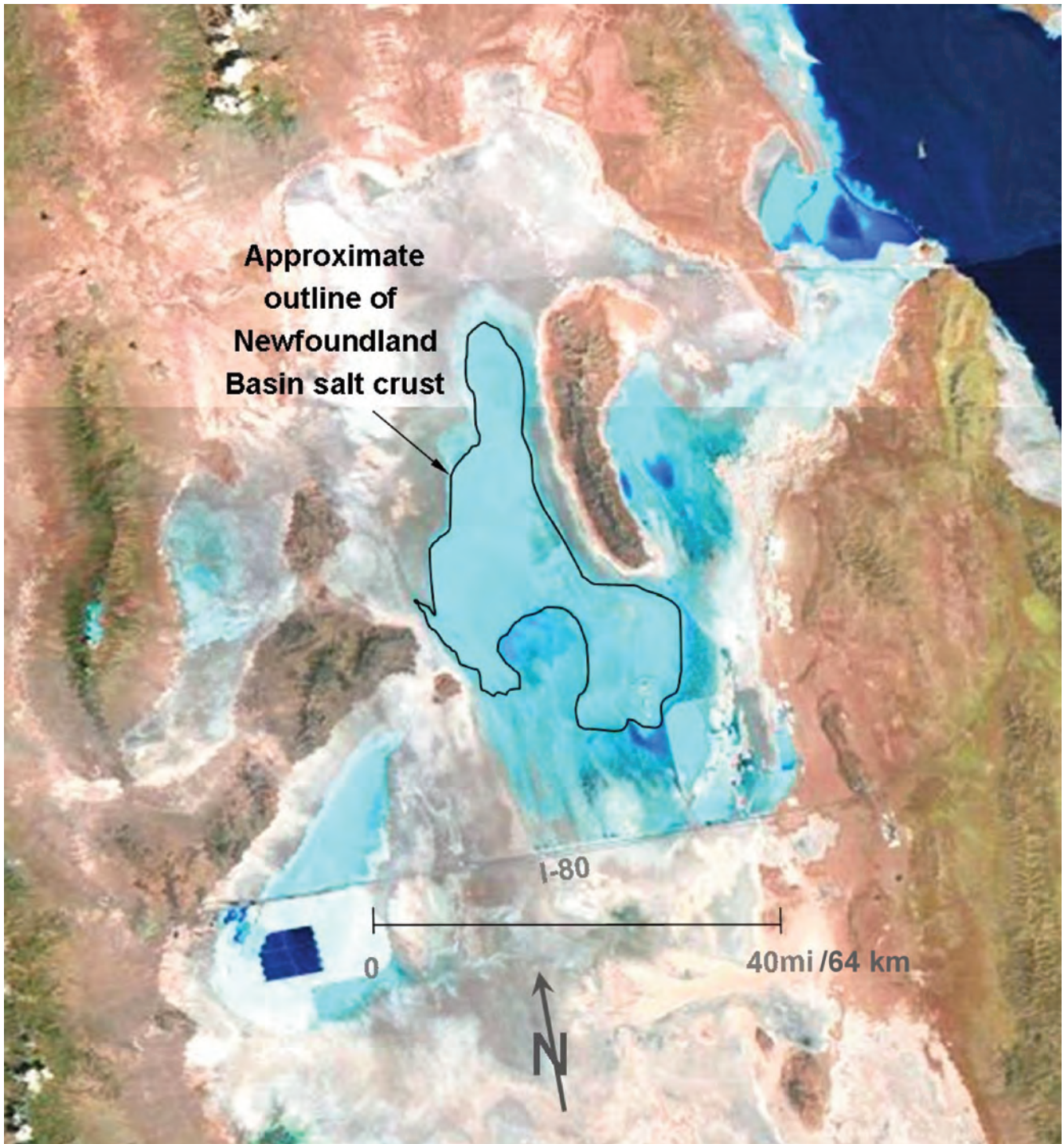


Figure 7. TM Landsat 4-5 view (13 April 2007, path 39, rows 31 and 32) showing the approximate outline of Newfoundland Basin salt crust. Scale bar is approximate. Imagery source is the U.S. Geological Survey Web site, <http://edcns17.cr.usgs.gov/EarthExplorer/>.

tion of West Pond brine, the resulting halite deposit was probably modified into strata with distinctly different morphology as a function of dissolution by and evaporation of the annual winter transient pond, and from effects of seasonal fluctuation of ground-water levels in the shallow-brine aquifer (White, 2004, p. 251).

Two visually different halite strata comprise the salt crust. These were described informally in the field as “dense-cemented halite,” and “cemented-coarse-porous-halite” (figures 8a and b). Unfortunately, these descriptions were made without benefit of thin-section examination by optical microscopy. However, based on the criteria described by Lowenstein and Hardie (1985) for recognition of salt-pan evaporites, the two informally-described strata are most likely a combination of morphologies resulting from alternating periods of flooding (from combined meteoric precipitation and ground-water discharge), evaporative concentration of the winter transient pond, and desiccation of briny pore water in salt-crust surface exposures. Based on the salt-pan evaporite criteria, the “dense-cemented halite” stratum is most likely similar to the dissolution and deposition features produced during the flooding stage of Lowenstein and Hardie (1985). Consequently, we would anticipate that the “dense-cemented halite” stratum would be characterized by repeated episodes of dissolution-truncated “chevron” and “coronet”-shaped halite crystals, clear diagenetic halite cement, and fine layers of clastic and/or carbonate sediment (see figures 8a and b). The “cemented-coarse-porous-halite” stratum is most likely due to accumulation of halite hopper-crystal rafts that formed during evaporation of the West Pond brine. As these halite hopper-crystal rafts accreted on the brine pool surface during summer evaporation, their accumulated mass eventually exceeded the surface tension and sank to the pond-sediment interface. The accumulation of these rafts on the pond bottom probably resulted in the uneven layering and porous texture observed in the “cemented-coarse-porous-halite” stratum (figure 8b), which was likely due to bridging of raft fragments and accumulation of additional hopper crystals. This stratum contains petrographic features similar to those described in the saline-lake stage of Lowenstein and Hardie (1985).

The different lacustrine sediments comprising the shallow-brine aquifer suggest the following depositional environments (after Eardley and Gvosdetsky, 1960, p. 1339):

- Oolites – shallow saline-water lake, within influence of wave base.
- Brine shrimp eggs and fecal pellets – very saline lake, within influence of wave base.
- Algal mat – either shallow saline-water lake, or locus of ground-water discharge from shallow-brine aquifer in vicinity of playa center (discharge points may coincide with vertical fissures in mudflat clay and silt).
- Aeolian gypsum – gypsum precipitated from evaporation of the shallow-brine aquifer as it discharges to the playa surface during the summer and then transported by wind action. Observed as gypsum dune deposits or as water-laid gypsum “sand” deposits in the winter transient pond (in either setting, gypsum crystals are sand size and

commonly rounded from attrition caused by saltation during wind transport).

- Diagenetic gypsum – dispersed in clay facies and resulting from growth of gypsum crystals from entrained brines in mudflat clay and silt (results in doubly terminated gypsum crystals as much as 0.5 inches in length and width).
- Laminated clay – perennial lake in which bottom sediments are below wave base.
- Fetid black clay – “rotten eggs” smell (H_2S) and finely-divided metal sulfide precipitates characterize the fetid black clay and are metabolic products of anaerobic sulfate-reducing bacteria that reside in the brine pore water entrained in the lacustrine clay and silt. Because of the low oxygen gas solubility in concentrated brine (Langmuir, 1997), this environment would be essentially anoxic and consequently hospitable only to anaerobic bacteria.

Key Elements of Borehole Stratigraphy

To identify key stratigraphic elements that characterize Newfoundland Basin sediments, borehole stratigraphy is described based on two categories of borehole location within the Newfoundland Basin (i.e., peripheral or central basin). The peripheral category includes west side (7 boreholes) and inlet canal (11 boreholes) locations, while the central basin category includes topographic low (3 boreholes), and UTTR transect (3 boreholes) locations (figure 2a and appendix A1).

Peripheral-location stratigraphy is characterized within the first 5 feet (1.5 meters) BGL by presence of clastics from erosion of nearby mountain ranges that bound the Newfoundland Basin and shoal-forming sediments such as oolite and fecal-pellet facies. Algal-mat material is commonly interbedded with the oolite/fecal-pellet facies. Beneath this sequence is layered tan plastic clay, which grades vertically and laterally to dark-gray or gray-green layered clay and commonly extends below the 5-foot (1.5-meter) depth.

Central-basin stratigraphy commonly begins at the top with bedded halite that most likely precipitated from West Pond brine. The recent origin of halite is supported by absence of reported salt crust in the Reynolds borehole logs from their 1965 exploratory drilling program. Bedded halite ranges from less than 1 inch (2.5 centimeters) to as much as 2.5 feet (0.8 meters) thick. Beneath the bedded halite is typically either fine-grained gypsum sand with clay matrix, or fine clastics with oolites, which may extend to depths of 3 to 6 feet (0.9 to 1.8 meters) BGL. The sequence is commonly completed to depths beyond 6 feet (1.8 meters) BGL by the presence of gray-green clay with numerous doubly-terminated gypsum crystals distributed in the clay matrix.

Pore-Fluid Geochemistry

Background

Hydrochemical variation of entrained brines in lacustrine sediments of the Newfoundland Basin is best determined from

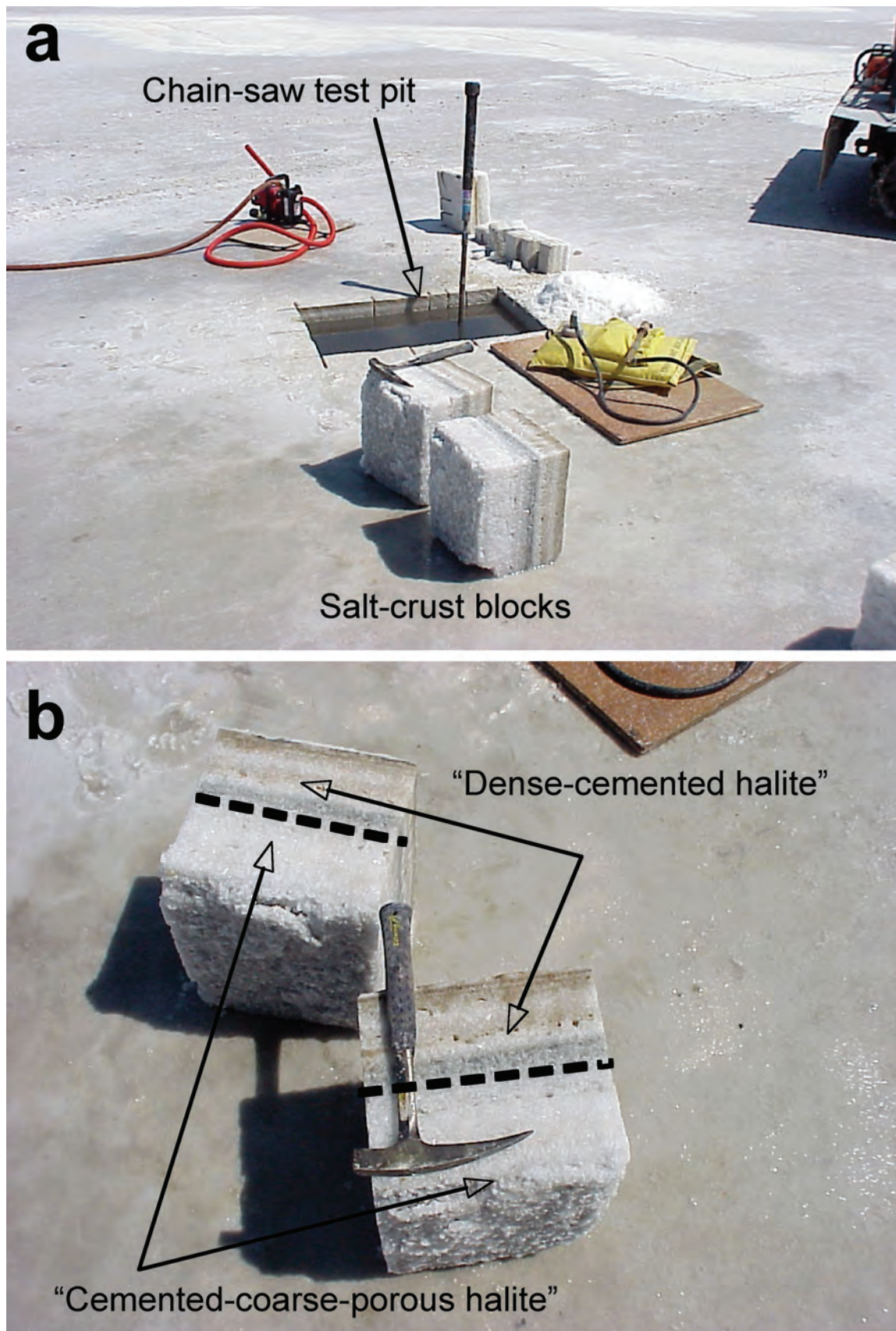


Figure 8. Examples of Newfoundland Basin salt-crust morphology adjacent to monitoring well MW-12 and near the central basin topographic low: 8a shows blocks of salt crust removed from a chain-saw test pit; 8b shows the approximate boundary (dashed line) between the “dense-cemented halite” and “cemented-coarse-porous halite” salt-crust strata (correlates respectively with flooding and saline-lake stages of Lowenstein and Hardie (1985)). Photographs by W. White, BLM, 24 August, 2001.

sediment pore fluids. For this study, pore fluids were obtained from borehole core samples by high speed centrifugation of carbonate-clay sediment, or draining (where possible) of fluids from more coarsely crystalline salt layers present in the samples.

As previously mentioned, boreholes were generally located either in the central or peripheral portions of the Newfoundland Basin. The central basin or topographic low point of the Newfoundland Basin (north of I-80) is an area approximately 4 miles (6.4 kilometers) west of the central-west flank of the Newfoundland Mountains block (see figure 2a). This area was anticipated to contain the most saline remnants (salt crust or brine) of the West Pond at the playa surface, and/or the residual brines at depth from the last stand of Lake Bonneville in this part of the Newfoundland Basin. Evidence of decreasing salinity was expected in surface and subsurface deposits peripheral to the topographic low.

As part of the pore-water collection effort, a 15-mile-long (24-kilometer) transect containing borehole sites on 3-mile (4.8-kilometer) centers was established that trended northwest and extended from the north end of the Knolls Facility inlet canal through the UTTR to the central portion of the Newfoundland Basin. The northwest-trending transect bisects the portion of the Newfoundland Basin playa located west and south of the Newfoundland Mountains. A second transect that trended east-west was established perpendicular to the 15-mile-long (24-kilometer) transect and extended from the eastern extremity of the Silver Island Mountains to the southern tip of the Newfoundland Mountains (see figure 2a). This transect also passes through the southern portion of the central basin's topographic low. Samples of brines, pore fluids, and associated sediments taken at depth along these two transects reveal solute distribution, mineral-water interaction, and conditions prior to the West Desert Pumping Project, while surface materials reflect the influence of the Pumping Project. In general, evidence of decreasing salinity and lower concentrations of residual salts, plus increased evidence of surficial fluids depleted in residual salts, was found to the west and south of the present central-basin topographic low.

The east-west transect noted above is represented by the borehole sequence NB#10, NB#8, NB#7, and NB#6 from central-basin topographic low to the basin's western periphery. Brines, sediments, and pore-fluid samples were also obtained from monitoring well MW-12 at borehole site NB#8, which is the intersection of the two transects near the central-basin topographic low (figure 2b). As expected, salt-crust thickness was greatest and pore-fluid concentrations were highest at NB#10, and lowest at NB#6 and NB#7.

The borehole sequence from central-basin topographic low to the basin's southern periphery (i.e., northwest to southeast) for the 15-mile (24-kilometer) transect and inlet canal is ST-05 through ST-01, NB#13, NB#12, NB#11, NB#18, NB#17, NB#16 and MW-04 (figure 2a). Two monitoring wells, MW-09 and MW-10, bridge the gap between the southeast end of the 15-mile (24-kilometer) transect and the northwest end of the inlet canal, and are considered as intermediate sites between the central and peripheral-basin sites. The most concentrated pore fluids on this transect occurred in the upper part of the NB-ST05 profile, whereas the lowest values for pore-fluid solutes were from core in shallow sediment at NB#16, and from core at depths greater than 12 feet (3.7 meters) in MW-04. Sites NB#16 and MW-04 were positioned at the greatest distance from the central-basin topographic low (figure 2c).

Pore-Fluid Profiles

Profile plots of K, Mg, and SO₄ from pore fluids extracted from borehole cores generally exhibit the following characteristics:

- Effects of mixing the two chemically different brines (i.e., Great Salt Lake and pre-pumping Newfoundland Basin brines) were typically restricted to the upper 5 feet (1.5 meters) of shallow-brine aquifer sediments.
- Within the upper 5 feet (1.5 meters) of shallow-brine aquifer sediments, pore-fluid concentration ranges for K, Mg, and SO₄ typically matched those of North Arm Great Salt Lake brine (for comparison, North Arm K, Mg, and SO₄ concentrations are illustrated as horizontal bars at base of each pore-fluid profile - see figures 9 through 12; respective North Arm concentrations are from Sturm 1980).
- Below 5 feet (1.5 meters), the brine chemistry resumed the character common to evaporated remnants of Lake Bonneville water.
- Trends in pore-fluid compositions correlated with spatial changes in sample location (e.g., lower concentrations at peripheral sites versus higher concentrations at central-basin sites).

Within the upper 5 feet (1.5 meters) - Pore-fluid samples from the upper 5 feet (1.5 meters) of the shallow-brine aquifer sediments exhibit peak K and Mg concentrations that range from about 1% to 2.6% at central-basin sites NB#10 and MW-12 (figure 9), while those from peripheral-basin sites such as NB#6 and NB#7 cluster around 0.5%. The SO₄ concentrations range laterally from about 1% to 1.3% at peripheral-basin sites such as MW-04 or NB#6 (figure 10), to as much as 4.6% at central-basin sites such as NB#10 (figure 9). Furthermore, SO₄ concentrations typically peak between 2 and 4-foot (0.6 and 1.2-meter) depths in pore-fluid samples from central-basin sites NB#10, MW-12, and ST-05 (figures 9 and 11), and resemble diffusion profiles obtained in Great Salt Lake sediments (Spencer and others, 1984). In contrast, upper pore-fluid profiles of K, Mg, and SO₄ from intermediate site MW-10 peak to 1.3%, 2.4%, and 4.3%, respectively, within 1 foot (0.3 meters) of the surface (figure 12). MW-10 is located between the central and peripheral-basin sites (see figure 2a).

Below 5 feet (1.5 meters) - Pore-fluid samples extracted at peripheral-basin locations from depths greater than 5 feet (1.5 meters) had K and Mg concentrations less than 0.7% (figure 10). However, pore fluids from the site nearest the central-basin topographic low exhibited somewhat higher K and Mg concentrations of 0.9% and 1.3%, respectively for NB#10 (figure 9). Similarly, SO₄ contents of samples at peripheral-basin locations NB#7 and MW-04 (figure 10) range from 0.5% to 1.3%, and from 1.4% to 1.6% at central-basin locations MW-12 and NB#10 (figure 9). At depths from 5 to 12 feet (1.5 to 3.7 meters), pore-fluid concentrations from intermediate site MW-10 ranged from 0.25% to 0.5% for K and Mg, and from 0.75% to 1.2% for SO₄ (figure 12).

Trends in pore-fluid compositions also generally correlate with semi-quantitative determinations of major mineral abun-

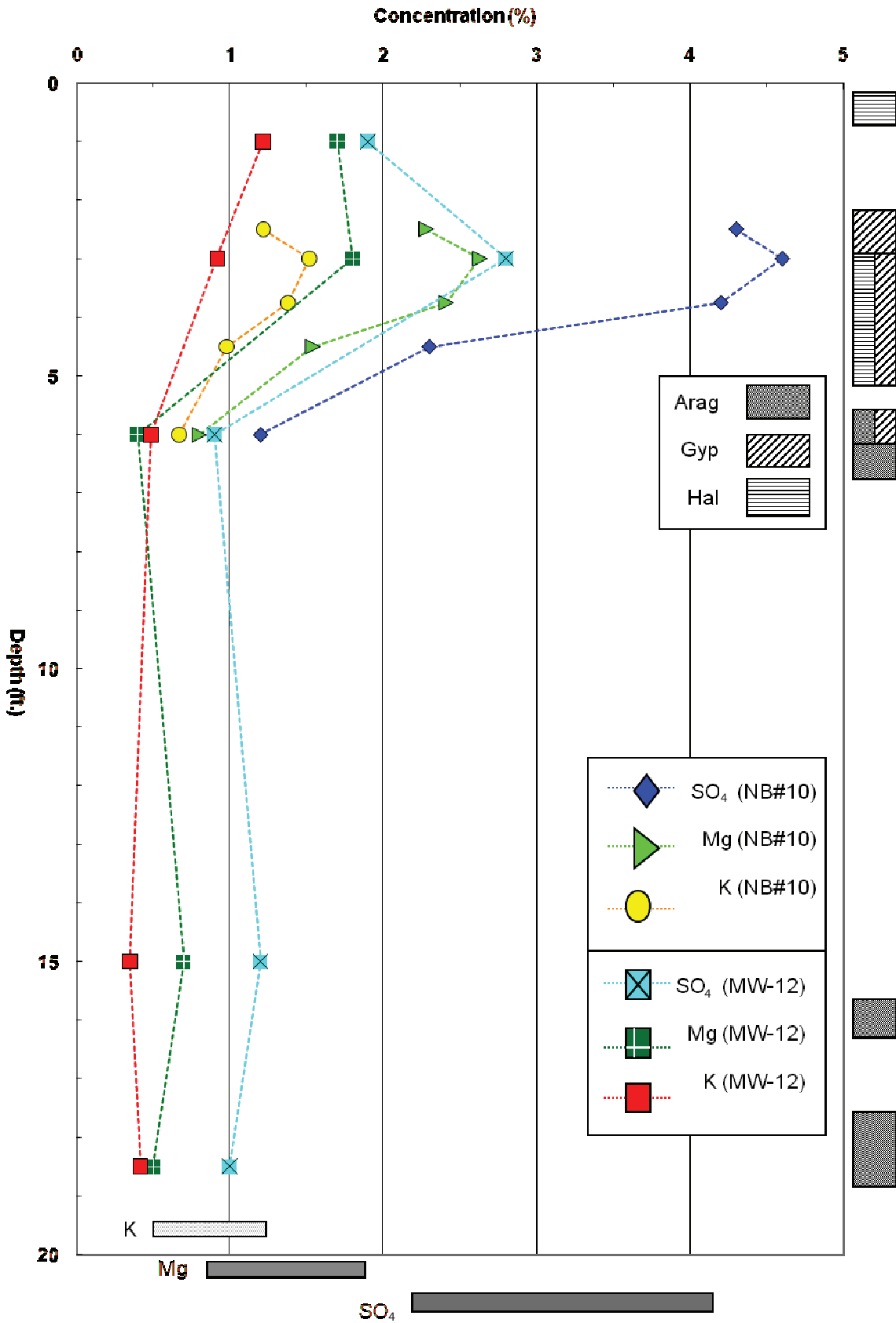


Figure 9. Pore-fluid solute profiles from shallow-sediment cores obtained from open borehole NB#10 and monitoring well MW-12 (core-sample dates are 16 September, 1999, and 13–15 November, 1999, respectively). Location is central basin topographic low, Newfoundland Basin. Mineralogic well log showing distribution of aragonite, gypsum, and halite is on right side of profile plot (blank gaps in the log indicate no data). A comparison of K, Mg, and SO₄ concentrations in Great Salt Lake North Arm brine (Sturm 1980) with those in pore fluids is depicted as horizontal bars across base of profile plot.

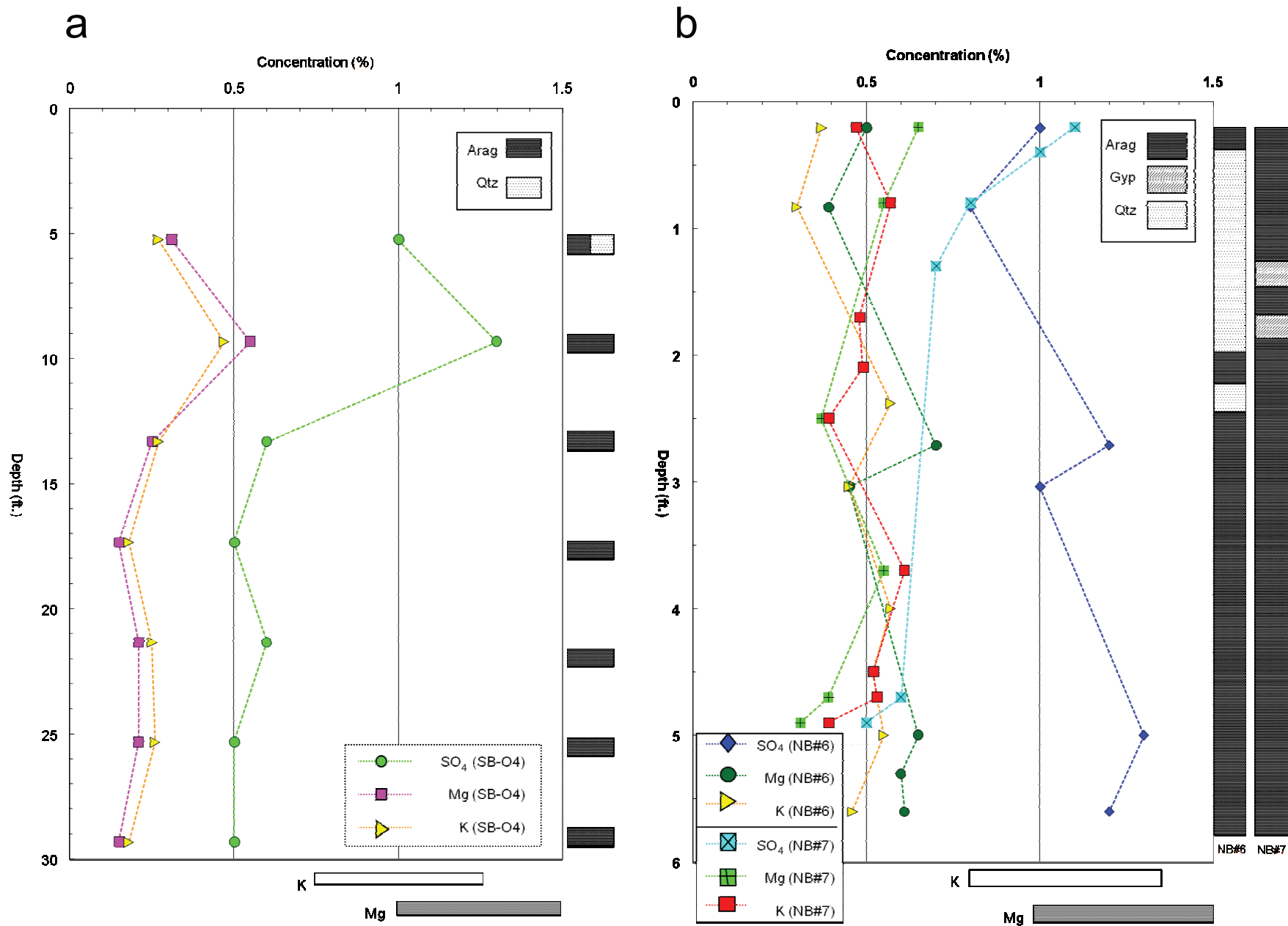


Figure 10. Pore-fluid solute profiles from shallow-sediment cores obtained from monitoring well SB-04 (10a – also known as MW-04) and open boreholes NB#6 and NB#7 (10b) (core-sample dates are 4 November, 1999, 13 August, 1999, and 2 September, 1999, respectively). Locations of SB-04 and NB#6 – NB#7 are from southern and western periphery of Newfoundland Basin. Mineralogic well log showing distribution of aragonite, gypsum, and quartz is on right side of each profile plot (blank gaps in the log indicate no data). A comparison of K and Mg concentrations from Great Salt Lake North Arm brine (Sturm 1980) with those in pore fluids is depicted as horizontal bars across base of profile plot (SO₄ bar was not included because it extended beyond the pore-fluid concentration range).

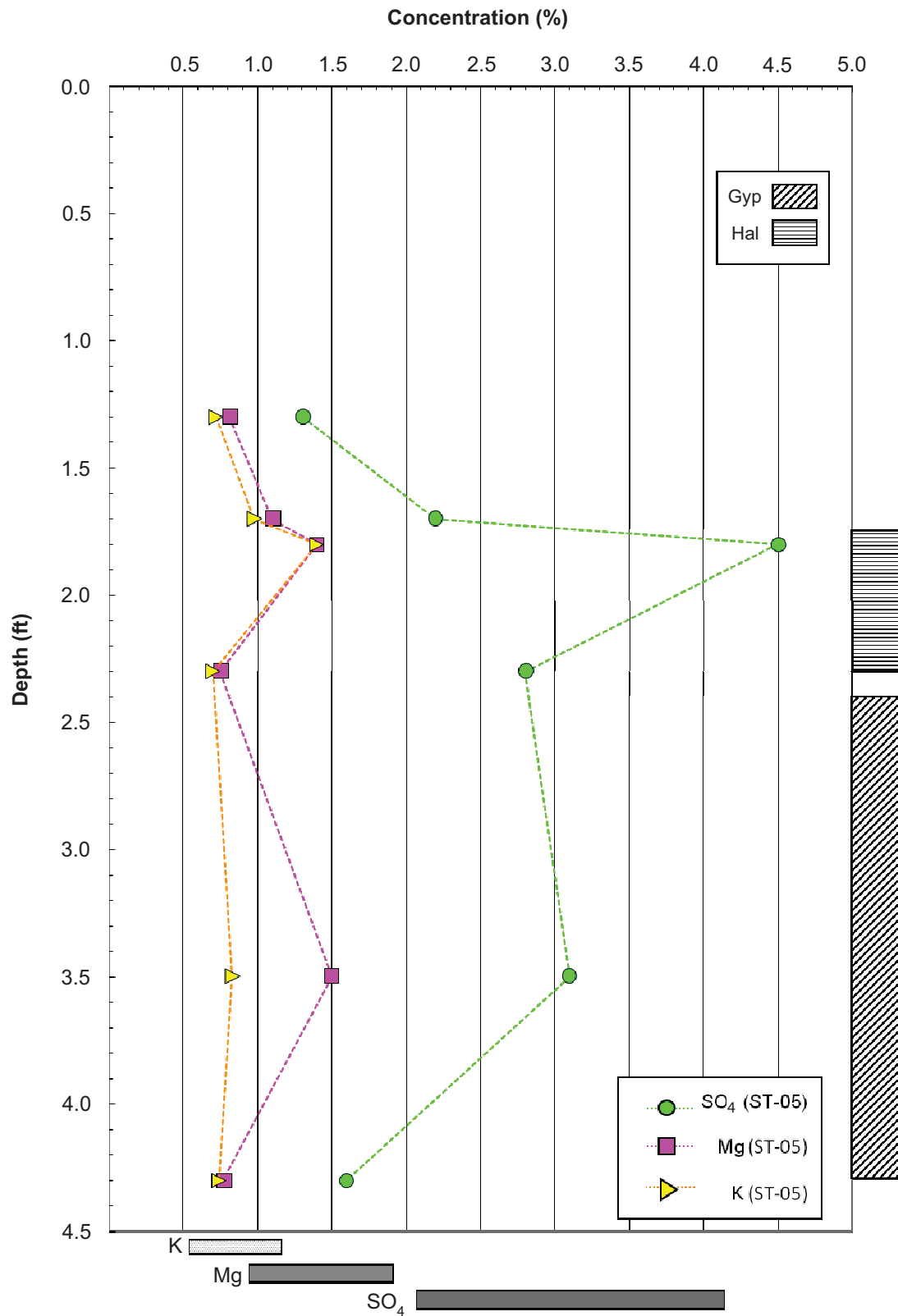


Figure 11. Pore-fluid solute profiles from shallow-sediment cores obtained from open borehole ST-05 (core-sample date is 29 August, 2001). Location is central basin topographic low, Newfoundland Basin, about 3 miles (4.8 kilometers) southeast of monitoring well MW-12. Mineralogic well log showing distribution of gypsum and halite is on right side of the profile plot (blank gaps in the log indicate no data). A comparison of K, Mg, and SO₄ concentrations in Great Salt Lake North Arm brine (Sturm 1980) with those in pore fluids is depicted as horizontal bars across base of profile plot.

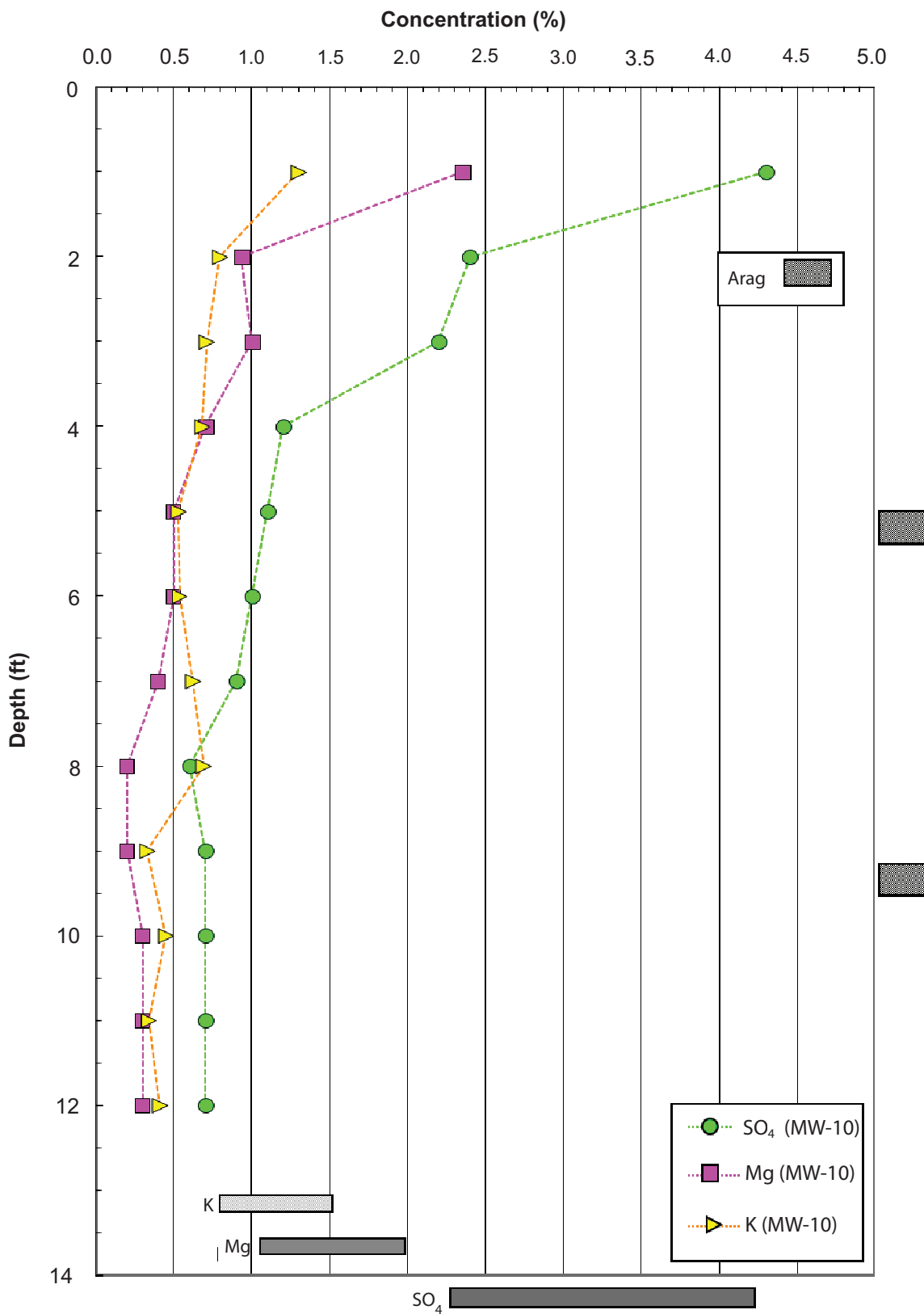


Figure 12. Pore-fluid solute profiles from shallow-sediment cores obtained from monitoring well MW-10 (core-sample date is 19 November, 1999). Location is an intermediate site between the end of the inlet canal and the central basin topographic low, Newfoundland Basin. Mineralogic well log showing distribution of aragonite is on right side of the profile plot (blank gaps in the log indicate no data). A comparison of K, Mg, and SO₄ concentrations in Great Salt Lake North Arm brine (Sturm 1980) with those in pore fluids is depicted as horizontal bars across base of profile plot.

dances in the sediment along each transect, both laterally and with depth. All samples examined by XRD, either from the surface, boreholes, or monitoring wells contained some halite from sample drying, and a trace of clay and alkaline earth-carbonate (aragonite, calcite and/or dolomite). Gypsum, quartz, mica, and an unidentified sulfate salt were also observed. Mineralogical examination of over 100 samples from more than 15 sites revealed some diagnostic mineral species associations, which appeared to fit the depositional environment deduced from pore-fluid distribution:

- An antithetical relationship exists between total carbonate and clastic sedimentary species such as quartz and total clay.
- Presence of aragonite in shallow-brine aquifer sediments is indicative of evaporating open-lake waters, while gypsum occurrence is characteristic of much more saline playa or mudflat conditions (Spencer and others, 1984).

Evaporating open-lake waters reaching saturation with calcium carbonate (CaCO_3) tend to precipitate aragonite rather than calcite from inhibition caused by a simultaneous increase in solute Mg. Because of the precipitate loss of solute Ca to CO_3 , greater concentrations of SO_4 are required to form gypsum than otherwise; thence gypsum precipitation takes place only under much more saline conditions and is commonly intermixed with carbonate sediments. An added suggested mineral association is halite with aragonite, probably due to the porosity in aragonitic carbonate muds yielding more fluid for evaporation on drying during sample storage. A small amount of dolomite is commonly associated with gypsum, reflecting higher Mg concentration and slow kinetics of formation (Arvidson and Mackenzie 1997, 1999).

- Along the two Newfoundland Basin transects, the abundance of aragonite and gypsum generally corresponds to later trends in pore-fluid salinity that changes from basin periphery to the central portion of the basin.

Gypsum increases towards the NB#10 and MW-12 sites to the point where gypsum composes 75% of the samples at depths greater than 3 feet (0.9 meters), reflecting in large part, the dominance of halite crust above (appendix A5). Aragonite generally increases not only toward the playa margin, but also with depth, reflecting the former lacustrine conditions of Pleistocene Lake Bonneville. The greatest amount of calcite in upper sediment intervals, coupled with somewhat elevated amounts of quartz, occurs in the western periphery of the basin at NB#6, and suggests added detrital material from a distal alluvial-fan toe. In sites distant from the central-basin topographic low, and particularly in the mini depression at the terminus of the inlet canal, an increase in pore-fluid SO_4 can occur in shallow sediments, with an increase in gypsum, but not accompanied by increases in pore-fluid Mg and K. This indicates deposition from recycled brine developed from the resolution of surficial salts (halite and gypsum) by meteoric precipitation at the playa surface.

Pore-Fluid X-Y Plots

Effects on pore-fluid brine composition and variability of

processes or factors other than general location and depth in the shallow-brine aquifer sediments is shown in simple two-variable plots of the major solute constituents of pore fluids grouped according to peripheral or central-basin location (note that intermediate sites MW-09 and MW-10 are plotted with central-basin sites; figures 13 through 20). For example, although the concentration ranges for Na and Cl are not very different between peripheral and central-basin pore fluids, the relationship between Na and Cl for the peripheral-basin sites is noticeably closer to the expected 1:1 molar ratio throughout the concentration range (figure 13a). This relationship projects to the origin through a point representing the most dilute sample collected, which was from a ground-water seep in Miry Wash at the NW periphery of the basin. The only significant departure from the 1:1 relationship is for two samples from NB#16, which plot in the direction of a sodium excess, suggesting a solute component derived from chemical weathering of clastic silicates (figure 13a).

In contrast, samples from central-basin sites present a more scattered Na versus Cl relation, particularly at high concentration values. This is mainly due to precipitation of halite and the consequent depletion of Na, and is especially evident in the higher concentration plots of NB#10 and MW-12 (figure 13b). By contrast, plots of pore-fluid points for MW-09 and MW-10 generally exhibit a 1:1 slope. This is most likely due to their locations; MW-09 and MW-10 are located midway between peripheral and central-basin sample sites and the bulk of their respective subsurface pore fluids are not quite at halite saturation. The greatest deviation from the 1:1 slope is in the direction of excess Cl for the MW-10 pore fluids nearest the playa surface, which represents fluid concentrate from the secondary topographic low at the distal end of the inlet canal. Presumably this brine has precipitated much of its halite (with proportionately higher loss of Na compared to Cl) during final evaporative concentration, as might be expected from the principle of mass action (Hardie and Eugster 1970; Eugster and Jones 1979).

The relationships of Cl, SO_4 , and K to Mg concentrations in pore-fluid samples provide added detail to suggested geochemical processes derived from the NaCl plot. For brine compositions undersaturated with respect to bitter salts (e.g., sylvite - KCl, carnallite - $\text{KMgCl}_3 \cdot 6\text{H}_2\text{O}$, and kieserite - $\text{MgSO}_4 \cdot \text{H}_2\text{O}$), K and Mg can be considered relatively conservative in solution, partly because authigenic reaction with clay minerals or carbonate, though likely, is relatively slow compared to direct precipitation of a salt phase (Jones and Spencer, 1999). Consequently, reference to K or Mg can be more informative. It must also be remembered that the elemental relationships between pore-fluid constituents from different depths at the same sample site can reflect significant differences in mineral stratigraphy. Points in a profile dominated by precipitate phases and salt-rich strata can thus appear more scattered and irregular in their X-Y plots than those controlled by diffusion and diagenetic reaction. This is most readily seen in the Mg versus Cl-referenced plots (figure 14a) for NB#8 (salt dominant, 3.7-foot/1.1-meter depth) versus MW-12 (clay-carbonate dominant, 18.5 foot/5.6-meter depth), even though the sites are only 100 feet (30 meters) apart (figure 2b).

The plots of Mg versus Cl for the central-basin pore fluids clearly show the limiting effects of halite saturation on Cl concentration at the highest salinities (figure 14a). The Cl maximum in NB#10 remains between 16% and 17% despite a five-fold range in Mg concentration. By contrast, concentrated brines

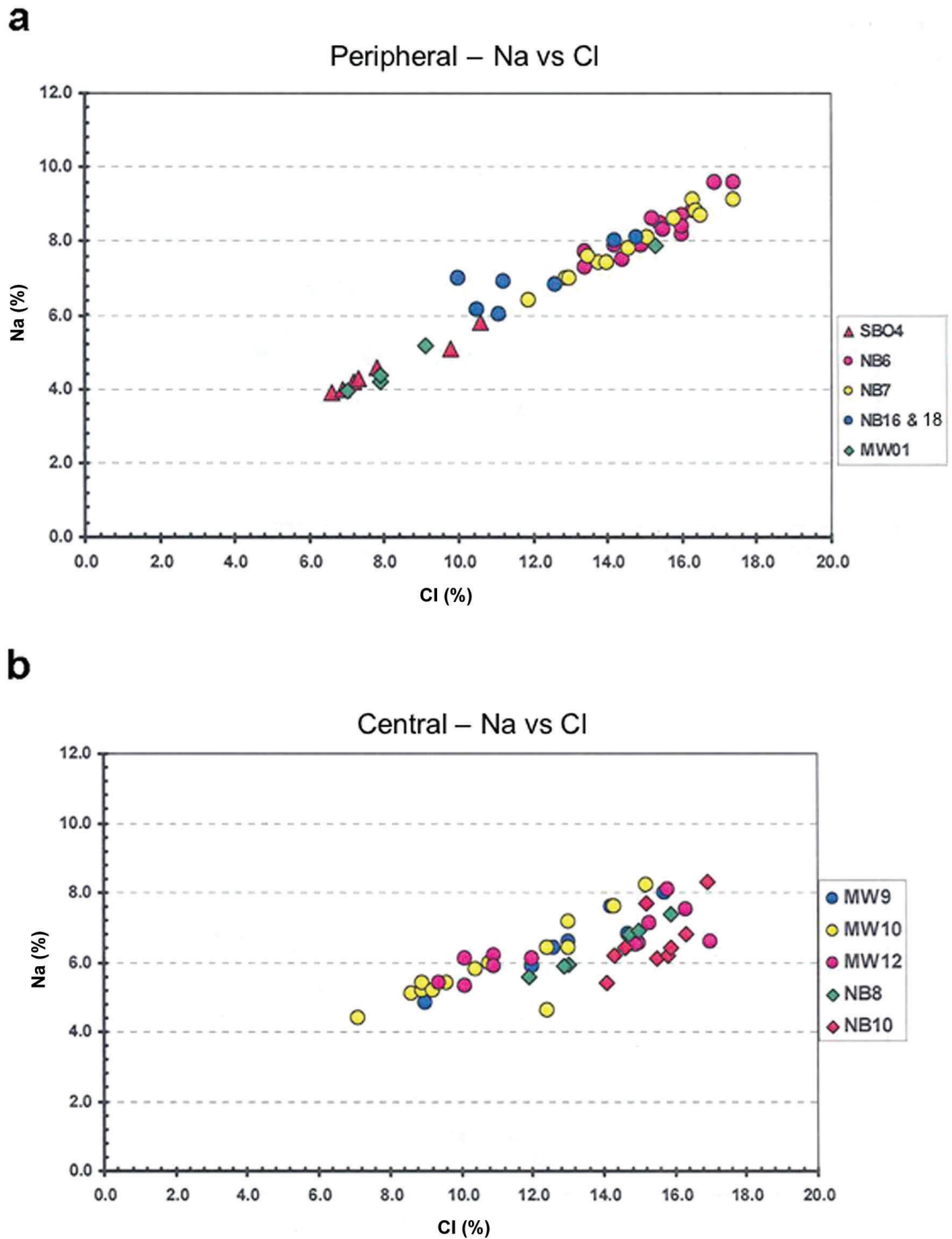


Figure 13. Pore-fluid X-Y plots of Na versus Cl from shallow-sediment cores obtained from monitoring wells and open boreholes located at peripheral (13a) and central basin sites (13b), Newfoundland Basin. Monitoring wells and open boreholes are prefixed with “MW” and “NB,” respectively (monitoring well SB-04 is the exception).

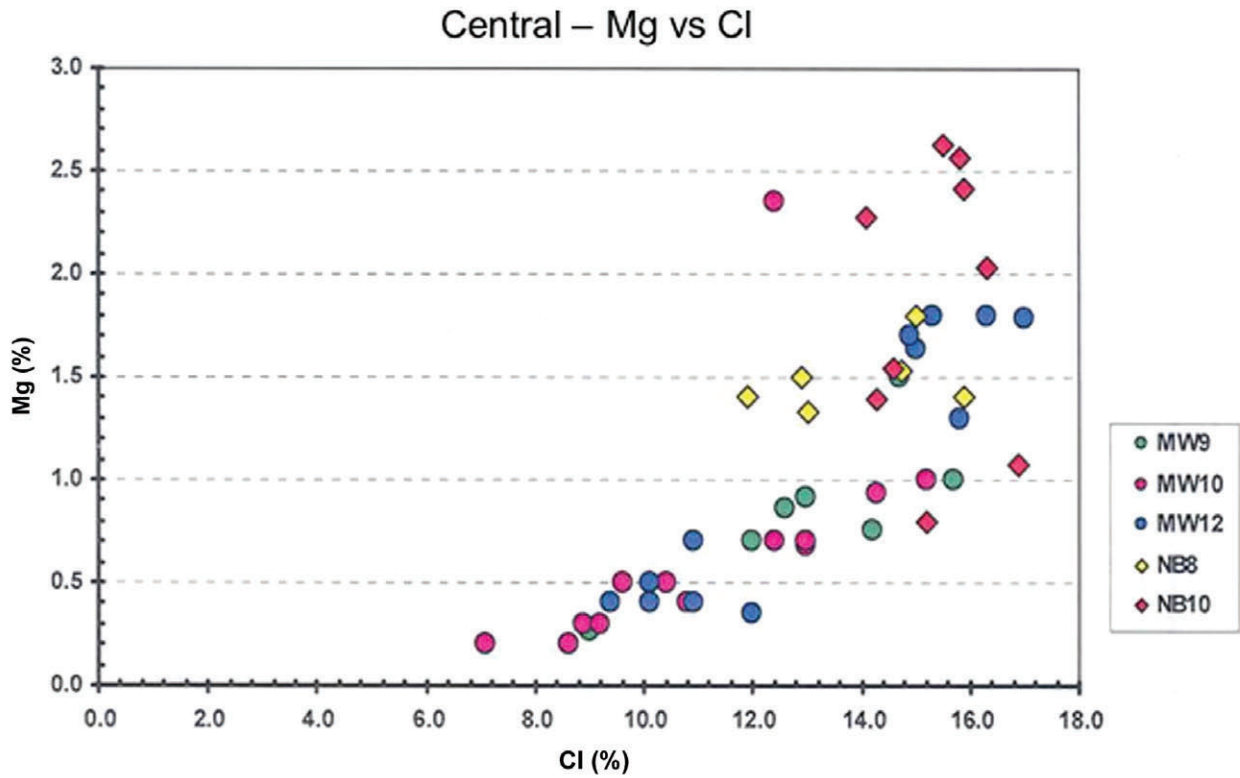
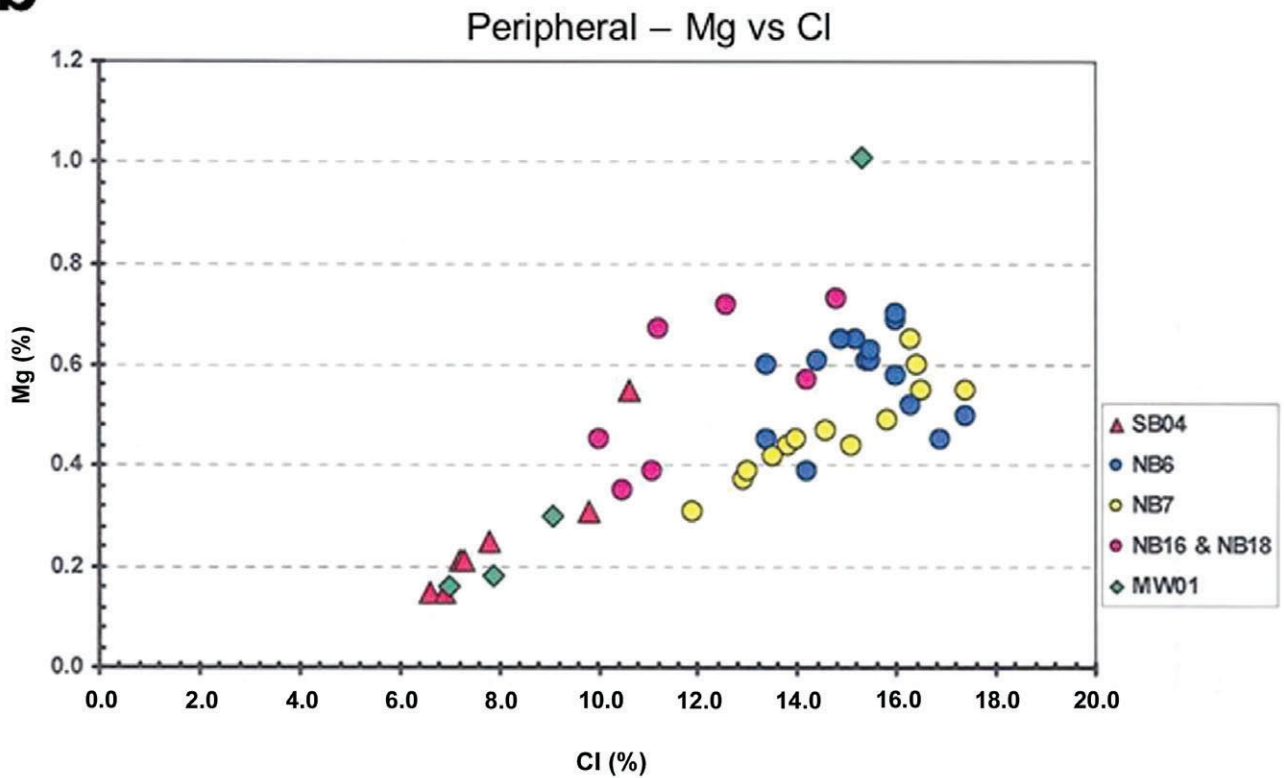
a**b**

Figure 14. Pore-fluid X-Y plots of Mg versus Cl from shallow-sediment cores obtained from monitoring wells and open boreholes located at central (14a) and peripheral basin sites (14b), Newfoundland Basin. Monitoring wells and open boreholes are prefixed with “MW” and “NB,” respectively (monitoring well SB-04 is the exception).

from NB#8 and the upper 6 to 7 feet (1.8 to 2.1 meters) of MW-12 are relatively constant in Mg, which is most likely the result of clay or carbonate precipitation (Jones and Spencer, 1999), while Cl ranges from 12% to 17%. Results for MW-12 pore fluids are clearly separated into two clusters at median Cl concentrations of 11% and 16%, without a clear trend in either group. This is related to a marked difference in mineralogy, with aragonite dominant in the lower half of the core and gypsum or halite in the upper half (appendix A5).

Samples from intermediate sites MW-09 and MW-10, which are the furthest of the central-basin group from the topographic low, show a nearly linear trend between 7% and 16% Cl and 0.2% to 1.0% Mg (figure 14a). This is very similar to the Mg versus Cl trend seen in many pore fluids from the peripheral-basin sites. The exceptions, NB#6 and NB#16-18, form two relatively distinct clusters with more scatter in the latter than the former (figure 14b). Both of these sample groups have an excess of Mg over Cl compared to the trend of points for peripheral-basin sites NB#7, SB-04, or MW-01. This can be most readily attributed to further dissolution of detrital sediment.

The plots of K versus Cl for the peripheral-basin pore fluids are similar to those for Mg versus Cl, both in terms of ion concentration range and distribution of values (see figures 14b and 15a). The most apparent difference is in the relationship of the samples from NB#6 and NB#7, which are clustered more closely in the K plot, with the exception of the three shallowest samples from NB#6. Because marked cation depletion does not appear in the K versus SO₄ plot (figure 16b) for central-basin pore fluids, we conclude that sorptive retention of K₂SO₄ probably occurs in the final stages of evaporative concentration. In contrast, marked cation excess is observed in the K versus Cl and K versus SO₄ plots for half the peripheral NB#16 and NB#18 samples (see figures 15a and 16a). As noted earlier, this is most likely due to solute weathering from clastic silicate matrix. In this regard, the lowest cation concentrations in the entire pore-fluid sample suite are from borehole MW-01, which is farthest from the central-basin topographic low.

The relationship of Mg to SO₄ content appears to reinforce some of the interpretations above. The samples from the central-basin sites illustrate a relatively regular trend over the full SO₄ concentration range, with a slight deflection toward lower Mg near the plot midpoint (figure 17b). Especially noteworthy is the nearly regular spacing of the sample points for NB#10 from about 1.25% to 4.75% SO₄, whereas MW-12 samples occur in two clusters separated roughly by a factor of three in Mg or SO₄ content. The more concentrated group illustrates roughly constant Mg over an increase in SO₄ from less than 2% to 3%. Samples from NB#8 cover an even greater range in SO₄ content (from less than 2% to about 4.25%) while Mg remains relatively constant. At concentrations less than about 0.25% Mg, pore fluids from intermediate and central-basin sites MW-09, MW-10, and MW-12 follow a distinct linear trend, which is coincident with the trend for pore fluids from peripheral-basin sites NB#6 and SB-04. Although approaching the limits for accurate SO₄ determination in high Cl brines, an expansion of plot scale reveals a separation of approximately parallel trends for the peripheral-basin sites, with NB#7 lower in SO₄, and SB-04 higher, than NB#6 (figure 17a). Inasmuch as the samples from an individual site plot closer to each other than to samples from any other site, this probably reflects a variable gypsum source.

The plots of either the K versus Cl or SO₄ (figures 15b and 16b) for the central-basin sites are quite similar to those for Mg,

but with additional scatter. Also, in the case of sample points for intermediate sites MW-09 and MW-10, and the more dilute cluster from central-basin site MW-12, linearity is most obvious in the less concentrated portions of the Mg plots, but it extends throughout. In all the plots, samples from central-basin sites NB#8 and NB#10 are among the highest concentrations, but the K plots typically offer the greatest spread of values. The SO₄ plots show the most definitive linear aspect for the sample profile from NB#10. The slight convexity in the relationship suggests a slow, but continuous loss of Mg and K, most readily attributed to up-take by clays.

The plot of K versus Mg content (figures 18a and 18b) for all pore-fluid samples benefits from the condition that the concentration of these two constituents is closer in value than SO₄. Although a distinction can be made between the groups from peripheral-basin sites SB-04, NB#6, NB#7 and intermediate-basin sites MW-09 and MW-10, the general impression is one of a linear relation controlled more by variations in mixing or extent of evaporation than source or specific reaction. The exception comes in the more concentrated samples where a very clear distinction can be made, not only between salt and mud-dominated points, as noted for Mg versus SO₄, but also for variation in the precipitate, itself. The higher K versus Mg for samples from NB#8 versus NB#10 suggests the formation of a Mg salt, most likely kieserite (MgSO₄·H₂O) or an equivalent hydrate such as epsomite (MgSO₄·7H₂O) or hexahydrate (MgSO₄·6H₂O) (figure 18b). TEQUIL modeling of West Pond evaporation (Kohler and White 2004) indicates that kainite (KMgClSO₄·¹/₄H₂O) would be the first salt to precipitate after halite (NaCl), but on continued concentration this phase is resorbed in favor of kieserite formation. In support of this idea, note an apparent limit to the Mg concentration in MW-12, and the point for the final vestige of evaporating interstitial brine at MW-10 (figure 18b). The latter occurs in topmost layers too thin to permit precipitate fractionation.

Relations between Ca and the major constituents of the pore fluids are complicated by the relatively very low levels of Ca in most of the brines. Plots of Ca versus SO₄ (figures 19a and 19b) revealed an irregular variation or near constancy (particularly NB#6), as might be expected from gypsum or anhydrite (CaSO₄·2H₂O or CaSO₄) saturation. Most samples from salt strata with SO₄ greater than 1.5% were nearly devoid of Ca. An interesting exception was several samples from the concentrated brines from NB#10 at the central-basin topographic low. This can be attributed to inorganic solute complexing. Plots of Ca versus Mg to provide insight on dolomite formation, show an interesting contrast between decreasing Ca with increased Mg in NB#7 samples and the tight cluster of NB#6 points (figures 20a and 20b), but the relation to mineral formation is unclear.

Open Borehole and Ground-Water Seep X-Y Plots

Examination of simple two-variable plots for major solute concentrations in unconfined fluids from seeps and boreholes open to the surface gives added detail about Newfoundland Basin brine compositional range and variation. Most of the points are consistent with the general Newfoundland Basin pore-fluid distributions, but some data points plot outside typical distribution envelopes, which suggest processes not easily explained from the pore-fluid data alone.

The plot of Na versus Cl (figure 21) illustrates good overall

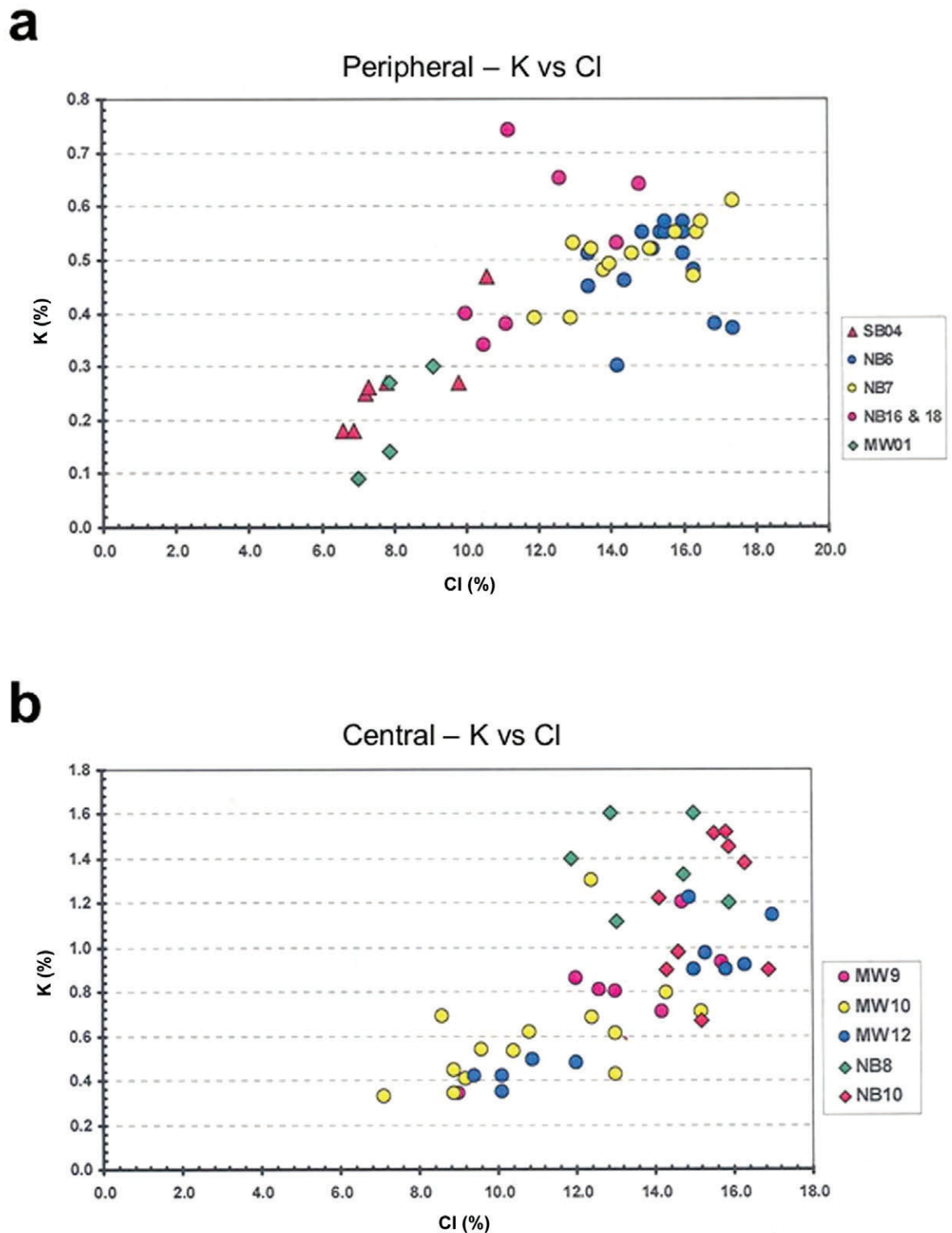


Figure 15. Pore-fluid X-Y plots of K versus Cl from shallow-sediment cores obtained from monitoring wells and open boreholes located at peripheral (15a) and central basin sites (15b), Newfoundland Basin. Monitoring wells and open boreholes are prefixed with “MW” and “NB,” respectively (monitoring well SB-04 is the exception).

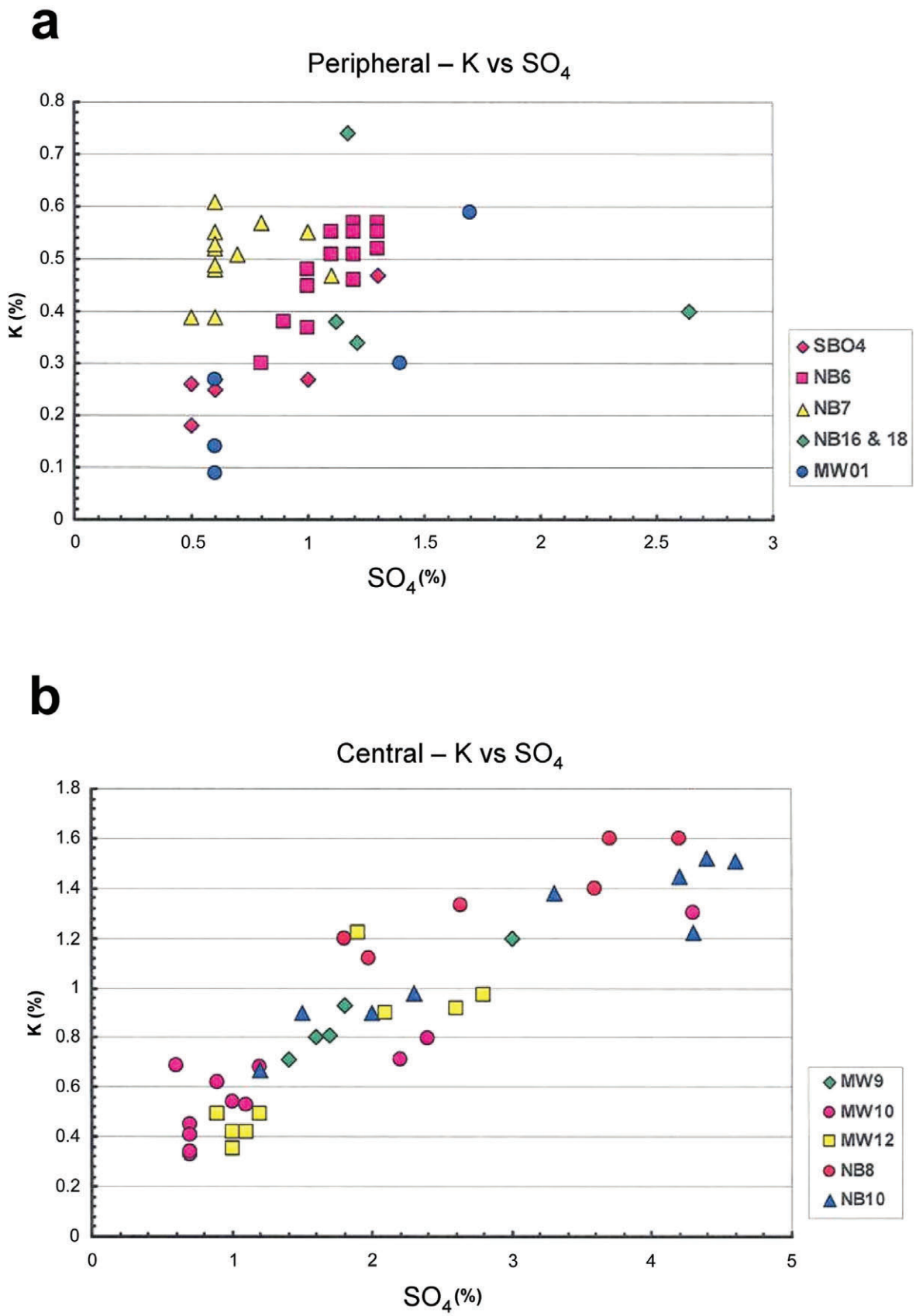


Figure 16. Pore-fluid X-Y plots of K versus SO₄ from shallow-sediment cores obtained from monitoring wells and open boreholes located at peripheral (16a) and central basin sites (16b), Newfoundland Basin. Monitoring wells and open boreholes are prefixed with “MW” and “NB,” respectively (monitoring well SB-04 is the exception).

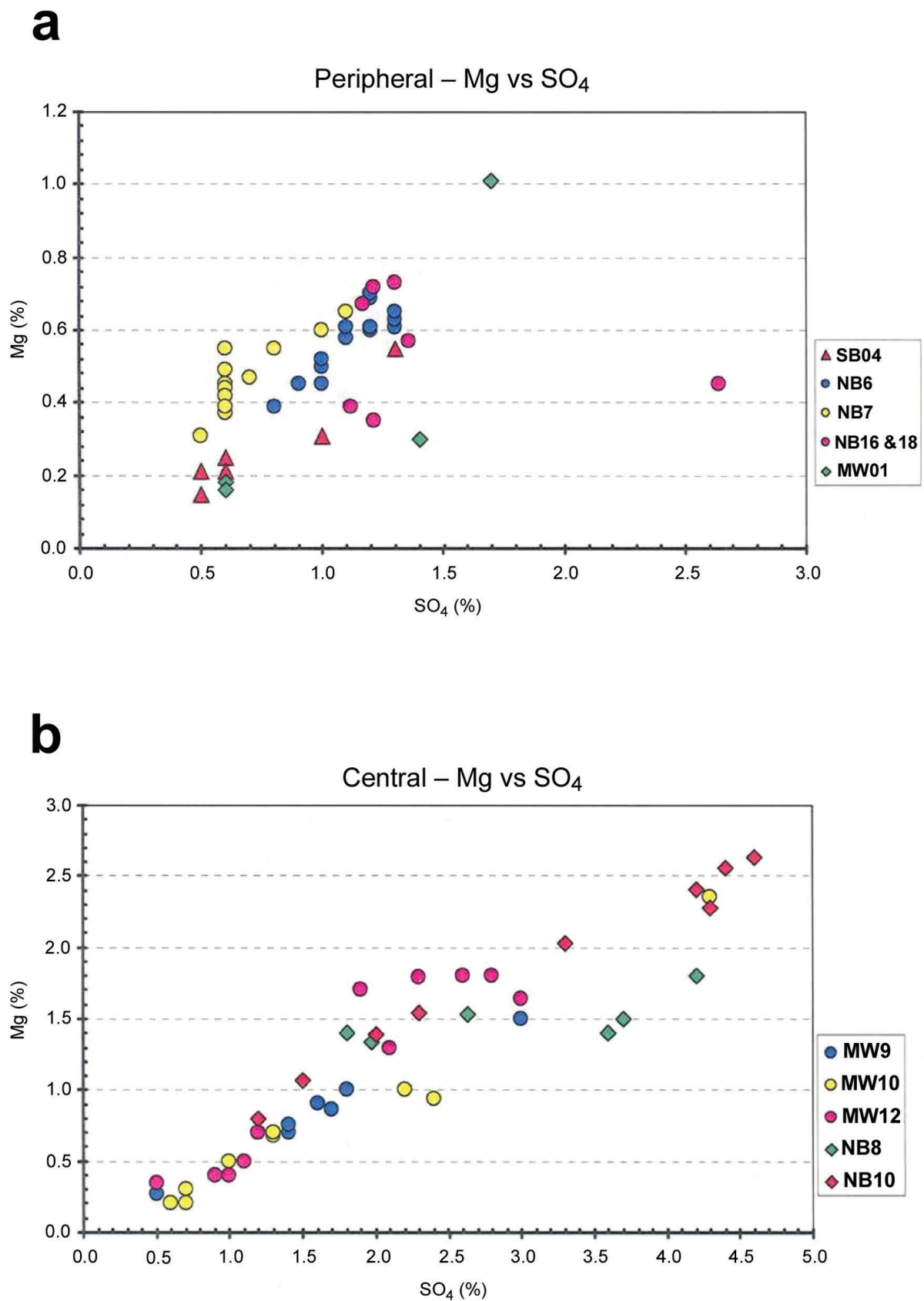


Figure 17. Pore-fluid X-Y plots of Mg versus SO₄ from shallow-sediment cores obtained from monitoring wells and open boreholes located at peripheral (17a) and central basin sites (17b), Newfoundland Basin. Monitoring wells and open boreholes are prefixed with “MW” and “NB,” respectively (monitoring well SB-04 is the exception).

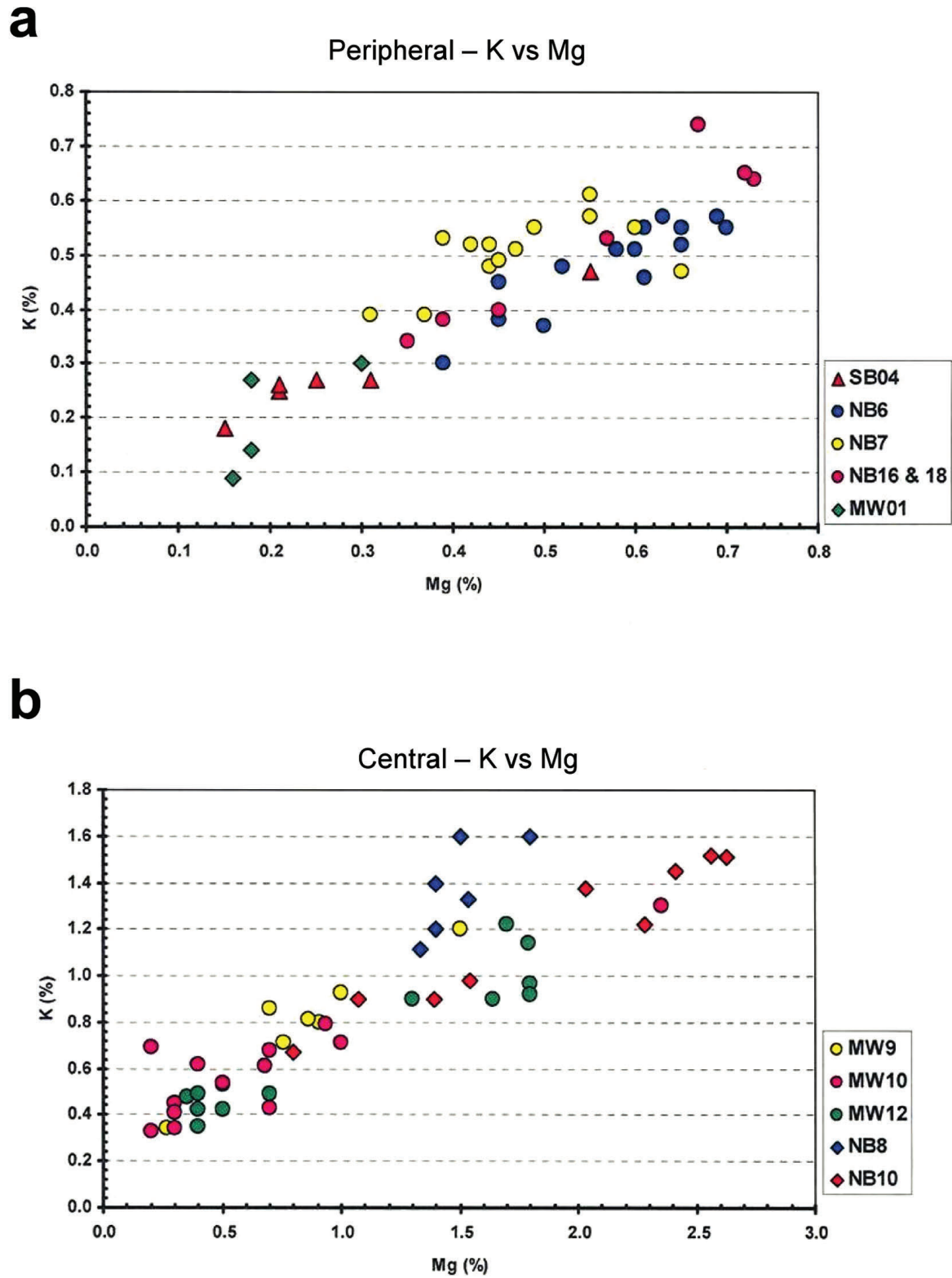


Figure 18. Pore-fluid X-Y plots of K versus Mg from shallow-sediment cores obtained from monitoring wells and open boreholes located at peripheral (18a) and central basin sites (18b), Newfoundland Basin. Monitoring wells and open boreholes are prefixed with “MW” and “NB,” respectively (monitoring well SB-04 is the exception).

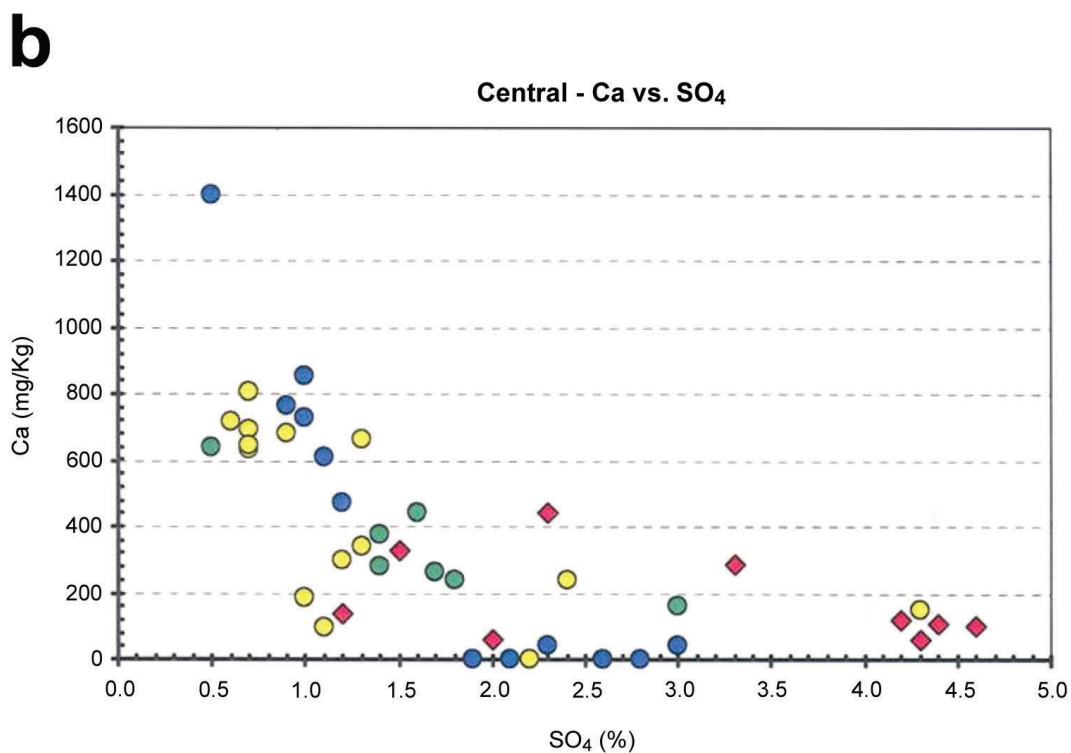
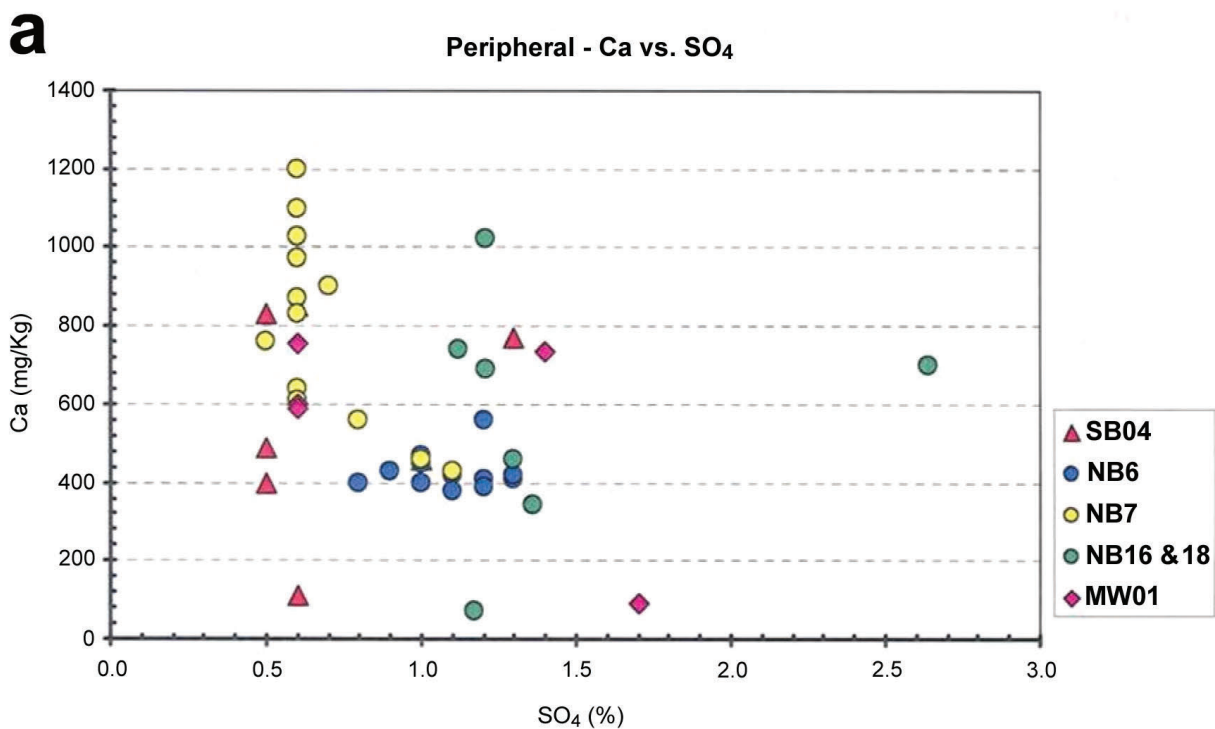


Figure 19. Pore-fluid X-Y plots of Ca versus SO_4 from shallow-sediment cores obtained from monitoring wells and open boreholes located at peripheral (19a) and central basin sites (19b), Newfoundland Basin. Because of low concentrations, Ca is expressed as mg/kg rather than percent. Monitoring wells and open boreholes are prefixed with “MW” and “NB,” respectively (monitoring well SB-04 is the exception).

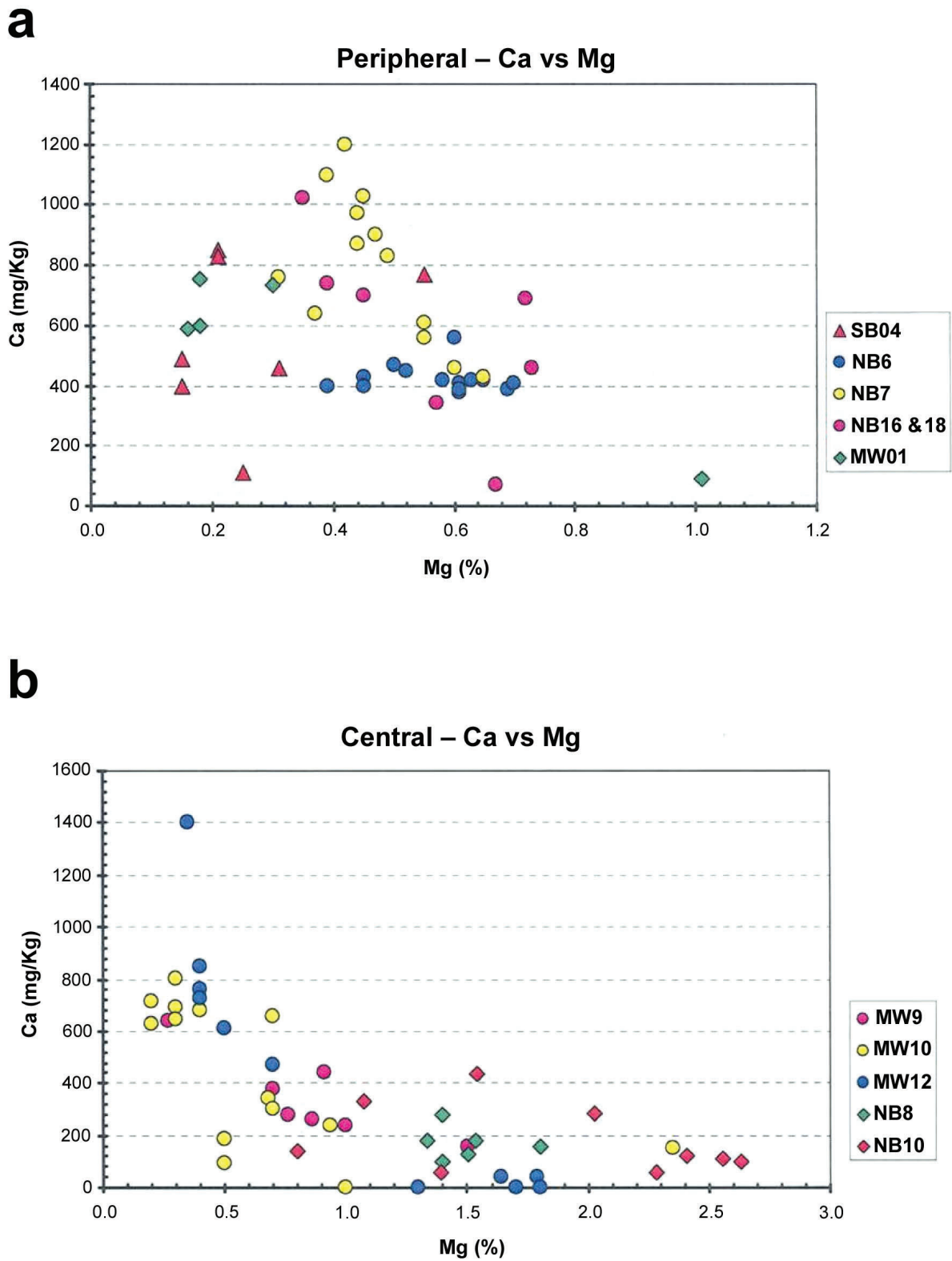


Figure 20. Pore-fluid X-Y plots of Ca versus Mg from shallow-sediment cores obtained from monitoring wells and open boreholes located at peripheral (20a) and central basin sites (20b), Newfoundland Basin. Because of low concentrations, Ca is expressed as mg/Kg rather than percent. Monitoring wells and open boreholes are prefixed with “MW” and “NB,” respectively (monitoring well SB-04 is the exception).

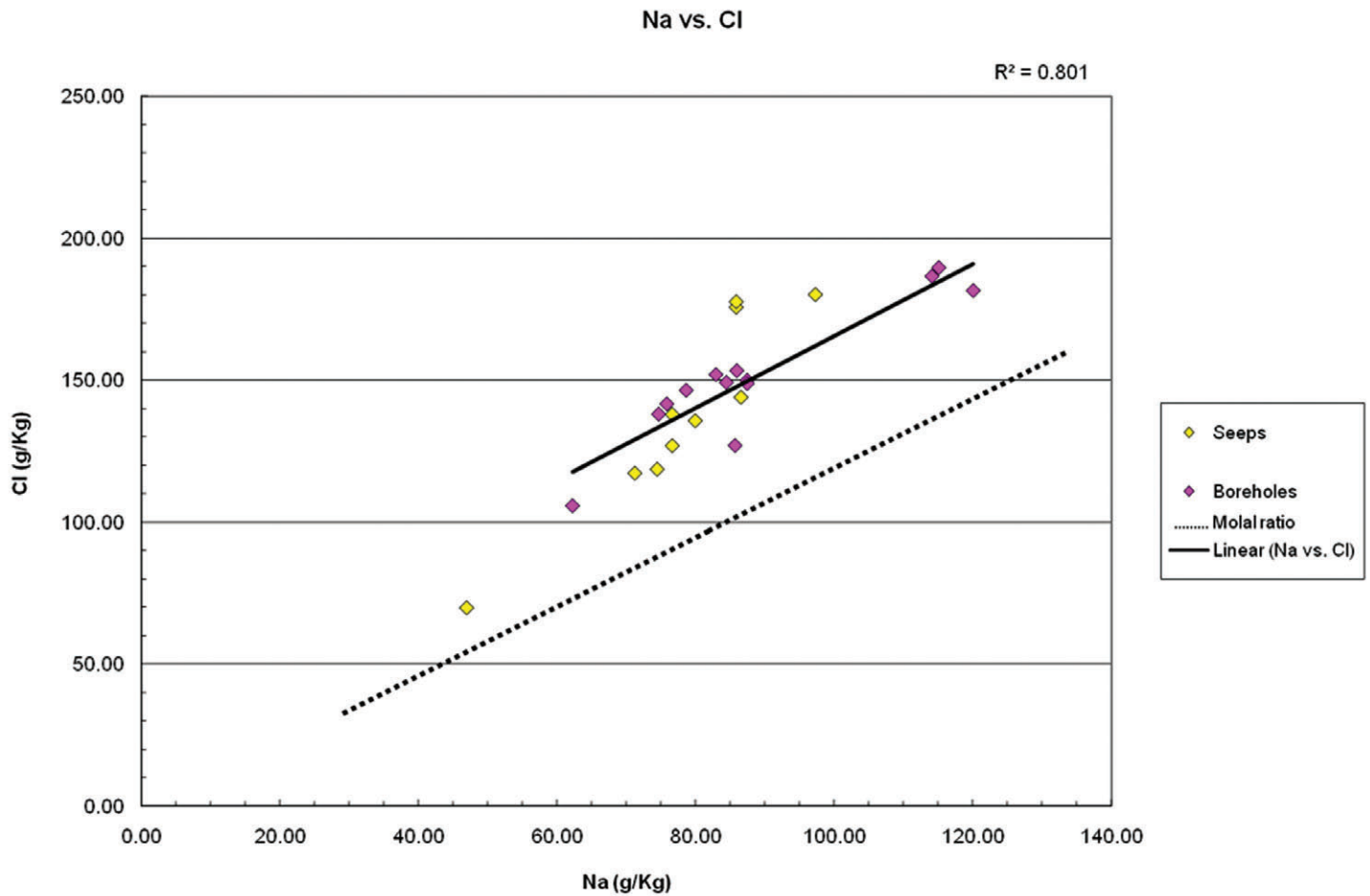


Figure 21. X-Y plots of Na versus Cl from brine samples obtained from open boreholes and ground-water seeps, Newfoundland Basin. A solid straight line was fitted to the data using linear-regression technique, and goodness of fit was indicated by the listed R^2 . Molal ratio was plotted as a dotted straight line.

correlation between the two principal constituents ($R^2 = 0.80$). This is illustrated by the bulk of these samples, which have a molar ratio very close to the 1:1 expected for halite, particularly in the lower part of the compositional range. The greatest deviation is at or near halite saturation, which reflects loss of Na from fluids in salt crust near the central-basin topographic low. The most dilute sample is from a ground-water seep in a meander channel of Miry Wash at the northwest edge of the playa. This sample has no apparent excess of Na, which suggests no contribution of Na from chemical weathering of silicate minerals comprising the adjacent alluvium. At concentrations near the maximum in NaCl, seeps discharging from salt crust near the central basin topographic low show a marked deficiency in Na, whereas seeps from clay-carbonate sediment beyond the end of the inlet canal fall closer to the regression line for all samples. This suggests variation in compositional fractionation associated with halite precipitation.

Similar to the pore-fluid X-Y plots, the only constituent pair that is slightly better correlated than Na with Cl over the entire compositional range is K with Mg, ($R^2 = 0.89$ – see figure 22). This indicates that these major solutes are essentially conservative in solutions undersaturated with respect to halite. As was observed in the Na versus Cl plot for seeps and boreholes, the only notable deviations from the overall regression relation are outliers at concentration extremes. The surface seep near the central-basin topographic low at ST-05 and the open borehole fluid at NB#14 (western peripheral basin) both show excess Mg, whereas the Miry Wash sample and seeps near the end of the inlet canal (southern peripheral basin) have an excess of K. The Mg enrichment in the highly concentrated ST-05 sample is the result of fractional crystallization of halite, while the deviations in the less concentrated fluids probably have more to do with solute source. The excess Mg at NB#14 might be attributed to peripheral upwelling of deeper basinal brine associated with resolution of metastable kerolitic smectite, such as noted by Cerling (1996) in the deeper sediments of Lake Turkana in east Africa.

In view of the correlation between K and Mg content for the open boreholes and seeps, it is not surprising that these constituents show a very similar, but rather irregular relationship to SO_4 ($R^2 = 0.43$ and 0.49 , respectively - figures 23 and 24). Again, the greatest departures from the regression line are outliers at the concentration extremes, but a few other points also deviate, particularly samples that appear cation deficient compared to SO_4 concentration. However, this has little consistent relation to location. In contrast, samples with a cation excess relative to the regression are commonly associated with boreholes in the inlet-canal area.

SNORM Analysis

In another attempt to describe relationships indicative of solute-mineral interactions, the Newfoundland Basin brine analyses were examined with the computer program SNORM (Bodine and Jones, 1986; Jones and Bodine, 1987). This program calculates the equilibrium assemblage of salts formed after a water sample is evaporated to dryness at $25C^\circ$ and ambient PCO_2 (i.e., partial pressure of CO_2 expressed as millimeters of mercury). The calculations are based on the relative solubility and thermodynamic stability of possible salt phases. For simplicity, the actual mineral assemblages, which can include complex double salts, are recalculated according to simple cation-

anion association. This can be related to solute origin. Thus alkali CO_3 and SO_4 are symptomatic of continental deposits, whereas $MgCl_2$ is indicative of marine origin, and $CaCl_2$ is a flag for diagenetic reactions.

In general, SNORM analyses of the Newfoundland Basin brines (appendix A6) emphasize the NaCl dominance in these fluids. However, a minor but consistent amount of $MgCl_2$ is also routinely present, which indicates ultimate marine origin of the solute matrix. The greatest variance observed in SNORM analysis is in the Mg phases, particularly $MgSO_4$, which is principally due to the large variation in SO_4 throughout the system. Where present, the $MgSO_4$ is inversely correlated with NaCl and $CaSO_4$, but the R^2 is unlikely to exceed 0.4 (figure 25). In relation to location, the peripheral-basin fluids carry somewhat higher NaCl percentages, whereas the lowest NaCl proportions are found in the highly concentrated, Mg-rich pore fluids of the central-basin topographic low.

Probably the most interesting result of the SNORM analysis is the occurrence of $CaCl_2$, which is commonly small in amount even when present. The largest percentages occur in clay-carbonate muds which have the most highly concentrated pore fluids. This corroborates the findings from studies of Great Salt Lake that have documented the authigenic formation of kerolitic smectite (and dolomite) in bottom sediments (Jones and Spencer 1999; Spencer et al., 1984).

Correlation of Key Stratigraphic Elements with Pore-Fluid Chemistry and Sediment Mineralogy

Pore-fluid chemistry: In addition to major concentration shifts in the pore-fluid profiles for principal solutes noted earlier (e.g., the significant concentration decreases below 6.5 feet (2 meters) at sites MW-12 and NB#10), further detail in the relation between the pore-fluid chemistry and mineral stratigraphy can be illustrated by reference to the depth of maximum and minimum values for individual solute concentrations at each site. These are recorded with their corresponding stratigraphic information in appendix A7.

In general, the pore-fluid profiles can be characterized using several basic categories. The simplest situation is where all constituents reach a maximum concentration at the top of the sedimentary column (where they are most subject to evaporative concentration), and a minimum at the bottom of the column, where they are mixed with dilute fluids from below. These conditions are most commonly met at peripheral sites, such as NB#6, NB#7, SB-04, and NB#18. At two such sites (NB#7 and NB#16), an association of Na with SO_4 at either top or bottom of the profile may be related to clastic (feldspar?) weathering.

The most characteristic situation at central-basin sites is to have salt crust at, or very near, the top of the profile, with a maximum in K and perhaps Mg from pore-fluid brines in the lower part of the crystalline salt, which may or may not contain the NaCl maximum (e.g., at NB#10 where the NaCl maximum is 6.5 feet/2 meters in depth). The SO_4 maximum typically occurs underneath the salt crust in pore fluids associated with crystalline gypsum and increased clay, following the solubility sequence of gypsum precipitating before halite. This is well illustrated at NB#8. Also, some association of black, fetid clay resulting from active SO_4 reduction is not unexpected.

The most central of the basin sites (e.g., NB#10 or MW-12) show a decrease of all the major constituents in pore fluids near the profile top. This is presumably due to rainfall dilution, the

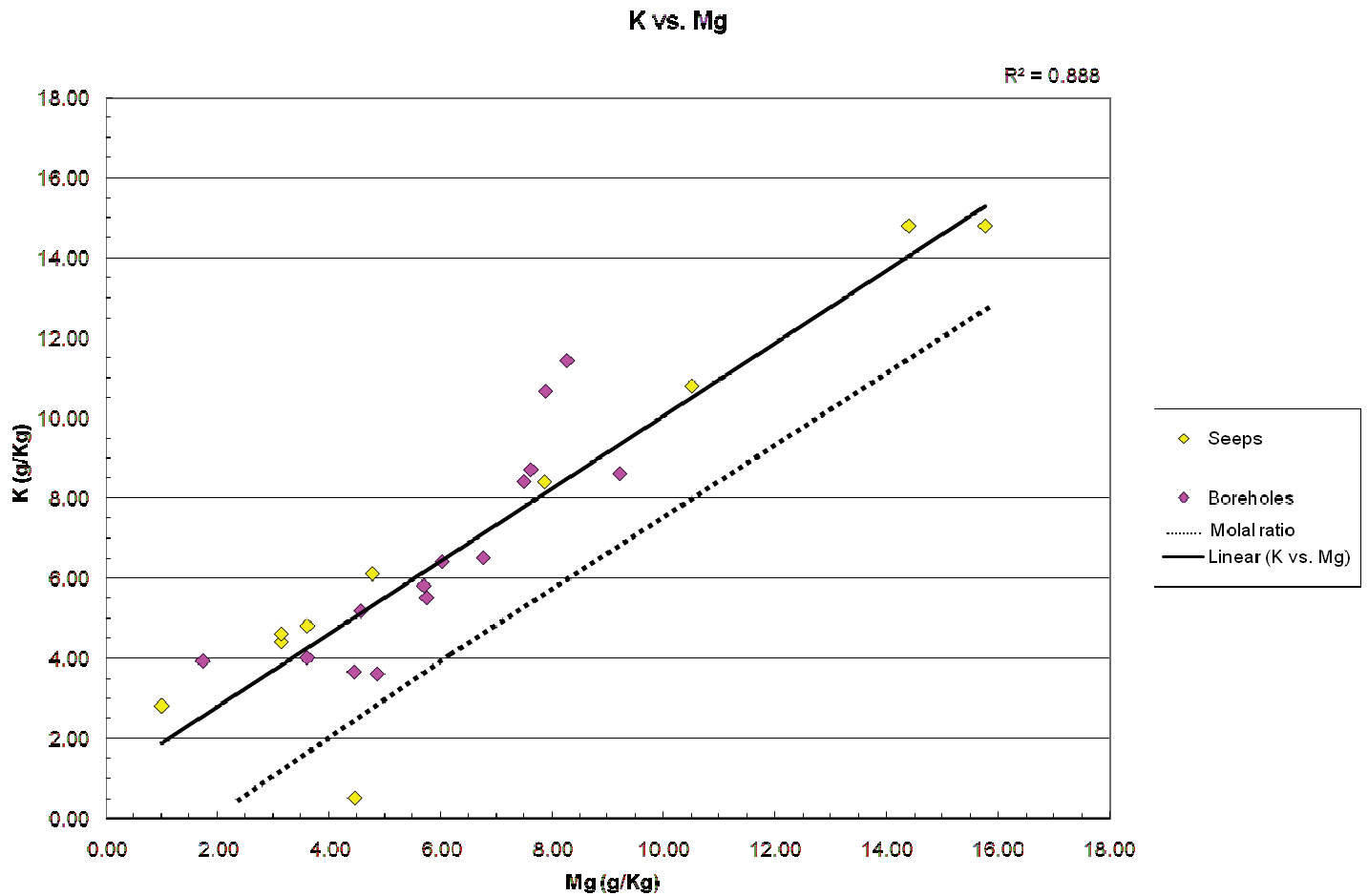


Figure 22. X-Y plots of K versus Mg from brine samples obtained from open boreholes and ground-water seeps, Newfoundland Basin. A solid straight line was fitted to the data using linear-regression technique, and goodness of fit was indicated by the listed R^2 . Molal ratio was plotted as a dotted straight line.

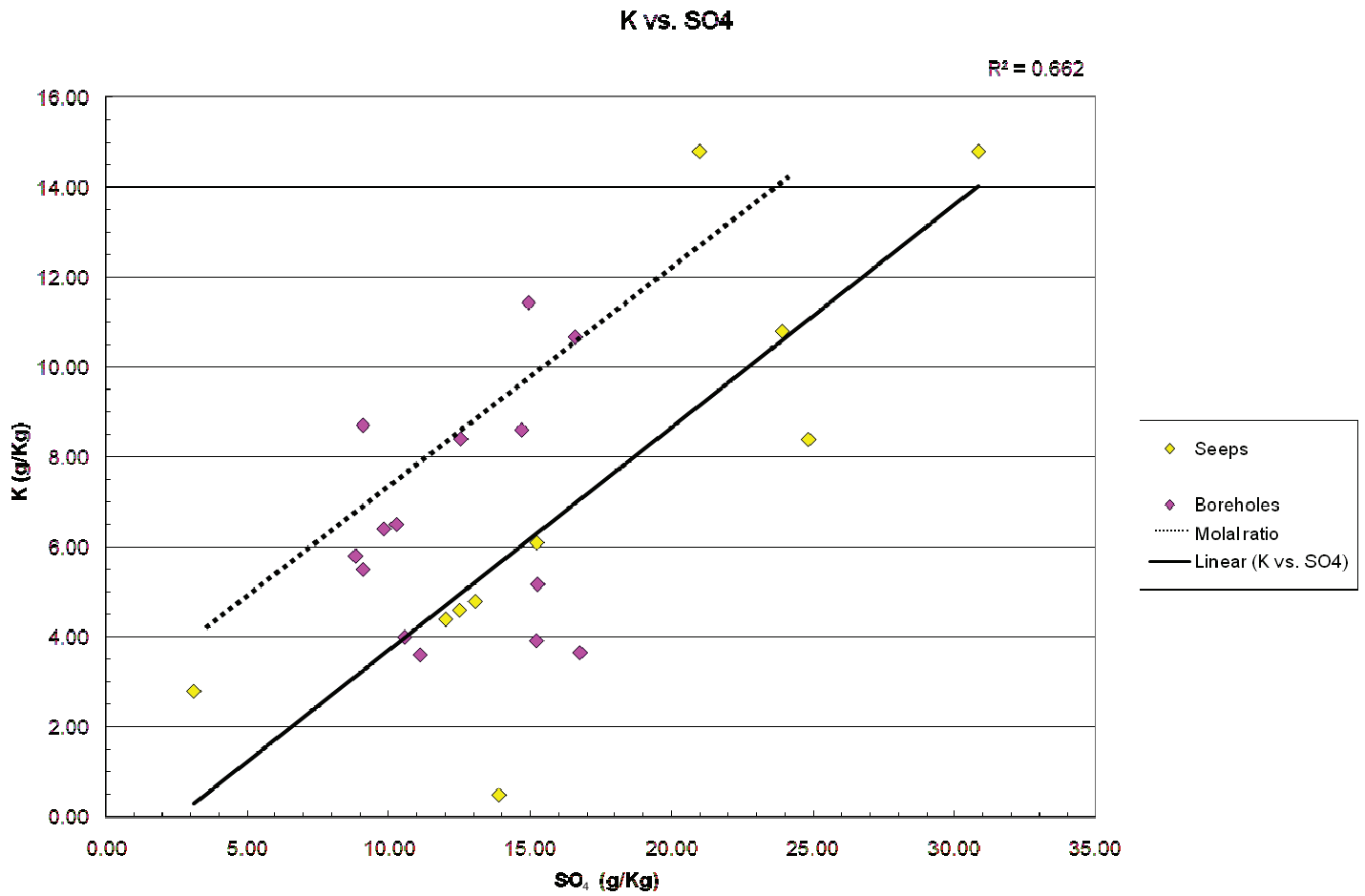


Figure 23. X-Y plots of K versus SO₄ from brine samples obtained from open boreholes and ground-water seeps, Newfoundland Basin. A solid straight line was fitted to the data using linear-regression technique, and goodness of fit was indicated by the listed R². Molal ratio was plotted as a dotted straight line.

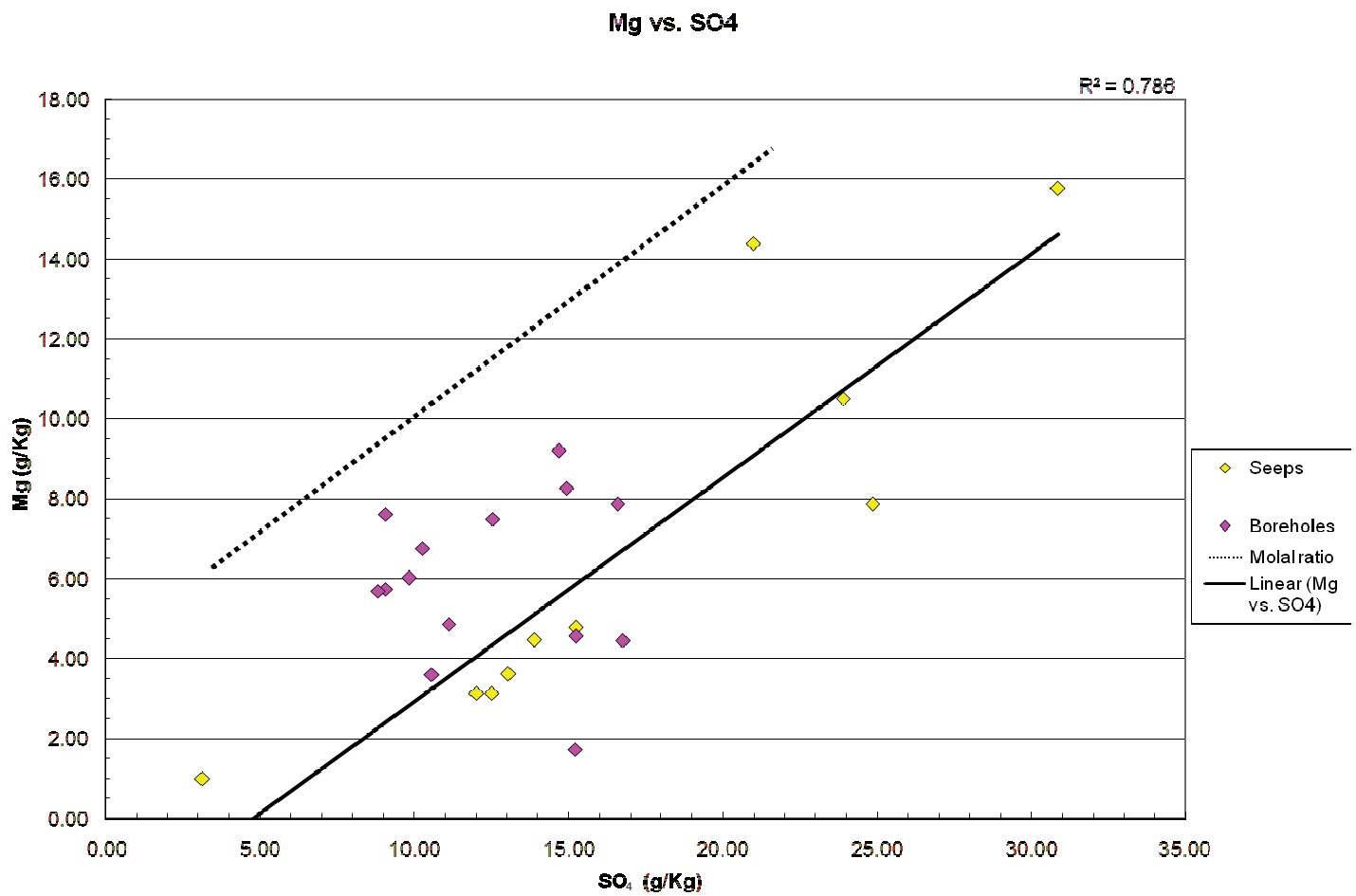


Figure 24. X-Y plots of Mg versus SO₄ from brine samples obtained from open boreholes and ground-water seeps, Newfoundland Basin. A solid straight line was fitted to the data using linear-regression technique, and goodness of fit was indicated by the listed R². Molal ratio was plotted as a dotted straight line.

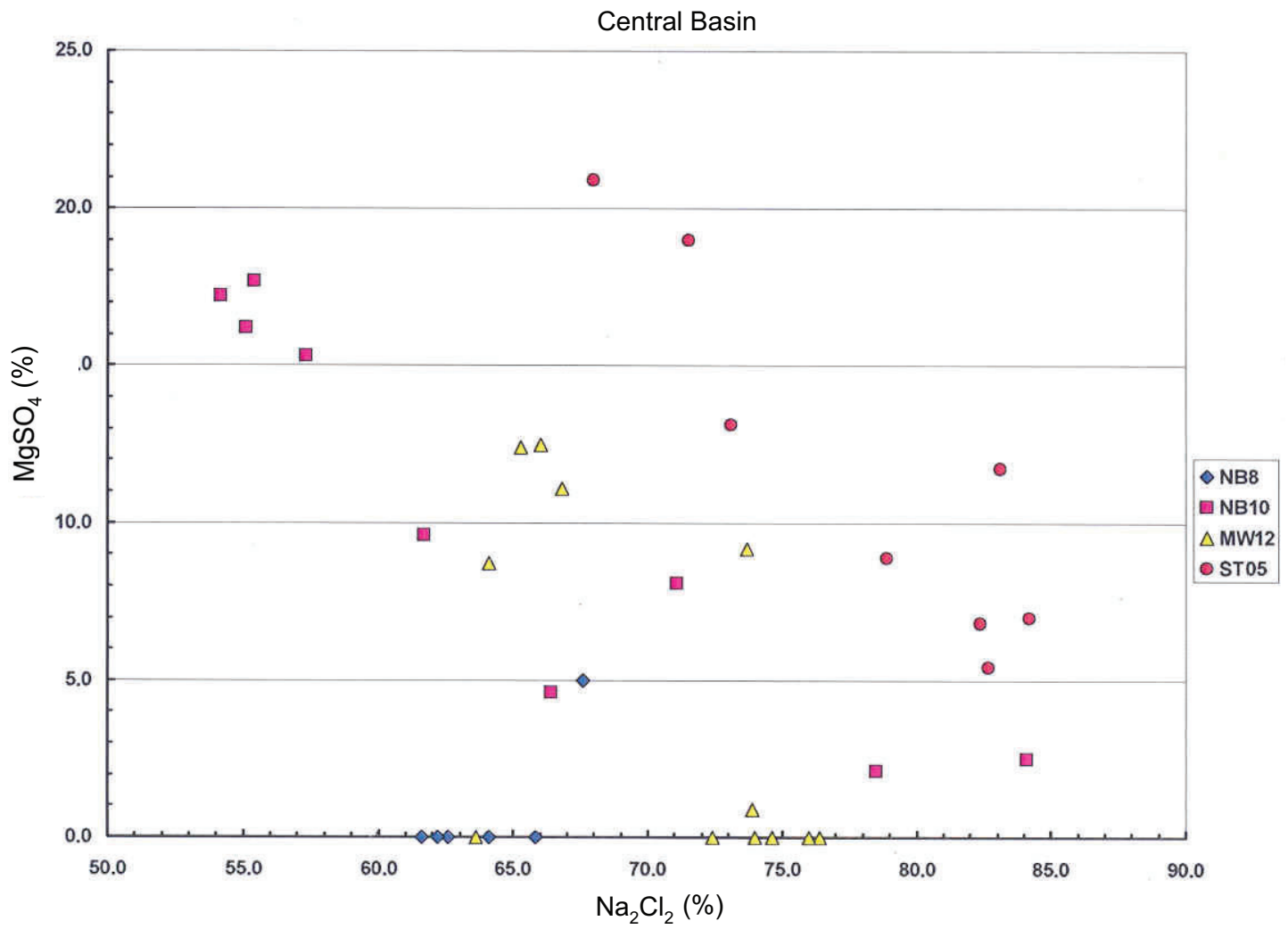


Figure 25. SNORM-generated X-Y plots of normative Na₂Cl₂ and MgSO₄ content (%) from pore fluids obtained from shallow-sediment cores. Core sites included three open boreholes (NB#8, NB#10, and ST-05) and one monitoring well (MW-12). Site locations are all from the central basin topographic low.

effects of which most frequently accumulate at the central-basin topographic low. Where the salt crust is not as well developed (MW-09 and MW-10), the K and Mg maxima occur in pore fluids very near the top of the profile, apparently retained by clay-carbonate mud. Here, the greatest evaporation effect does not appear to be diluted by rainfall. The NaCl maxima appear associated with more permeable zones at depth characterized by the presence of carbonate fragments from algal-mat deposits.

Core-sample mineralogy: A comparison of the mineralogy and the stratigraphic profiles for those borehole sites where core was collected suggest an apparent lateral correlation of some intervals based on dominant mineral occurrence (appendix A5). The most readily observed situation is in the development of the surface halite crust, which during the period of observation ranged in thickness from a fraction of an inch to non-existent at the peripheral sites to at least 25 inches (64 centimeters) of nearly pure halite at site NB#10. Individual layers 6 inches (15 centimeters) or more in thickness containing elevated levels (greater than 10%) of halite can be found at depths up to 5 feet/1.5 meters (NB#7) in peripheral sites, and up to 25 feet/7.6 meters (MW-12) in central-basin sites. Also near the basin center, halite can make up over 90% of subcrustal layers to depths exceeding 3 feet (0.9 meters).

In the central basin, gypsum may occur immediately below the surface halite crusts as abundant, coarse, doubly-terminated crystals (33% to 76%) in a clay matrix, and reach depths of more than 10 feet/3 meters (NB#10). However, gypsum also occurs in fine-grained crystal layers at 3 to 6-foot (0.9 to 1.8-meter) depths (37% to 76% in NB#8, MW-12) beneath massive halite at the surface. In the peripheral areas (NB#7 and NB#14), two gypsiferous zones at about 2.5 and 3.0 feet (0.6 and 0.9 meters) are apparent, which can be correlated roughly with similar strata in the central-basin area, such as at NB#8, NB#9, and NB#10.

The most abrupt and consistent mineralogical changes noted in the mud-dominated cores collected outside the most central sites are observed in the carbonates. The principal feature is the increase in aragonite with depth, commonly from zero to a double-digit percentage (NB#6, NB#7, NB#18, ST-01 and ST-02, MW-09, MW-10 and MW-12). However, at peripheral sites (NB#6, NB#16 and SB-04) the mud of the immediate surface can be high in aragonite as well. An abrupt increase in aragonite typically occurs at a depth of about 2.5 to 3 feet/0.8 to 0.9 meters (NB#6, ST-02, and MW-12). At the central-basin core sites, insufficient borehole depth was reached to observe a change in carbonate type. However, a very small amount of dolomite is found in cores from the central-basin sites. Calcite is present in double-digit percentage quantities only in the most peripheral-basin core sites (NB#6, NB#7, SB-04, NB#16, and NB#18), and then only persists in the upper 3 feet (0.9 meters) of NB#6 accompanied by significant amounts of quartz but no aragonite. This appears to represent local detrital input. Intermediate and central-basin sites (MW-09, MW-10, ST-01 and ST-02, MW-12, and NB#10) contain consistent small amounts of calcite not exceeding 10%. No carbonate was observed in NB#8 core (0 to 6-foot/0 to 1.8-meter depth). These observations suggest sedimentation of Ca was introduced as aerosol particles associated with meteoric precipitation.

The clay mineral content of all the core samples examined was highly variable, with slightly higher amounts in the peripheral-basin sites than in central-basin sites. Significant amounts

of clay occurred even in the presence of substantial percentages of halite or gypsum. No consistency was found in ratios of total clay to the percentage of other mineral phases.

Based on the mineral suite contained in the core samples, presence of aragonite indicated a lacustrine environment, whereas gypsum (and sparse dolomite) was characteristic of playa or mudflat conditions. In peripheral-basin sites, calcite was associated with increased quartz, suggesting alluvial input. Consequently, Newfoundland Basin sediments associated with the shallow-brine aquifer illustrate the zoned "evaporation dish" pattern originally described by Hunt (1960) for the Death Valley salt pan.

Geochemical Modeling of Newfoundland Basin Brines

Background

Kohler and White (2004) used chemical analyses from 1966 Reynolds brine samples (Kohler 2002, appendix 1) and published 1978 brine analyses from the Great Salt Lake (GSL) North Arm (Sturm 1980, table 9) as two compositional extremes possible for mixtures used to simulate effects of brine mixing as a result of the Pumping Project. A 50–50 mix of the two compositional extremes was used as input for the mixing simulation. The mixing simulation was performed using the TEQUIL model, which is based on Pitzer electrolyte equations and calculates liquid-solid-gas equilibria in complex brine systems (Harvie and Weare 1980, Moller and others 1997). Various versions of this program are available. The 25°C version for the Na-K-Ca-Mg-H-Cl-OH-SO₄-HCO₃-CO₃-CO₂-H₂O system (Harvie and others 1984) was used in both the Kohler and White (2004) simulations and those in this study.

As an expansion of Kohler and White's study (2004), TEQUIL was used in this investigation to better understand how the GSL brines introduced into the Newfoundland Basin may have interacted with pore fluids contained within the basin's shallow-brine aquifer sediments, and identify the depths to which this interaction could be recognized. Brine chemistries used in the TEQUIL simulations are listed in table 2. TEQUIL-predicted mineral species, along with their respective chemical formulas and gram-molecular weights are listed in table 3.

Summary of Kohler and White TEQUIL Simulations

TEQUIL identified the sequence of mineral species precipitated from simulated step-wise evaporation of pre- and post-pumping Newfoundland Basin shallow-brine aquifer fluids and GSL North Arm brine (figures 26 and 27):

- Pre-pumping sequence: gypsum-anhydrite-halite-polyhalite-sylvite-kainite-carnallite-kieserite (figure 26a).
- Post-pumping sequence: glauberite-halite-polyhalite-leonite-sylvite-kainite-carnallite-kieserite-bischofite (figure 27a).
- GSL North Arm brine sequence: anhydrite-glauberite-halite-polyhalite-leonite-kainite-carnalite-kieserite-bischofite (figure 26b)
- The model was also used to simulate 50-50 mixing of 1978 GSL North Arm brine with 1966 Reynolds

Table 2. – Brine chemistries used in TEQUIL simulations from Kohler and White (2004), and from pore-fluid samples of core recovered from peripheral and central-basin boreholes NB#7 and NB#10. Core-depth intervals listed in inches below ground level (BGL). Ion concentrations expressed in moles/kg.

Simulation ID	Na ⁺	K ⁺	Ca ⁺²	Mg ⁺²	Cl ⁻	SO ₄ ⁻²
Kohler and White Study:						
1966 Reynolds pre-pumping brine ¹	2.835	0.097	0.029	0.148	3.138	0.074
1978 GSL north-arm brine	4.515	0.216	0.011	0.494	5.287	0.227
Reynolds & GSL 50 – 50 mix	3.675	0.157	0.019	0.321	4.212	0.151
NB#8 post pumping brine ¹	3.454	0.425	0.004	0.823	4.803	0.365
Pore-Fluid Study:						
NB#7-At (0 to 2.5 inches) ²	4.756	0.144	0.013	0.321	5.294	0.138
NB#7-Lb (56.5 to 59 inches) ²	3.214	0.115	0.022	0.147	3.547	0.060
NB#10-Bb (30 to 36 inches) ¹	3.330	0.485	0.003	1.358	5.335	0.601
NB#10-Ib (72 to 78 inches) ¹	3.992	0.204	0.004	0.392	4.691	0.149

¹Central basin borehole²Peripheral basin borehole**Table 3.** TEQUIL-predicted mineral species (common minerals italicized) from simulated stepwise evaporation of Newfoundland Basin borehole and pore-fluid brine samples (after Braitsch, 1971, table 4).

Name	Formula	Molecular Weight, g/mole
<i>Anhydrite</i>	CaSO ₄	136.15
<i>Bischofite</i>	MgCl ₂ ·6H ₂ O	203.33
<i>Bloedite</i>	Na ₂ Mg(SO ₄) ₂ ·4H ₂ O	334.51
<i>Carnallite</i>	KMgCl ₃ ·6H ₂ O	277.88
<i>Epsomite</i>	Mg SO ₄ ·7H ₂ O	246.50
<i>Glauberite</i>	Na ₂ Ca(SO ₄) ₂	278.21
<i>Gypsum</i>	CaSO ₄ ·2H ₂ O	172.18
<i>Hexahydrate</i>	Mg SO ₄ ·6H ₂ O	228.49
<i>Leonite</i>	K ₂ Mg(SO ₄) ₂ ·2H ₂ O	366.71
<i>Kainite</i>	KMgClSO ₄ · ¹ / ₄ H ₂ O ¹	244.48
<i>Kieserite</i>	MgSO ₄ ·H ₂ O	138.41
<i>Polyhalite</i>	Ca ₂ K ₂ Mg(SO ₄) ₄ ·2H ₂ O	602.98
<i>Rock salt (Halite)</i>	NaCl	58.45
<i>Sylvite</i>	KCl	74.55
<i>Syngenite</i>	K ₂ Ca(SO ₄) ₂ ·H ₂ O	328.43

¹Water content is expressed as a fraction so that resulting molecular weight is comparable with other salt minerals (required for subsequent calculations of salt precipitation).

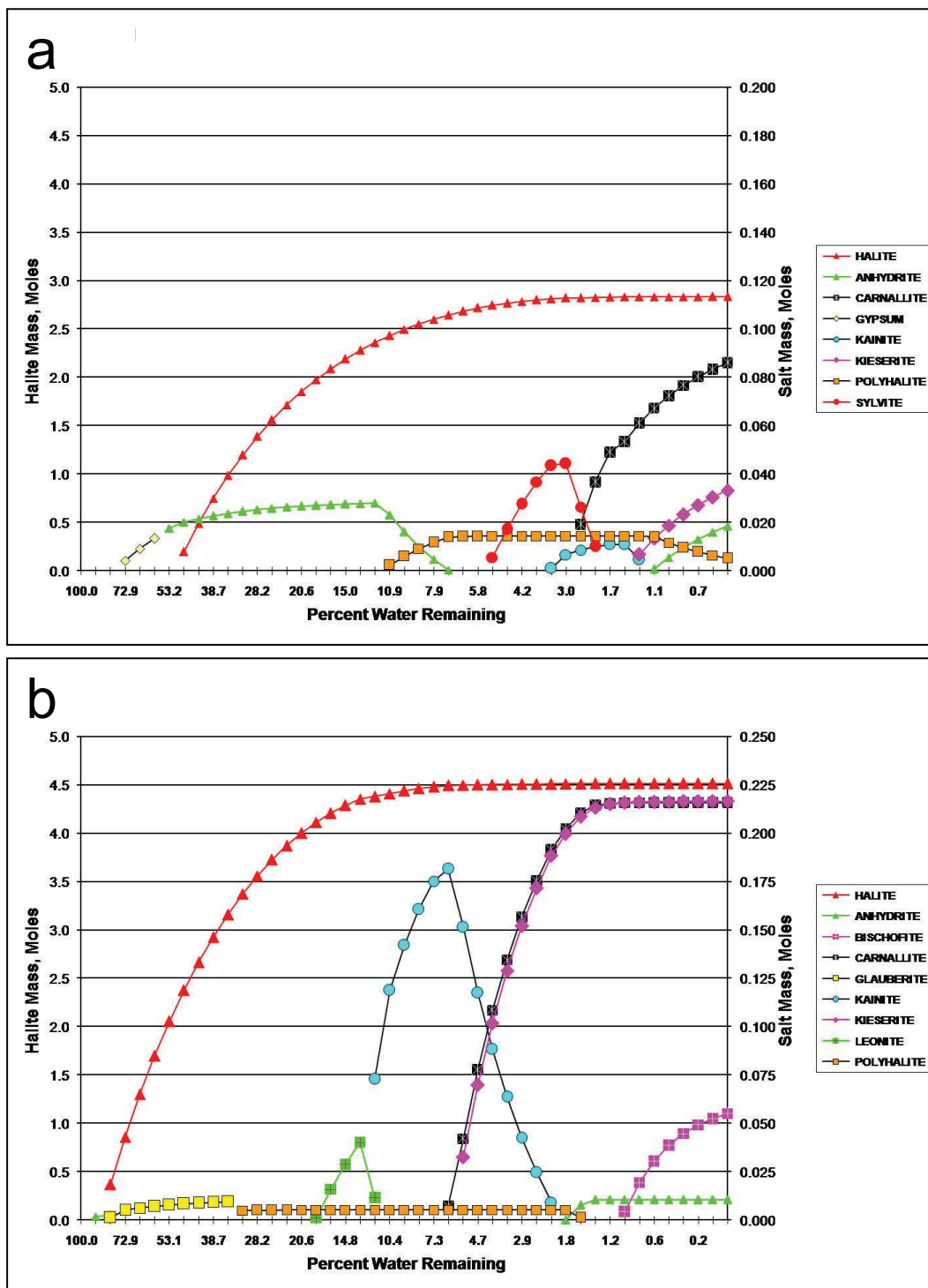


Figure 26. TEQUIL-predicted mineral sequence plots of chemical analyses from 1966 Reynolds brine sample, borehole #60238 (26a), and Great Salt Lake North Arm brine, 27 October, 1978 (26b) (after Kohler and White, 2004). Note: because moles of precipitated-salt species were different between their respective 26a and 26b plots, different numerical scales for salt mass (right Y-axis) and percent water remaining (X-axis) were used to optimize plot presentation.

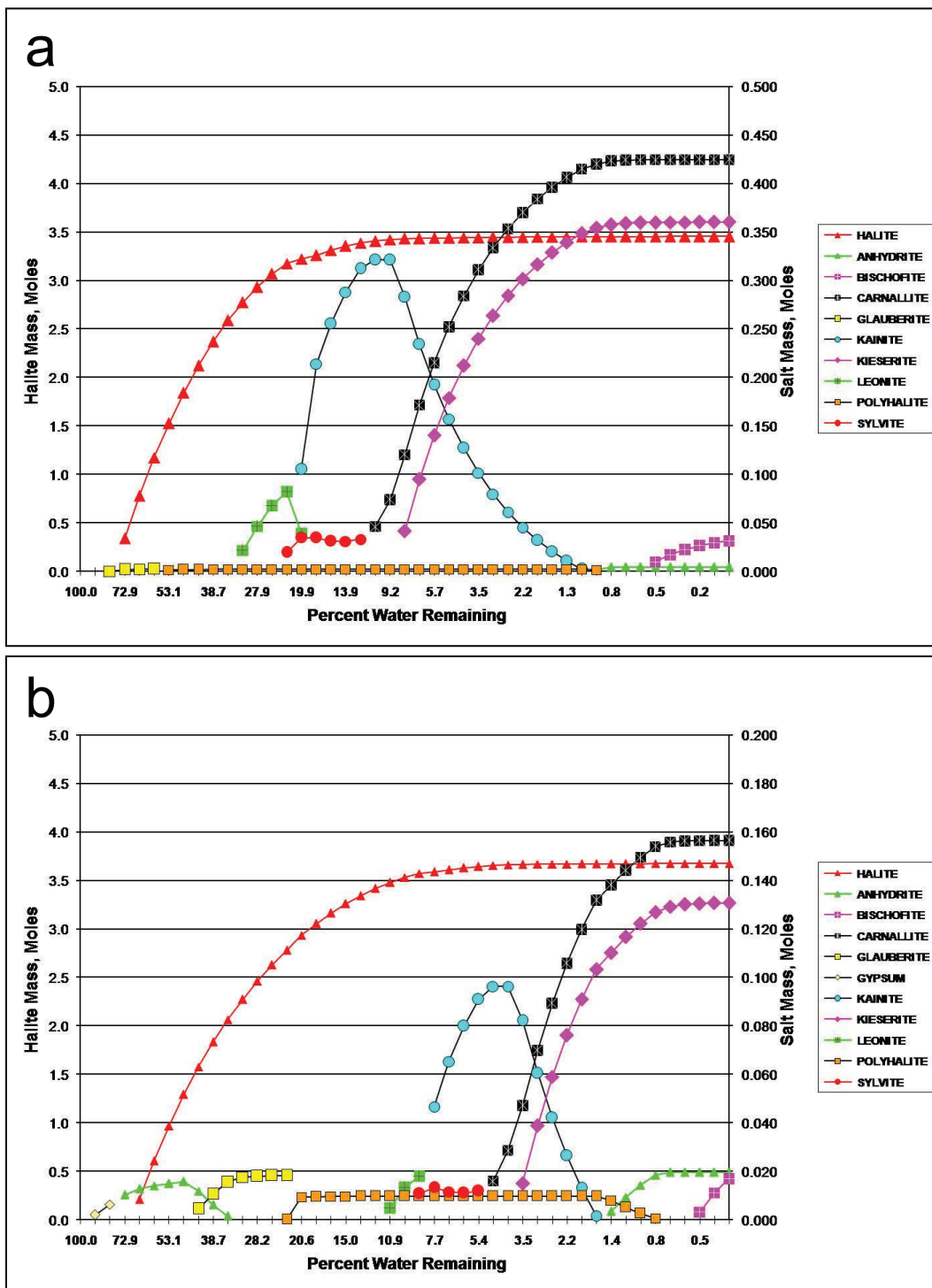


Figure 27. TEQUIL-predicted mineral sequence plots of chemical analyses from 1999 BLM borehole NB#8 brine (27a) and simulated 50–50 mix of 1966 Reynolds borehole #60238 brine and 1978 Great Salt Lake North Arm brine (27b) (after Kohler and White, 2004). Note: because moles of precipitated-salt species were different between their respective 27a and 27b plots, different numerical scales for salt mass (right Y-axis) and percent water remaining (X-axis) were used to optimize plot presentation.

brine (pre-pumping Newfoundland Basin shallow-aquifer fluids - figure 27b).

- The resulting precipitated mineral suite from step-wise evaporation of the simulated brine mix (figure 27b) was nearly identical to that from TEQUIL simulation of the post-pumping Newfoundland Basin brine (figure 27a).

Summary of Pore-Fluid TEQUIL Simulations

The sequence of TEQUIL-predicted mineral species precipitated from simulated step-wise evaporation of pore-fluid brines from core samples of peripheral and central-basin boreholes NB#7 and NB#10 are shown in figures 28 and 29 and listed below:

- NB#7 (0 to 2.5 inches/0 to 6.4 centimeters BGL): anhydrite-halite-glauberite-polyhalite-leonite-sylvite-kainite-carnalite-kieserite-bischofite (figure 28a).
- NB#7 (57 to 59 inches/1.4 to 1.5 meters BGL): gypsum-anhydrite-halite-polyhalite-sylvite-kainite-carnallite-kieserite (figure 28b).
- NB#10 (30 to 36 inches/0.8 to 0.9 meters BGL): glauberite-halite-polyhalite-bloedite-leonite-epsomite-kainite-kieserite-carnallite-bischofite (figure 29a).
- NB#10 (72 to 78 inches/1.8 to 2.0 meters BGL): halite-anhydrite-glauberite-polyhalite-leonite-sylvite-kainite-carnallite-kieserite-bischofite (figure 29b).

Peripheral-basin pore-fluid sample from NB#7 core depth 0 to 2.5 inches (0 to 6.4 centimeters) BGL showed predicted mineral-sequence plots (figure 28a) that were most similar to those of the 50–50 simulated mix of 1978 GSL North Arm brine with 1966 Reynolds brine (see figure 27b).

However, peripheral-basin pore-fluid sample from NB#7 core depth 57 to 59 inches (1.4 to 1.5 meters) BGL showed predicted mineral-sequence plots (figure 28b) nearly identical to those of the pre-pumping 1966 Reynolds brine (see figure 26a).

Central-basin pore-fluid sample from NB#10 core depth 30 to 36 inches (0.8 to 0.9 meters) BGL showed predicted mineral-sequence plots (figure 29a) that were similar to those of open-hole brines from the adjacent central basin borehole NB#8 (see figure 27a); sample depth interval was from top of lacustrine sediments in contact with 26-inch (0.7-meter) thick overlying salt crust precipitated from the West Pond.

Conversely, central-basin pore-fluid sample from NB#10 core depth 72 to 78 inches (1.8 to 2.0 meters) BGL showed predicted mineral-sequence plots (figure 29b) that were similar to those of the pre-pumping 1966 Reynolds brine (see figure 26a), but also had some residual characteristics of the GSL North Arm brine (i.e., kainite ($\text{KMgClSO}_4 \cdot \frac{1}{4} \text{H}_2\text{O}$) peak was greater than the sylvite (KCl) peak, and a trace of leonite ($\text{K}_2\text{Mg}(\text{SO}_4)_2 \cdot 2\text{H}_2\text{O}$) was present).

The chemical character of the Newfoundland Basin shallow-brine aquifer was substantially changed when mixed with GSL brine during the West Desert Pumping Project. The TEQUIL model results from Kohler and White (2004) showed that the mineral suite precipitating from GSL brine was very different from mineral suites predicted from the pre-pumping Newfoundland Basin shallow-brine aquifer.

TEQUIL-predicted mineral-sequence plots from simulated step-wise evaporation of pore-fluid brines from peripheral and central-basin core samples demonstrated that near surface pore-fluid brines were a mixture of pre-pumping ground water and GSL brine, while pore fluids from core depths ranging from 5 to nearly 7 feet (1.5 to 2.0 meters) BGL had predicted mineral-sequence plots similar to the pre-pumping 1966 Reynolds brine.

Hydrology

Permeable Facies in Sediments of the Shallow-Brine Aquifer

Permeable facies within sediments of the shallow-brine aquifer are typically relatively clean oolitic sand (i.e., minimal clay matrix), sponge-like algal mat, and loosely aggregated fine-grained gypsum crystal facies. These permeable facies are typically interbedded with impermeable clay-bearing sediments. Oolitic sand facies are commonly saturated with brine and in some instances are associated with algal-mat material. Wavy algal-mat material with active green or brown-colored algal coatings have been observed as components of discrete low-relief mound occurrences on the mudflat surface near the center of the basin. Wavy algal-mat material has also been encountered at depth as horizontal strata in boreholes. Presence of subsurface wavy algal-mat material also coincides with the first occurrence of ground-water brines in several boreholes.

Ground-water brine transport in sediments of the shallow-brine aquifer occurs mainly in the permeable sedimentary facies described above, and from vertical fissures observed in mudflat clay facies. These vertical fissures appear similar to vertical fissures described by Turk (1969, p.38) and Turk and others (1973, p. 69, 76-77) in the clays exposed by brine collection ditches adjacent to the Bonneville Salt Flats. Similar vertical fissures have been observed in clays exposed in the inlet-canal walls and in dendritic drainages adjacent to breaches in the inlet-canal berm.

The vertical fissures are made more visible in Newfoundland Basin mudflat sediments by algal-mat material that was observed as fracture fillings. Algae that help form the algal-mat material are apparently associated with the brine observed discharging from some of the vertical fissures because brown-colored algae have been observed clinging to fissure surfaces. Both open fissures and algal-mat filled fissures have been observed side-by-side and occur in the clay floors of dendritic drainages adjacent to breaches in the inlet-canal berm (figure 3a). At least seven breaches allowed West Pond brine to be withdrawn by the inlet canal during the 1987-89 Pumping Project and resulted in the erosional formation of a series of dendritic drainages that were cut down through the mudflat surfaces and into the underlying shallow-brine aquifer sediments. Ground-water brine was observed discharging from vertical fissures in the clay floors of dendritic drainages at three different breach locations along the west side of the inlet canal (figure 3b).

Hydraulic Conductivity of Shallow-Brine Aquifer Lacustrine Sediments

Presence of permeable facies was recorded in the geologic logs of all 24 boreholes (appendix A1). As each borehole was being drilled in mudflat sediments, ground-water brine was typically intercepted at depths ranging from about 1.5 to 3 feet (0.5

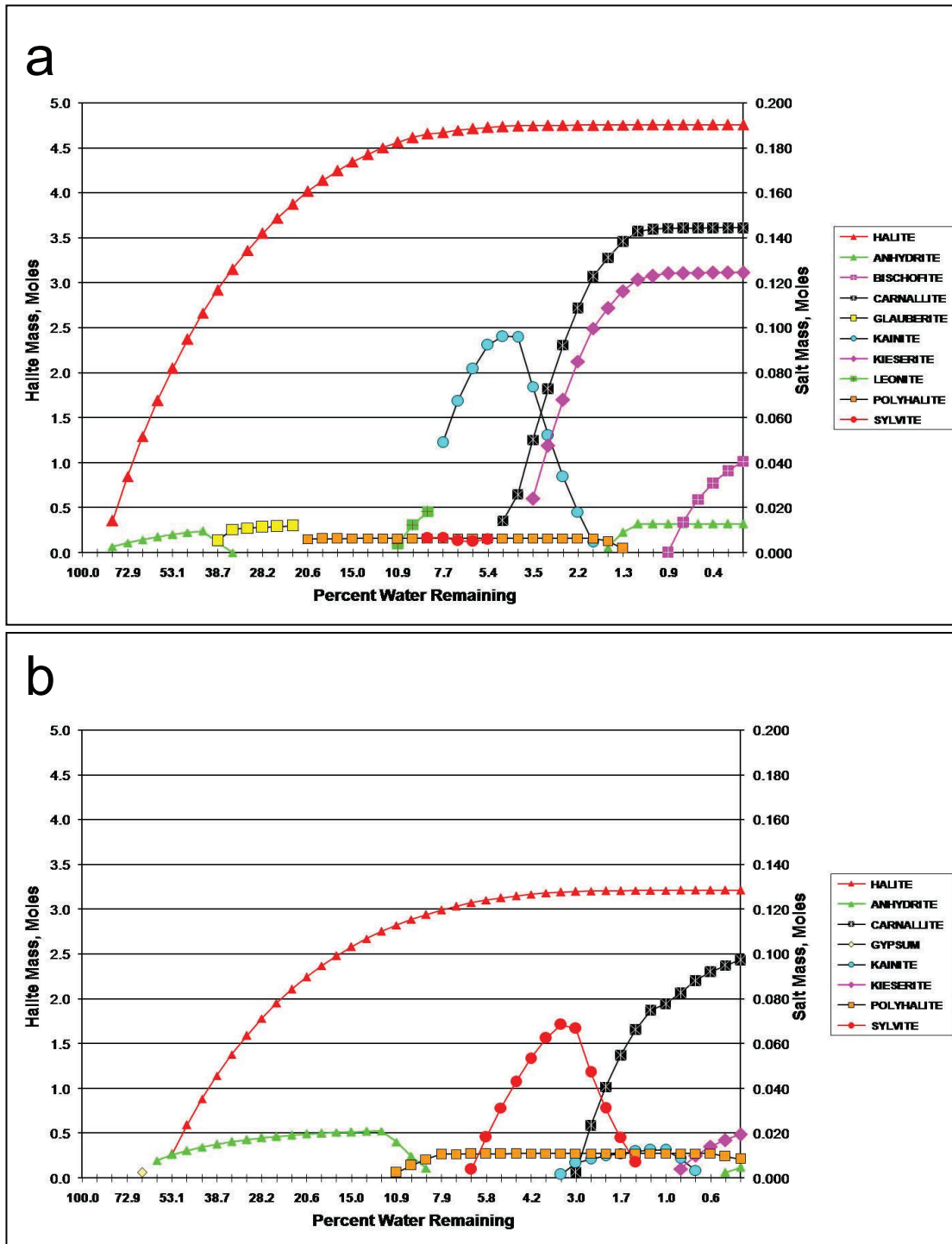


Figure 28. TEQUIL-predicted mineral sequence plots from simulated step-wise evaporation of pore-fluid brines from core samples of peripheral basin borehole NB#7: 28a near-surface pore fluid from core depth of 0 to 2.5 inches (0 to 6.4 centimeters) below ground level (BGL); 28b pore fluid from core depth of 56.5 to 59 inches (1.4 to 1.5 meters) BGL.

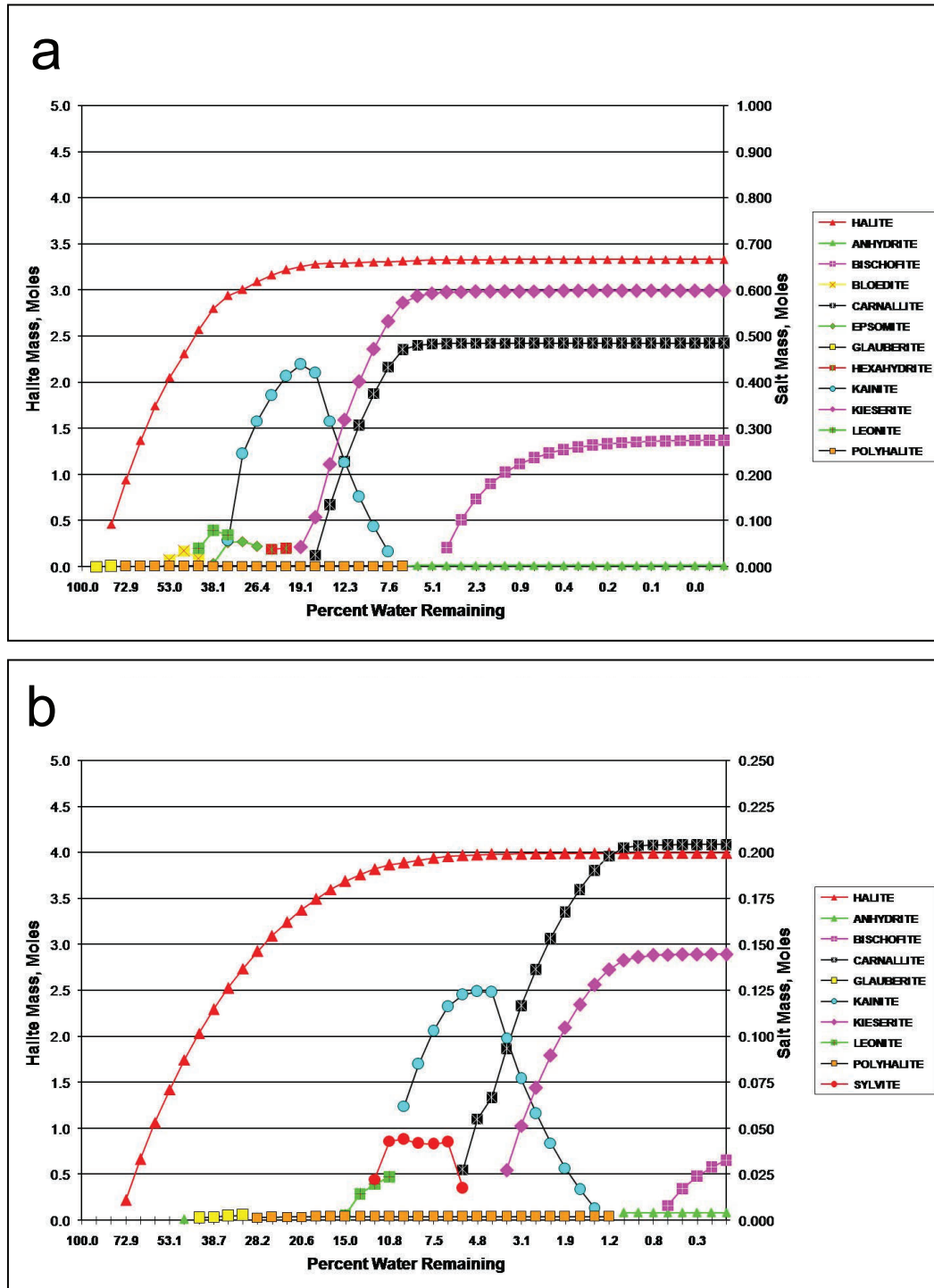


Figure 29. TEQUIL-predicted mineral sequence plots from simulated step-wise evaporation of pore-fluid brines from core samples of central basin borehole NB#10: 29a pore fluid from core depth of 30 to 36 inches (0.8 to 0.9 meters) BGL; 29b pore fluid from core depth of 72 to 78 inches (1.8 to 2.0 meters) BGL. Note: because moles of precipitated-salt species were different between their respective 29a and 29b plots, different numerical scales for salt mass (right Y-axis) and percent water remaining (X-axis) were used to optimize plot presentation.

to 0.9 meters) BGL, and commonly rose up in the borehole to static water levels 6 to 20 inches (15 to 51 centimeters) above the interception depths (table 4). Boreholes drilled in salt crust near the central-basin topographic low intercepted ground water either very near to or at the salt-crust surface. When each borehole was pumped, the water level would drop several inches below the static water level to a new equilibrium level. When the pump was turned off, the water level would rapidly recover to its original static water level. We were unable to pump the boreholes dry with our small pumps, and the pumped boreholes never failed to recover to their original static water levels at the termination of pumping (appendix A8).

Although aquifer tests were performed in six boreholes and pumping rate, duration of test, and time versus rising head data were collected (table 4), the suite of data did not include a sufficiently detailed period of record at the beginning of the recovery curve to calculate hydraulic conductivity (K) through use of AQTESOLVE methods (<http://www.aqtesolv.com/>). However, because data collected from these six aquifer tests enabled us to calculate specific capacity (Q/s), these data were used as input to TGUSS to estimate K from the shallow-brine aquifer sediments intercepted by these boreholes (table 5). Input parameters used in TGUSS are listed in appendix A9. The following assumptions were made for the TGUSS input parameters:

- Water-bearing facies (i.e., oolitic sand, porous algal-mat material, and gypsum sand) comprising the shallow-brine aquifer were considered porous media that obey Darcy's Law.
- Distance from the top of the water table to the total depth of the borehole was considered as the saturated thickness (6 to 9 feet).
- Simulated screened-interval distance was made equivalent to the saturated thickness.
- Storage and well-loss coefficients were estimated at 0.001 and 1.0, respectively.

Potential sources of error in TGUSS-computed K values included 1) variable pump rates, 2) non-Darcy fracture flow, and 3) artificial changes in permeability due to borehole wall smearing by the auger. Pump-rate differences were due to slight variations in brine density among boreholes, and variation of head difference during the aquifer test. Fracture flow was not considered because density of vertical fissures present in clay facies of the lacustrine sediments was not measured during the study. Borehole wall smearing of clay facies onto water-bearing facies by removal and re-insertion of the auger during drilling may have reduced the permeability of some water-bearing facies. Additionally, potential inaccuracy in manual measurement of rising-head water levels during the recovery phase of aquifer tests may also have been a source of error.

Table 5 summarizes TGUSS computed K values for six tested boreholes. Five of the boreholes were drilled adjacent to the inlet canal and distributed along its 6-mile length (southern periphery). The sixth borehole was located on the western periphery of the Newfoundland Basin. Hydraulic conductivities ranged from 47 to 88 feet (14 to 27 meters) per day for four of the five boreholes adjacent to the inlet canal. The largest K value was 536 feet (163 meters) per day from a borehole located at the north end of the inlet canal. Hydraulic conductivity for the west margin borehole was 77 feet (23 meters) per day.

With exception of the borehole at the north end of the inlet

canal, K values for the other five boreholes were in reasonable agreement with those determined from aquifer tests conducted by S. S. Papadopulos and Associates (SSP) in eight sets of nested monitoring wells. SSP installed these monitoring wells along the inlet canal and in the central-basin topographic low during 1999 and 2000. The nested monitoring wells were completed in the shallow-brine aquifer. Two or three wells comprised each well set for a total of 21 wells, and their depths were staggered. Shallow wells were 7 to 12 feet (2 to 3.7 meters) deep, intermediate wells were 17 to 20 feet (5 to 6 meters) deep, and deep wells were up to 28 feet (8.5 meters) deep. Based on data from these wells, estimated aquifer thicknesses were 15 to 30 feet (4.6 to 9 meters). Hydraulic conductivity values from aquifer tests (pump and slug) conducted in the monitoring wells ranged from 0.4 to 77 feet (0.1 to 23 meters), and 0.05 to 30 feet (0.02 to 9 meters) per day, respectively (S.S. Papadopulos written communication, October 19, 2000). Pump-test data were input to AQTESOLV where Theis and Hantush-Jacob methods were used to determine K. Slug test data were input to a spreadsheet model where K was determined using the Cooper-Bredehoeft-Papadopulos method (Bryan Grigsby, Hydrogeologist, S.S. Papadopulos, personal communication, September 20, 2006). The higher K values from both ranges were typically from the upper 10 feet (3 meters) of the lacustrine sediments comprising the shallow-brine aquifer.

The magnitude of K values determined from boreholes (TGUSS) and monitoring wells (AQTESOLV) demonstrates that ground-water transport occurs mainly in the porous-media facies comprising the shallow-brine aquifer sediments (i.e., oolitic sand, porous algal-mat material, and gypsum sand).

Quantification of Ground-Water Discharge

As was previously mentioned, ground-water brine was observed discharging from vertical fissures in the clay floors of dendritic drainages at three different breach locations along the west side of the inlet canal. During July 2001, a discharge flow rate from vertical fissures in one of these drainages was measured with a 3-inch (7.6 centimeter) modified Parshall flume. The dendritic drainage was located about 1.5 miles (2.4 kilometers) northwest of the inlet-canal pump (pump was adjacent to monitoring well MW-01 in figure 2c) and flowed to the inlet canal through the west side of a single breach. The flume measurement site was just east of borehole location NB#19 where branches of this dendritic drainage converged toward the east into a single channel (see figures 2c and 3a). The flume was placed midway in the single channel, which extended about 90 feet (27 meters) between the inlet canal and the location where the branches of the dendritic drainage converged into the single channel. Measured water level in the Parshall flume was 0.1 foot (0.03 meter), which was equivalent to 0.03 cubic feet (850 cubic centimeters) per second or 13.5 gallons (51 liters) per minute of discharge from the point of the flume location (Rantz and others 1982, table 14). This measurement was a rough estimate of ground-water brine discharge from the flume location in the main channel as it drained towards the inlet canal.

Ground-water brine discharge was also measured from two locations of horizontal seepage zones flowing from permeable facies of shallow-brine aquifer sediments exposed in side walls of the Knolls Facility inlet canal. Locations were 0.5 and 1.5 miles (0.8 and 2.4 kilometers) northwest of the inlet-canal pump (near monitoring well MW-01 and borehole NB#19, respectively - see figure 2c). Measurable ground-water discharge was con-

Table 4. Open borehole characteristics and timed aquifer-test parameters from six tested boreholes. Five of the boreholes are positioned along the inlet canal's 6-mile (9.6-kilometer) length (southern periphery of Newfoundland Basin study). The sixth borehole (NB#7B) is located on the western periphery of the Newfoundland Basin study area. Borehole locations are shown on figures 2b and 2c.

USGS Site Identifier	BLM Borehole ID	Date	Surface Elevation, ft	TD ¹ , ft	BH ² Dia., in	1st H ₂ O BGL ³ , ft	STWL ⁴ BGL ³ , ft	Drawdown Depth BGL ³ , ft	Test Duration, h ⁵	Pump Rate, gpm	Observed H ₂ O-bearing thickness, ft	Saturated thickness, ft
NB-BH-0	NB#2	09/16/1998	4218.81	8.3	3	2.17	1.21	1.33	0.4	0.18	1.83	6.16
NB-BH-1	NB#3	10/7/1998	4217.82	9	3	2.67	1.5	1.96	0.05	1.4	0.83	6.33
NB-BH-5	NB#7B	9/2/1999	4214.13	6	3.625	1.58	0.88	1.5	0.07	1.22	2.5	4.42
NB-BH-12	NB#11B	10/12/1999	4216.25	5.5	4.625	1.75	0.25	0.75	0.03	1.07	0.67	3.75
NB-BH-8	NB#12	9/22/1999	4216.59	6.8	4.625	1.5	1	1.5	0.05	1.35	1	5.33
NB-BH-10	NB#13	10/12/1999	4215.27	7	4.625	0.83	0.33	0.44	0.01	1.99	1.33	6.17

¹TD = Total depth

²BH = Borehole

³BGL = Below ground level

⁴STWL = Static water level

⁵h = hours

Table 5. TGUESS-derived hydraulic conductivities (*K*) from six tested boreholes. Five of the boreholes are positioned along the inlet canal's 6-mile (9.6-kilometer) length (southern periphery of Newfoundland Basin study). The sixth borehole (NB#7B) is located on the western periphery of the Newfoundland Basin study area.

USGS Site Identifier	BLM Borehole ID	STWL ¹ Elevation, ft	Saturated Thickness, ft	K, ft/sec	K, ft/day
NB-BH-0	NB#2	4217.60	6.2	5.446E-04	47
NB-BH-1	NB#3	4216.32	6.3	1.025E-03	89
NB-BH-5	NB#7B	4213.25	4.4	8.942E-04	77
NB-BH-12	NB#11B	4216.00	3.8	1.004E-03	87
NB-BH-8	NB#12	4215.59	5.3	9.835E-04	85
NB-BH-10	NB#13	4214.94	6.2	6.202E-03	536

¹STWL = Static water level

centrated in deeply-incised rivulets of brine (spaced on 10 to 15-foot/3 to 4.6-meter centers) that flowed downward across these two seepage zones. Timed flow-rate measurements taken during October 1999 from a selected rivulet at each of the 0.5 and 1.5-mile (0.8 and 2.4 kilometer) locations were 1.5 and 0.7 gallons (5.7 and 2.6 liters) per minute, respectively. Brine specific gravities were 1.125 and 1.165. Source of the brine discharge was from a 1.5 to 3.0-inch (3.8 to 7.6-centimeter) thick facies of very fine (0.01 to 0.02 inches/0.25 to 0.5 millimeters) loosely-agglomerated gypsum crystals. While neither the Parshall flume nor the seep flow-rate measurements are sufficient to estimate total ground-water discharge to the inlet canal or from adjacent dendritic drainages, they do confirm presence of ground-water discharge and provide an estimate of discharge at specified point sources.

In addition to Parshall-flume measurements of ground-water brine discharge from vertical fissures in sediments of the shallow-brine aquifer, discharge gradients were also determined from data collected from the eight sets of nested monitoring wells installed by SSP. Vertical gradients based on measured water-level elevations and ground-water density differences were determined by mathematical analysis explained by Mason and Kipp (1998). Vertical gradients from five different measurement periods during 1999-2001 are listed in table 6.

In four of the five measurement periods, peripheral (MW-01 – MW-05) and intermediate (MW-09, MW-10) basin well gradients between the shallow, intermediate, and deep wells were positive, indicating an upward direction of ground-water discharge. However, during the March-April 2000 measurement period, corresponding gradients were negative or downward. The reason for this change in gradient direction from the other four measurement periods is unknown.

Data from the central-basin nested well (MW-12) were only available from two of the five measurement periods (December 1999, and September 2001). Negative gradients were observed between the shallow, intermediate, and deep wells during December 1999, and between the shallow and intermediate wells during September 2001. However, the gradient between the intermediate and deep well was positive in September 2001. A positive or upward gradient was expected for the central-basin nested well set because of its location, and the presence of several cavernous upwelling structures in salt crust observed near boreholes NB#8 and NB#9 (see figure 4). These upwelling

structures are believed to be the result of upward discharge of unsaturated brine from the shallow-brine aquifer into the existing salt crust.

In summary, documentation and quantification of ground-water discharge to the surface of the Newfoundland Basin playa was provided for point locations by Parshall flume and seep flow-rate measurements. Additionally, the majority of monitoring-well measurements in the peripheral and central portions of the basin indicated an upward ground-water gradient.

SUMMARY AND CONCLUSIONS

Summary

This study was undertaken as part of the USGS and BLM's responsibility to classify and characterize federal-mineral resources on federal lands. Information gained from the study could be used by BLM to further delineate the known potassium resource area within the Newfoundland Basin. During the period September 1998 to August 2001, BLM and USGS conducted field investigations of mineralogy, pore-fluid chemistry, and hydrologic properties of surficial sediments comprising the shallow-brine aquifer of the Newfoundland Basin. Based on the joint study, BLM and USGS identified changes in Newfoundland Basin shallow-brine aquifer chemistry that resulted from pumping GSL brine into the Newfoundland Evaporation Basin during the West Desert Pumping Project (April 1987 to June 1989).

Effects of the pumping on the Newfoundland Basin included altering the chemical character of the shallow-brine aquifer by mixing two chemically different brines, and depositing a halite crust where none was previously reported on the lacustrine sediments of the Newfoundland Basin playa. The halite crust resulted from evaporation of the brine pond generated by the pumping project.

The BLM-USGS joint study is based on chemical and mineralogical characterization of brine and selected core samples collected from the shallow-brine aquifer intercepted by 24 reconnaissance boreholes and eight sets of nested monitoring wells, which were installed during 1998-2001. Changes in shallow-brine aquifer chemistry were determined by examining variation of specific analyte concentrations with changes in

Table 6. Listing of Newfoundland Basin monitoring well water-level elevations, brine-sample specific gravities, and ground-water total gradients (Bryan Grigsby, Hydrogeologist, S.S. Papadopoulos, written communication, January 7, 2008).

Well ID	WL ¹ Elev., ft	Specific Gravity	Total Gradient ²	WL ¹ Elev., ft	Specific Gravity	Total Gradient ²	WL ¹ Elev., ft	Specific Gravity	Total Gradient ²	WL ¹ Elev., ft	Specific Gravity	Total Gradient ²	WL ¹ Elev., ft	Specific Gravity	Total Gradient ²
	12/1-4/1999			3/3-5/2000, 4/3/2000 (MW09, -10)			8/4-8/8/2000			11/30/2000			9/17-18/2001		
Inlet canal (approx.)	4211.3	1.215	4215.5, 4210.5				4214.5	1.22		4216.0	1.20		4215.6	1.215	
MW01A	4212.36	1.210		4215.89	1.18		4214.53	1.20		4214.53	1.19		4214.53	1.20	
MW01B	4212.97	1.100	0.098	4215.31	1.10	-0.112	4215.18	1.10	0.058	4215.18	1.10	0.059	4215.18	1.10	0.062
MW01C	4213.82	1.080	0.121	4216.18	1.08	0.125	4215.64	1.09	0.064	4215.64	1.08	0.054	4215.64	1.09	0.054
MW02A							4214.94	1.209 ³		4214.94	1.13		4214.94	1.12	
MW02C	4214.79	1.085		4217.00	1.09		4215.52	1.088 ³	-0.012	4215.52	1.08	0.021	4215.52	1.09	0.029
MW02D							4216.75	1.102 ³	0.051	4216.75	1.10	0.054	4216.75	1.11	0.058
MW03A	4214.82	1.145		4217.12	1.14		4215.31	1.13		4215.31	1.13		4215.31	1.13	
MW03B	4215.96	1.090	0.042	4216.97	1.08	-0.033	4216.60	1.09	0.053	4216.60	1.08	0.050	4216.60	1.08	0.053
MW03C	4216.34	1.095	0.088	4217.08	1.08	0.002	4216.74	1.09	0.026	4216.74	1.09	0.048	4216.74	1.09	0.048
MW03D							4217.12	1.10	0.024	4217.12	1.09	0.015	4217.12	1.09	0.020
MW04A	4214.81	1.140		4217.21	1.13		4215.28	1.14		4215.28	1.13		4215.28	1.13	
MW04B	4215.60	1.090	0.041	4217.10	1.09	-0.026	4216.27	1.09	0.054	4216.27	1.08	0.056	4216.27	1.09	0.056
MW04C	4215.95	1.090	0.079	4216.97	1.09	-0.029	4216.41	1.09	0.032	4216.41	1.08	0.031	4216.41	1.09	0.031
MW05A	4214.70	1.150		4217.07	1.15		4215.21	1.14		4215.21	1.14		4215.21	1.14	
MW05B	4214.36	1.115	-0.068	4217.11	1.12	-0.011	4215.46	1.11	0.021	4215.46	1.10	0.020	4215.46	1.11	0.024
MW05C	4215.53	1.095	0.086	4216.95	1.09	-0.044	4215.76	1.09	0.003	4215.76	1.08	0.007	4215.76	1.09	0.004
MW05D							4216.63	1.10	0.046	4216.63	1.10	0.047	4216.63	1.10	0.046
MW09A	4214.78	1.160		4214.96	1.16 ³		4215.01	1.16 ³							
MW09B	4215.25	1.115	0.002	4214.70	1.12 ³	-0.051	4215.69	1.12 ³	0.016						
MW10A	4214.95	1.175		4215.36	1.18 ³		4215.42	1.18 ³							
MW10B	4215.54	1.115	0.004	4214.65	1.12 ³	-0.111	4216.06	1.12 ³	0.006						
MW12A (salt)	4212.67	1.225											4213.02	1.24	
MW12B	4212.60	1.210	-0.022										4212.97	1.19	-0.038
MW12C	4213.05	1.130	-0.026										4214.51	1.12	0.080

¹WL = Water level

²Total gradients based on reference specific gravity of 1.10. Positive gradient = upward flow.

³Specific gravity estimated from earlier measurements.

borehole and monitoring-well stratigraphy, depth, and location. Additionally, shallow-brine aquifer chemistry and its relation to solid-phase mineral assemblages were characterized from analyses of core-sample pore water and mineralogy, and illustrated using concentration profiles and X-Y plots of selected analytes. For comparison with pore fluids, diagnostic analytes of brine samples from open boreholes and ground-water seeps were also illustrated with X-Y plots. To further describe solute-mineral interactions, brine-sample analyses were also examined by the computer programs SNORM and TEQUIL. We concluded the following based on our chemical and mineralogical characterization data, along with the SNORM and TEQUIL analyses:

Pore-fluid profiles: Effects of mixing the two chemically different brines (GSL and pre-pumping Newfoundland Basin brines) were typically restricted to within the first 5 feet (1.5 meters) of the shallow-brine aquifer sediments. Within this zone, pore-fluid concentration ranges for K, Mg, and SO_4 typically matched those of GSL North Arm brine. Below 5 feet (1.5 meters), pore-fluid concentrations decreased and reverted to the character common to evaporated remnants of Lake Bonneville waters.

Trends in pore-fluid compositions correlated with spatial changes in sample location (i.e., lower concentrations at peripheral-basin sites versus higher concentrations at central-basin sites). These trends also correlated with semi-quantitative determinations of major mineral abundances in shallow-brine aquifer sediments both laterally and with depth. Specifically, mineralogical examination of 100 samples from 15 sites identified mineral-species associations that fit the depositional environment deduced from pore-fluid chemistry. For example, presence of aragonite in shallow-brine aquifer sediments is indicative of evaporating open-lake waters, while gypsum occurrence is characteristic of much more saline playa or mudflat conditions. In the Newfoundland Basin, gypsum content in shallow-brine aquifer sediments increased towards the central-basin topographic low to where its content was 75% of the sample at depths greater than 3 feet (0.9 meters), which reflected dominance of overlying halite crust. Conversely, aragonite generally increased towards the basin periphery and with stratigraphic depth.

Pore-fluid X-Y plots: For comparison purposes, plots were grouped by their respective locations (i.e., peripheral versus central basin). Concentration ranges for Na versus Cl were similar between the peripheral and central-basin locations. However, the relationship between Na and Cl for the peripheral-basin sites was closer to a 1:1 molar ratio throughout the concentration range. By contrast, the Na versus Cl plot for central-basin samples exhibited more scatter, particularly at high concentrations, and was due mainly to precipitation of halite and consequent depletion of solute Na.

Generally, Mg versus Cl plots of peripheral-basin pore fluids showed a distinctive linear trend. An exception was excess of Mg over Cl due to dissolution of detrital sediment sources adjacent to three peripheral-basin boreholes. Conversely, plots of Mg versus Cl for central-basin pore fluids from two boreholes situated one mile apart exhibited the following scatter effects due to mineral precipitation and solute sorption on solid-phase mineral substrate. In the first borehole, Cl remained relatively constant, but Mg increased fivefold due to the limiting effects of halite saturation on Cl concentration. In the second borehole, Mg remained constant as Cl ranged from 12% to 17%

due to Mg sorption on clays.

Plots of K versus Cl for peripheral-basin pore fluids were similar to those of Mg versus Cl, both in ion-concentration range and distribution of values. However, central-basin pore-fluid plots exhibited scatter similar to but greater than Mg versus Cl. Some of the scatter may have resulted from sorption of K by clays.

Open borehole and ground-water seep X-Y plots: Most of the plots were consistent with those of pore-fluid distributions. The Na versus Cl plots exhibited a mole ratio very close to halite, particularly at the center of the compositional range. The greatest deviations were at the concentration extremes. The most dilute sample was from the northwest margin of the basin periphery and had excess Na, which was attributed to silicate weathering from adjacent alluvial materials. Seeps near the central-basin topographic low exhibited a marked deficiency in Na due to halite precipitation.

Correlation of the species pair K versus Mg over its entire compositional range was slightly better than that of Na versus Cl. This indicates that these major solutes are conservative in solutions undersaturated with respect to halite.

SNORM analysis: Although the SNORM analysis emphasized NaCl dominance in the brine samples, a minor but consistent amount of MgCl_2 was routinely present in the SNORM output. Presence of MgCl_2 indicated an ultimate marine origin for the bulk of the solutes. Another species of interest in the modeled output was CaCl_2 , which was present in small amounts. The largest percentage of CaCl_2 was generated from highly concentrated pore fluids extracted from clay-carbonate muds. Presence of CaCl_2 in the SNORM output suggested authigenic formation of dolomite and kerolitic smectite in lacustrine sediments of the shallow-brine aquifer.

Geochemical modeling: The chemical character of the Newfoundland Basin shallow-brine aquifer was substantially changed when mixed with GSL brine during the West Desert Pumping Project. The TEQUIL model results from Kohler and White (2004) showed that the mineral suite precipitating from GSL brine was very different from mineral suites predicted from the pre-pumping Newfoundland Basin shallow-brine aquifer. For example, the predicted mineral suite from the pre-pumping Newfoundland Basin brine was gypsum-anhydrite-halite-polyhalite-sylvite-kainite-carnallite-kieserite. However, the mineral suite from the present Newfoundland Basin brine after mixing with GSL brine was glauberite-halite-polyhalite-leonite-sylvite-kainite-carnallite-kieserite-bischofite. A TEQUIL 50-50 mixing simulation using pre-pumping Newfoundland Basin brine and GSL brine matched the present Newfoundland Basin brine.

TEQUIL-predicted mineral-sequence plots from simulated step-wise evaporation of pore-fluid brines from peripheral and central-basin core samples showed the following:

- Peripheral basin near-surface pore-fluid brines were a mixture of pre-pumping ground water and GSL brine; however, pore fluids from core depths approaching 5 feet (1.5 meters) BGL had predicted mineral sequence plots identical to the pre-pumping 1966 Reynolds brine.
- Central basin pore-fluid brines in the upper portions of lacustrine sediments in contact with

bedded salt crust precipitated from the West Pond were a similar mixture of pre-pumping ground water and GSL brine.

- Pore fluids from core depths approaching 6.5 feet (2 meters) BGL had predicted mineral sequence plots similar to the pre-pumping 1966 Reynolds brine, but also had some residual characteristics of the GSL North Arm brine.

Hydraulic conductivity studies: Ground-water brine transport in sediments of the shallow-brine aquifer occurred mainly in the permeable sedimentary facies, and possibly in vertical fissures observed in mudflat clay facies. Permeable facies were typically relatively clean oolitic sand, algal-mat material, and loosely aggregated fine-grained gypsum crystal sand. These permeable facies were usually interbedded with impermeable clay-bearing sediments and were commonly saturated with brine.

Permeable facies were recorded in the geologic logs of all 24 boreholes. As each borehole was drilled in mudflat sediments, ground-water brine was typically intercepted at depths ranging from about 1.5 to 3 feet (0.5 to 0.9 meters) BGL, and commonly rose up in the borehole to static water levels 6 to 20 inches (15 to 51 centimeters) above the interception depths. When each borehole was pumped, the water level would drop several inches below the static water level to a new equilibrium level. When the pump was turned off, the water level would rapidly recover to its original static water level. The pumped boreholes never failed to recover to their original static water levels at the termination of pumping.

Aquifer tests were performed in 6 of the 24 boreholes and pumping rate, duration of test, and time versus rising head data were collected. Data collected from these six aquifer tests were used as input to TGUESS to estimate K from the shallow-brine aquifer sediments intercepted by these boreholes. Hydraulic conductivities ranged from 47 to 88 feet (14 to 27 meters) per day for four of the five boreholes adjacent to the inlet canal. The largest K value was 536 feet (163 meters) per day from a borehole located at the north end of the inlet canal. Hydraulic conductivity for the west margin borehole was 77 feet (23 meters) per day.

With exception of the borehole at the north end of the inlet canal, K values for the other five boreholes were in reasonable agreement with those determined from aquifer tests conducted in 8 sets of nested shallow monitoring wells installed along the inlet canal and in the basin topographic low. Hydraulic conductivity values from aquifer tests conducted in the monitoring wells ranged from 0.4 to 77 feet (0.1 to 23 meters), and from 0.05 to 30 feet (0.02 to 9 meters) per day, respectively. The higher K values from both ranges were typically from the upper 10 feet (3 meters) of the lacustrine sediments comprising the shallow-brine aquifer.

The magnitude of K values determined from boreholes and monitoring wells demonstrated that ground-water transport occurred mainly in the porous-media facies comprising the shallow-brine aquifer sediments (i.e., oolitic sand, algal-mat material, and gypsum sand).

Quantification of ground-water discharge: Estimates of ground-water discharge to the surface of the Newfoundland Basin playa were provided for point locations by Parshall-flume and seep flow-rate measurements. The majority of monitoring-well measurements in the peripheral and central portions of the basin indicated upward gradients of ground-

water discharge.

A single Parshall-flume measurement taken in July 2001 from one of multiple dendritic drainages flowing into the inlet canal was 0.03 cubic feet (850 cubic centimeters) per second or 13.5 gallons (51 liters) per minute. Ground-water brine discharge was also measured from two horizontal seepage zones flowing from permeable facies of shallow-brine aquifer sediments exposed in side walls of the Knolls Facility inlet canal. Locations of the zones were 0.5 and 1.5 miles (0.8 and 2.4 kilometers) northwest of the inlet-canal pump. Timed flow-rate measurements taken during October 1999 from a selected rivulet at each of the 0.5 and 1.5-mile (0.8 and 2.4 kilometer) locations were 1.5 and 0.7 gallons (5.7 and 2.6 liters) per minute, respectively. Although neither the Parshall-flume nor the seep flow-rate measurements are sufficient to estimate total ground-water discharge to the inlet canal or from adjacent dendritic drainages, they confirm ground-water discharge and provide an estimate of discharge at specified point sources.

Vertical gradients based on measured water-level elevations and ground-water density differences were determined from data collected from eight sets of nested monitoring wells. In four of five measurement periods between 1991 and 2001, peripheral (MW-01 – MW-05) and intermediate (MW-09, MW-10) basin well gradients between the shallow, intermediate, and deep wells were positive, indicating an upward direction of ground-water discharge. The two measurement periods available for the central basin set of nested wells (MW-12) showed mixed results. Negative gradients were observed between shallow, intermediate, and deep wells during December 1999, and between shallow and intermediate wells during September 2001. However, the gradient between the intermediate and deep wells was positive in September 2001. In summary, the majority of ground-water gradient measurements were positive.

Conclusions

The following are the major conclusions of the study:

1. Effects of mixing the two chemically-different brines (GSL and pre-pumping Newfoundland Basin brines) were typically restricted to a zone made up of the first 5 feet (1.5 meters) of sediments comprising the shallow-brine aquifer. Within this zone, pore-fluid concentration ranges of K, Mg, and SO₄ typically matched those of GSL North Arm brine. Below this zone, pore-fluid concentrations decreased and reverted to the character assumed common to evaporated remnants of Lake Bonneville waters.
 - a. Lower concentrations at peripheral-basin sites versus higher concentrations at central-basin sites correlated with spatial changes in sample location.
 - b. Mineral-species associations fit the depositional environment deduced from pore-fluid chemistry.
2. Simple X-Y plots of major brine solutes indicated the evaporative effects of significant saline-mineral precipitation or dissolution including

carbonate and clay. Close correlation of K and Mg (greater than Na and Cl) argues for conservancy of these solutes. The greatest deviation of these relationships occurred at the brine concentration extremes, suggesting silicate dissolution at the basin periphery, and substantial halite precipitation at the basin center.

3. SNORM cation-anion-association analysis suggests an ultimate marine source for some solutes (deduced from $MgCl_2$ occurrence), and loss of Mg to authigenesis of dolomite and Mg-bearing smectite (deduced from occurrence of small amounts of $CaCl_2$).
4. Geochemical modeling indicated that the pre-pumping chemical character of the Newfoundland Basin shallow-brine aquifer was substantially changed when mixed with GSL brine during the West Desert Pumping Project.
 - a. TEQUIL-predicted mineral-sequence plots from simulated step-wise evaporation of pore-fluid brines extracted from peripheral-basin core samples showed that their near-surface pore-fluid brines were a mixture of pre-pumping ground water (represented by 1966 Reynolds brine) and GSL brine. However, peripheral-basin pore fluids from core depths approaching 5 feet (1.5 meters) BGL had the predicted mineral-sequence plots identical to the pre-pumping ground water (represented by 1966 Reynolds brine).
 - b. Predicted mineral-sequence plots of central-basin pore fluids from the upper portions of lacustrine sediments in contact with bedded halite precipitated from the West Pond were also a mixture of pre-pumping ground water (represented by 1966 Reynolds brine) and GSL brine. However, central-basin pore fluids from core depths of 6.5 feet (2 meters) BGL not only had predicted mineral-sequence plots similar to the pre-pumping ground water, but also had some residual characteristics of the GSL brine.
5. Ground-water brine transport in sediments of the shallow-brine aquifer occurred mainly in permeable sedimentary facies, and from vertical fissures observed in clay floors of dendritic drainages excised in clay mudflats adjacent to breaches in the inlet canal. Permeable facies were typically relatively clean oolitic sand, algal-mat material, and loosely aggregated fine-grained gypsum crystal sand. These permeable facies were usually saturated with brine and

interbedded with impermeable clay-bearing sediments.

6. Estimates of ground-water discharge to the surface of the Newfoundland Basin playa were provided for point locations by Parshall-flume and seep flow-rate measurements. The majority of monitoring-well measurements in the peripheral and central portions of the basin indicated positive or upward gradients of ground-water transport.

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APPENDICES

APPENDIX A1

Table A1.1. Borehole stratigraphy, western periphery of Newfoundland Basin. BGL = below ground level, and STWL = static water level.

USGS Site Identifier	BLM Sample Number	Date	Logged Interval, ft BGL	Stratigraphic Description
NB-BH-2	NB#5	7/13/1999	0 to 0.042	Salt crust (0.5 inches thick)
NB-BH-2		7/13/1999	0.042 to 2.0	Olive-green clay
NB-BH-2		7/13/1999	2.0 to 3.0	Tan clay, soggy
NB-BH-2		7/13/1999	3.0 to 3.5	Tan clay, soggy - clay is like flowing mud (first water at 3.5 feet BGL)
NB-BH-2		7/13/1999	3.5 to 5.0	Tan varved clay, soggy (note, interbedded zones of very-fine clastics with oolite after fecal pellets; clastics made up of rounded and bladed fragments)
NB-BH-2		7/13/1999	5.0 to 6.0	Black varved clay, runny (saturated with water) and fetid
NB-BH-3	NB-6A	8/13/1999	0 to 0.21	Salt crust (0 to 0.5 inches); very-fine clastics and oolites in tan clay matrix (0.5 to 2.5 inches/0.21 feet)
NB-BH-3	NB-6A	8/13/1999	0.21 to 0.42	Very-fine clastics and oolites in tan clay matrix
NB-BH-3	NB-6B	8/13/1999	0.42 to 0.83	Very-fine clastics and oolites in tan clay matrix
NB-BH-3	NB-6C&D	8/13/1999	0.83 to 1.5	Very-fine clastics and oolites in tan clay matrix (clay has blocky appearance)
NB-BH-3	NB-6E	8/13/1999	1.5 to 2.0	Very-fine clastics and oolites in tan clay matrix
NB-BH-3	NB-6F	8/13/1999	2.0 to 2.38	Very-fine clastics and oolites in tan clay matrix
NB-BH-3		8/13/1999	2.38 to 3.04	Very-fine clastics and oolites in tan clay matrix interbedded with zones dominated by oolites (first water at 2.38 feet BGL)
NB-BH-3	NB-6I	8/13/1999	3.04 to 3.52	Dominated by fine gypsum laths supported in white clay matrix
NB-BH-3	NB-6J	8/13/1999	3.52 to 4.0	Fine gypsum laths supported in white clay matrix (1.0 inches), and very-fine clastics and oolites in tan clay matrix (5 inches)
NB-BH-3		8/13/1999	4.0 to 5.0	White clay interbedded with zones of oolites and fine-grained gypsum laths
NB-BH-3	NB-6N	8/13/1999	5.0 to 5.58	Fine clastics with some gypsum laths and oolites in a dark gray to black clay
NB-BH-5	NB-7A&B	9/2/1999	0 to 0.83	Clay (1.5 inches) with sand and oolites (8.5 inches)
NB-BH-5	NB-7C&D	9/2/1999	0.83 to 1.66	Sand and oolites (first water at 1.58 feet BGL)
NB-BH-5	NB-7E&F	9/2/1999	1.66 to 2.5	Fine sand and oolites at top, bottom in white clay with gypsum laths and fine sand
NB-BH-5	NB-7G&H	9/2/1999	2.5 to 3.25	Fine sand transitioning to gray green clay with gypsum crystals at 2.9 feet; oolites in clay matrix at 3.25 feet BGL
NB-BH-5	NB-7I&J	9/2/1999	3.25 to 4.08	Oolites and fine clastics to 3.66 feet; carbonate-mat fragments, oolites, and fine clastics in clay matrix to 4.0 feet; brown clay with carbonate mat fragments from 4.0 to 4.08 feet
NB-BH-5	NB-7K&L	9/2/1999	4.08 to 4.92	Gray-green clay (no gypsum laths observed); clay is prismatic and moist

Yellow highlight indicates depth to first occurrence of ground water; blue highlight identifies first occurrence of possible anaerobic conditions.

Table A1.1. Borehole stratigraphy, western periphery of Newfoundland Basin (continued). BGL = below ground level, and STWL = static water level.

USGS Site Identifier	BLM Sample Number	Date	Logged Interval, ft BGL	Stratigraphic Description
NB-BH-13	NB#14 SE/SE/NE sec3, T3N, R16W	6/24/2000	0 to 0.75	Oolites and carbonate fragments in clay matrix
NB-BH-13		6/24/2000	0.75 to 0.833	Algal mat facies - fragments 0.25 inches thick (first water at 0.833 feet BGL)
NB-BH-13		6/24/2000	0.833 to 1.333	Oolites in tan clay matrix with root fragments and some FeOx staining
NB-BH-13		6/24/2000	1.333 to 1.916	Mainly oolites with some carbonate fragments - grades into varved blocky clay at 1.916 feet BGL
NB-BH-13		6/24/2000	1.916 to 2.5	Tan clay (damp) with hint of bedding planes
NB-BH-13		6/24/2000	2.5 to 3.166	Tan clay with ostracod fragments and occasional gypsum crystals
NB-BH-13		6/24/2000	3.166 to 3.833	Tan clay (damp) grading to dark-gray clay (some FeOx in tan clay)
NB-BH-13		6/24/2000	3.866 to 4.33	Dark gray clay with some residual fragments of bedded tan clay with FeOx on bedding planes
NB-BH-14		NB#15 SE/SE/ sec 32, T5N, R16W	9/13/2000	0 to 1.5
NB-BH-14	9/13/2000		1.5 to 2.33	Oolite facies
NB-BH-14	9/13/2000		2.33 to 2.5	Green-gray clay, wet
NB-BH-14	9/13/2000		2.5 to 3.33	Green oolite facies, wet
NB-BH-14	9/13/2000		3.33 to 3.416	Green clay, silty
NB-BH-14	9/13/2000		3.416 to 4.83	Green fetid oolite facies, saturated (first water at 3.5 feet BGL)
NB-BH-14	9/13/2000		4.83 to 6.0	Interbedded greenish black clay and green oolite facies
NB-BH-14	9/13/2000		6.0 to 7.0	Oolites in clay matrix
NB-BH-21	NB#22 SE/NW sec 14, T6N, R16W	8/8/2001	0 to 0.5	Tan fine oolitic sand (75%) with clastic sand (25%).
NB-BH-21		8/8/2001	0.5 to 1.0	Mainly tan fine clastic sand with few oolites
NB-BH-21		8/8/2001	1.0 to 1.5	Tan fine oolitic sand and clastic sand (50-50)
NB-BH-21		8/8/2001	1.5 to 2.0	Tan fine oolitic sand with clastic sand (75-25); sand grains and oolites damp
NB-BH-21		8/8/2001	2.0 to 2.79	Tan fine oolitic sand with trace of clastics; damp from 2 to 2.7 feet and wet from 2.71 to 2.78 feet
NB-BH-21		8/8/2001	2.79 to 3.0	Tan fine oolitic sand with trace of clastics; wet from 2.79 to 3.0 feet
NB-BH-21		8/8/2001	3.0 to 3.5	Fine oolitic sand; grades from tan to gray at 3.16 feet; wet from 3.0 to 3. feet, and saturated from 3.16 to 3.5 feet (water visible in bottom of hole)
NB-BH-21		8/8/2001	3.5 to 4.0	Fine gray oolitic sand (nearly 100% oolites); saturated from 3.5 to 4.0 feet

Yellow highlight indicates depth to first occurrence of ground water; blue highlight identifies first occurrence of possible anaerobic conditions.

Table A1.1. Borehole stratigraphy, western periphery of Newfoundland Basin (continued). BGL = below ground level, and STWL = static water level.

NB-BH-23	NB#24	5/2/2001	0.0 to 0.5	Brown sand in clay matrix
NB-BH-23	SE/NW sec	5/2/2001	0.5 to 1.83	Brown clay
NB-BH-23	19, T5N, R16W	5/2/2001	1.83 to 2.0	Brown clastic sand (quartz grains) - Note: brown clastic sand much finer than black clastic sand described below.
NB-BH-23		5/2/2001	2.0 to 2.5	Brown clastic sand - wet
NB-BH-23		5/2/2001	2.5 to 3.0	Brown clastic sand with clay - wet
NB-BH-23		5/2/2001	3.0 to 3.5	Brown to olive clay with sand - saturated
NB-BH-23		5/2/2001	3.5 to 4.0	Clastic sand (first water at 3.5 feet BGL)
NB-BH-23		5/2/2001	4.0 to 6.16	Black clastic sand - hard turning; contains mainly fine to coarse black, gray and some green sand grains up to 0.125-inch dia, with sparse pebbles ranging from 0.25 to 0.375 inch dia. Some scattered organic fragments but no clay.
NB-BH-23		5/2/2001	6.16 to 6.5	Gray oolitic sand in clay matrix

Yellow highlight indicates depth to first occurrence of ground water.

Table A1.2. Borehole stratigraphy, central basin topographic low of Newfoundland Basin. BGL = below ground level, and STWL = static water level.

USGS Site Identifier	BLM Sample Number	Date	Logged Interval, ft BGL	Stratigraphic Description
NB-BH-4	NB-8A-1	8/23/2001	0 to 0.25	Dense cemented halite with multiple "dust" layers in first 1 inch. Crystals grade from fine (0.125-inch) to coarse (0.25-inch) at 0.25 feet BGL (first water at 1.5 inches BGL)
NB-BH-4	NB-8A-2	8/23/2001		
NB-BH-4		8/24/2001		
NB-BH-4	NB-8B-1	8/24/2001	0.25 to 0.88	Coarse, porous cemented halite with crystals becoming larger (0.375 to 0.5 inch) with depth
NB-BH-4	NB-8B-3	8/24/2001	0.875 to 1.25	Coarse, porous poorly cemented halite with friable layering
NB-BH-4	NB-8B-2	8/28/2001	1.25 to 1.54	Coarse, porous poorly cemented halite
NB-BH-4	NB-8C-2	8/28/2001	1.54 to 2.5	Fine-grained gypsum in clay matrix
NB-BH-4	NB-8D-1	8/28/2001	2.5 to 3.16	Tightly-packed fine-grained gypsum crystals (0.0625 x 0.125 inches) in clay matrix
NB-BH-4	NB-8E	8/28/2001	3.16 to 3.66	Tightly-packed fine-grained gypsum crystals (0.0625 x 0.125 inches) in clay matrix with very-fine black organic detritus
NB-BH-4	NB#8	8/27/1999	0 to 1.666	Salt crust (20 inches thick) (first water at 2.25 inches BGL)
NB-BH-4		8/27/1999	1.666 to 2.0	Fine clastics and oolites
NB-BH-4		8/27/1999	2.0 to 2.666	Fine clastics (silty sand?) with some clay
NB-BH-4		8/27/1999	2.666 to 3.166	Fine clastics and abundant gypsum laths (0.125 X 0.25 inch)
NB-BH-4		8/27/1999	3.166 to 3.416	Coarse sand
NB-BH-4		8/27/1999	3.416 to 3.5	Gray-green clay
NB-BH-4		8/27/1999	3.5 to 3.916	Fine clastics mixed with gypsum laths (0.125 X 0.25 inch)
NB-BH-4		8/27/1999	3.916 to 4.083	Dominantly gypsum lath
NB-BH-4		8/27/1999	4.083 to 5.0	Gray-green clay with abundant gypsum laths (0.125 X 0.25 inch); clay difficult to cut with auger because of gypsum laths
NB-BH-4		8/27/1999	5.0 to 5.5	Gray-green clay with abundant doubly-terminated gypsum laths; laths increasing in size (0.25 X 0.5 inch); clay difficult to cut with auger because of gypsum laths
NB-BH-4		8/27/1999	5.5 to 6.0	Gray-green clay with abundant doubly-terminated gypsum laths; laths increasing in size (0.5 X 0.5 inch); clay difficult to cut with auger because of gypsum laths
NB-BH-6	NB#9	9/9/1999	0 to 2.083	Salt crust (25 inches thick) (first water at 1.0 inches BGL)
NB-BH-6		9/9/1999	2.083 to 2.25	Black rubbery clay
NB-BH-6		9/9/1999	2.25 to 3.25	Clastics in clay matrix
NB-BH-6		9/9/1999	3.25 to 3.5	Gypsum laths (0.1875 X 0.25 inch) and clastics in clay matrix (gyp + clastics > clay)

Yellow highlight indicates depth to first occurrence of ground water; blue highlight identifies first occurrence of possible anaerobic conditions.

Table A1.2. Borehole stratigraphy, central basin topographic low of Newfoundland Basin (continued). BGL = below ground level, and STWL = static water level.

USGS Site Identifier	BLM Sample Number	Date	Logged Interval, ft BGL	Stratigraphic Description
NB-BH-6		9/9/1999	3.5 to 3.833	Gypsum laths (0.1875 X 0.25 inch) and clastics in clay matrix
NB-BH-6		9/9/1999	3.833 to 4.166	Gypsum laths (0.1875 X 0.25 inch) in clay matrix (no clastics)
NB-BH-6		9/9/1999	4.166 to 4.5	Gradation from 0.1875 X 0.25-inch gypsum laths to fine gypsum laths mixed with organic detritus and clay
NB-BH-6		9/9/1999	4.5 to 5.166	Fine gypsum with some clay for matrix
NB-BH-6		9/9/1999	5.166 to 5.666	Gray-green clay with large gypsum laths (0.375 X 0.5 inch); some organic horizons present in clay
NB-BH-6		9/9/1999	5.666 to 5.75	Fine gypsum
NB-BH-6		9/9/1999	5.75 to 6.0	Gray-green clay with large gypsum laths (0.375 X 0.5 inch)
NB-BH-7	NB-10A	9/16/1999	0.0 to 2.17	Salt crust (26 inches thick) (first water at 1.0 inches BGL)
NB-BH-7	NB-10B	9/16/1999	2.17 to 3.0	Fine clastics, oolites, small gypsum laths in clay matrix
NB-BH-7	NB-10C&D	9/16/1999	3.0 to 3.75	Fine-grained gypsum "sand"
NB-BH-7	NB-10E&F	9/16/1999	3.75 to 4.5	Fine-grained gypsum "sand" - grades into black fetid clay containing fine-grained gypsum "sand" at 4.5 feet
NB-BH-7	NB-10G&H	9/16/1999	4.5 to 5.33	Fine-grained gypsum "sand" in clay matrix - dark color due to fine-grained organic fragments
NB-BH-7	NB-10I	9/16/1999	5.33 to 6.5	Gray-green clay with larger gypsum laths distributed in clay matrix; lath size ranged from 0.1875 to 0.375 in.

Yellow highlight indicates depth to first occurrence of ground water; blue highlight identifies first occurrence of possible anaerobic conditions.

Table A1.3. Borehole stratigraphy, adjacent to inlet canal, southern periphery of Newfoundland Basin. BGL = below ground level, and STWL = static water level.

USGS Site Identifier	BLM Sample Number	Date	Logged Interval, ft BGL	Stratigraphic Description
	NB#2	9/11/1998	0 to 0.20 0.20 to 0.54 0.54 to 1.5 1.5 to 2.17 2.17 to 3.5 3.5 to 6.5 6.5 to 9.5	Black-gray plastic clay (saturated) Tan clay (dry) Silty clay Sandy clay Clay and fragments of algal mat facies (first water at 2.17 feet, which rose up in hole to 1.33 feet BGL) Green-gray plastic clay without algal mat fragments Varved plastic clay, gray-green alternating with black laminae
NB-BH-1	NB#3	9/18/1998	0 to 0.25 0.25 to 1.83 1.83 to 1.92 1.92 to 2.66 2.66 to 3.5 3.5 to 5.0 5.0 to 5.5 5.5 to 6.0 6.0 to 6.5 6.5 to 7.08 7.08 to 9.0	Tan loose sand and clay Tan silty clay, moist Algal-mat carbonate in clay matrix Tan plastic clay, wet but not saturated (first water at 2.66 feet BGL - rose up in hole to 2.04 feet BGL) Tan plastic clay, wet Varved plastic clay, wet Gray-tan plastic clay (note, STWL now at 1.875 feet BGL) Gray-tan varved plastic clay Mix of dark plastic clay (with fetid odor) and varved clay Dark plastic clay with fetid (hydrogen sulfide) odor Dark plastic clay
NB-BH-8	NB#12	9/22/1999	0 to 1.25 1.25 to 1.5 1.5 to 2.0 2.0 to 2.5 2.5 to 4.0 4.0 to 5.0 5.0 to 6.0 6.0 to 6.83	Tan prismatic clay Tan clay with some algal-mat fragments; hit grit at 1.25 and 1.5 feet; can hear water draining into hole at 1.5 feet Tan clay; water coming up in hole-can actually see it upwelling; STWL = 1.5 feet BGL @1815 Algal mat fragments (0.25 X 1 to 2 inches) in tan clay; grinding in hole from 2.0 to 2.5 feet BGL; when auger removed from hole, water upwelled rapidly (STWL = 1.0 feet @1820) Algal mat from 2.5 to 2.583 feet; varved tan clay from 2.583 to 4.0 feet Tan & black mottled clay (black clay mottles are varved) Gray-green fetid clay Classic varved clay (alternating tan and black varves); fetid

Yellow highlight indicates depth to first occurrence of ground water; blue highlight identifies first occurrence of possible anaerobic conditions.

Table A1.3. Borehole stratigraphy, adjacent to inlet canal, southern periphery of Newfoundland Basin (continued). BGL = below ground level, and STWL = static water level.

USGS Site Identifier	BLM Sample Number	Date	Logged Interval, ft BGL	Stratigraphic Description
NB-BH-10	NB#13	10/5/1999	0 to 1.0	Salt crust (0.5 inches thick); Tan clay from 0.5 to 12 inches with algal-mat facies fragments at 12 inches BGL (first water pours into hole from zone at 10 inches BGL)
			1.0 to 1.5	Tan, varved clay with algal-mat facies - out of algal-mat facies by 18 inches BGL
			1.5 to 2.0	Tan, varved clay
			2.0 to 2.5	Tan, varved clay
			2.5 to 3.0	Tan, varved clay until 35 inches BGL, then grinding in hole from 35 to 36 inches BGL resulting from tan varved clay with minor algal-mat fragments in clay matrix
			3.0 to 3.5	Tan, varved clay transitioning to gray-green varved clay
			3.5 to 4.0	Gray-green varved clay 42 to 45 inches; thin, platy and cemented carbonate mud 45 to 48 inches (grinding in hole at 45 inches, and difficult to auger from 45 to 48 inches BGL)
			4.0 to 4.5	Platy and cemented carbonate mud to 53 inches; gray-green clay from 53 to 54 inches BGL
			4.5 to 5.0	Gray-green varved clay
			5.0 to 5.5	Alternating gray-green and brown varved clay that separates along bedding planes like pages in a book (still moist, but less so than above); clay darker brown and fetid from 65 to 66 inches BGL
			5.5 to 6.0	Dark-green varved clay that transitions to massive dark-olive-green clay
6.0 to 6.5	Dark-olive-green clay transitions to slightly lighter-olive-green clay with dark organic layers (0.0625 to 0.125 inches thick) that are about 0.5 inches apart			
6.5 to 7.0	Olive-green varved clay with dark organic inclusions from 78 to 81 inches; dark-gray massive clay from 81-84 inches BGL			
NB-BH-11	NB-11A&B	9/22/1999	0.0 to 1.25	Salt crust (1.5 inches thick); organic clay 1.5 to 3.5 inches BGL; clay 3.5 to 15 inches BGL; Note: hole initially dry, however, after removing 12 inch length of core barrel, water came into hole and established STWL of 4.0 inches BGL
NB-BH-11	NB-11C&D	9/22/1999	1.25 to 2.08	Mix of clay matrix with some oolites and algal-mat facies fragments; Note: when core barrel pulled from hole, observed water flowing into hole from between overlying salt crust and underlying organic clay
NB-BH-11	NB-11E&F	9/22/1999	2.08 to 3.08	Clay matrix and oolites from 25 to 28 inches; at 28 inches BGL intercepted algal-mat facies 1.0 inch thick; clay matrix and oolites from 29 to 35 inches; varved clay from 35 to 37 inches BGL; Note: stopped hole because of sample contamination from surface water flowing from between salt crust and underlying organic clay

Yellow highlight indicates depth to first occurrence of ground water; blue highlight identifies first occurrence of possible anaerobic conditions.

Table A1.3. Borehole stratigraphy, adjacent to inlet canal, southern periphery of Newfoundland Basin (continued). BGL = below ground level, and STWL = static water level.

USGS Site Identifier	BLM Sample Number	Date	Logged Interval, ft BGL	Stratigraphic Description
NB-BH-12	NB#11B	10/12/1999	0.0 to 1.75	Salt crust (1.0 inch thick); Tan, massive clay from 0.08 to 1.75 feet (first water at 21 inches BGL)
NB-BH-12		10/12/1999	1.75 to 1.92	Tan clay with large fragments of algal-mat facies
NB-BH-12		10/12/1999	1.92 to 2.33	Tan, massive clay
NB-BH-12		10/12/1999	2.33 to 2.42	Tan clay with large fragments of algal-mat facies; Note: when mud auger is pulled from hole and displaces water column, water comes into hole from bottom and establishes STWL at 3.25 inches BGL
NB-BH-12		10/12/1999	2.42 to 3.17	Tan, varved clay
NB-BH-12		10/12/1999	3.17 to 3.75	Tan and gray varved clay; Note: when mud auger is pulled from hole and displaces water column, water comes up in hole rapidly and degasses (CO2 bubbles?)
NB-BH-12		10/12/1999	3.75 to 4.5	Tan-gray varved clay
NB-BH-12		10/12/1999	4.5 to 4.75	Tan-gray varved clay
NB-BH-12		10/12/1999	4.75 to 5.0	Black, massive fetid clay
NB-BH-12		10/12/1999	5.0 to 5.5	Black and tan-gray varved clay
NB-BH-15	NB-16A	12/21/2000	0 to 1.0	Top of core sample in wet clay; bottom of core sample in oolites with clay matrix (first water at 12 inches BGL)
NB-BH-15	NB-16B	12/21/2000	1.0 to 2.0	Bottom of core in oolites with clay matrix
NB-BH-15	NB-16C	12/21/2000	2.0 to 3.0	Bottom of core in alternating layers of oolites in clay matrix and layers of clay
NB-BH-15	NB-16D	12/21/2000	3.0 to 4.0	Top 9 inches of core in oolites with clay matrix; lower 3 inches of core in dirty, fine-grained sand with ostracods - has olive-gray clay matrix
NB-BH-16	NB#17	12/8/2000	0.0 to 0.67	Moist light-gray silty clay, blocky; Note: beneath 0.5-inch thickness of surface clay is paper-thin black organic layer with doubly-terminated gypsum crystals; light-gray silty clay continues under organic layer
NB-BH-16		12/8/2000	0.67 to 1.67	Light-gray silty clay; presence of olive-green algae on near-vertical fracture surfaces; algal-mat facies from 10 to 12 inches BGL; approximately 2-inch thickness of oolites within 16 to 20 inches BGL
NB-BH-16		12/8/2000	1.67 to 1.83	Light-gray clay with some oolites, very wet; also includes some algal-mat facies
NB-BH-16		12/8/2000	1.83 to 2.0	Light-gray sandy oolites, very very wet (first water seeping very slowly into hole)
NB-BH-16		12/8/2000	2.0 to 2.17	Very-light-gray silty clay with oolites, not as blocky
NB-BH-16		12/8/2000	2.17 to 2.33	Sandy oolites, very wet
NB-BH-16		12/8/2000	2.33 to 3.0	Olive-green to gray clay; from 28 to 33 inches BGL, interbedded clay and oolite faces with each facies ranging from 0.125 to 0.5 inches thickness

Yellow highlight indicates depth to first occurrence of ground water; blue highlight identifies first occurrence of possible anaerobic conditions.

Table A1.3. Borehole stratigraphy, adjacent to inlet canal, southern periphery of Newfoundland Basin (continued). BGL = below ground level, and STWL = static water level.

NB-BH-17	NB-18A	12/20/2000	0 to 1.0	Light-gray silty clay
NB-BH-17	NB-18B	12/20/2000	1.0 to 2.0	Light-gray silty clay with sandy oolites from 1.67 to 2.0 feet (first water at 2.0 feet BGL)
NB-BH-17	NB-18C	12/20/2000	2.0 to 3.0	Alternating light-gray sandy clay and oolites from 2.0 to 2.33 feet; olive-green to gray clay from 2.33 to 3.0 feet
NB-BH-18	NB#19	7/6/2001	0 to 0.5	Oolites & sand in tan clay matrix (wet)
NB-BH-18	NE/NE sec 1, T1S, R14W	7/6/2001	0.5 to 1.5	Tan blocky clay (damp) (first water at 1.5 feet BGL)
NB-BH-18		7/6/2001	1.5 to 1.5833	Algal mat fragments and oolites in clay matrix; water rising in hole to 1.208 feet BGL
NB-BH-18		7/6/2001	1.5833 to 3.66	Tan blocky clay (damp)
NB-BH-18		7/6/2001	3.66 to 4.0	Gray and tan varved clay

Yellow highlight indicates depth to first occurrence of ground water; blue highlight identifies first occurrence of possible anaerobic conditions.

Table A1.4. Borehole stratigraphy, Salt Transect from north end of inlet canal (southern periphery) across UTTR to MW-12 (central basin topographic low). BGL = below ground level, and STWL = static water level.

USGS Site Identifier	BLM Sample Number	Date	Logged Interval, ft BGL	Stratigraphic Description
	NB-ST-01A-1	4/7/2000	0.0 to 0.75	Salt crust 0.0 to 0.5 feet; mix of salt and dark-gray organic clay 0.5 to 0.75 feet (first water not reported - at 0.5 inches BGL on 26 April 2000)
	NB-ST-01B-1	4/7/2000	1.0 to 1.58	Mix of salt and dark-gray organic clay 1.0 to 1.166 feet; tan clay 1.166 to 1.58 feet
	NB-ST-01A-2	4/7/2000	0.0 to 0.666	Salt crust 0.0 to 0.5 feet; mix of salt and dark-gray organic clay 0.5 to 0.666 feet
	NB-ST-01B-2	4/7/2000	1.0 to 1.75	Mix of salt and dark-gray organic clay 1.0 to 1.25 feet; tan clay 1.25 to 1.75 feet
	NB-ST-02A-1	4/7/2000	0.0 to 0.625	Salt crust 0.0 to 0.33 feet; clay-salt mix 0.33 to 0.5 feet; salt 0.5 to 0.625 feet (first water not reported - at 0.5 inches BGL on 26 April 2000)
	NB-ST-02B-1	4/7/2000	1.0 to 1.54	Salt-crust slough 1.0 to 1.25 feet; tan clay 1.25 to 1.54 feet
	NB-ST-02A-2	4/7/2000	0.0 to 0.625	Salt-crust 0.0 to 0.33 feet; clay-salt mix 0.33 to 0.5 feet; salt 0.5 to 0.625 feet
	NB-ST-02B-2	4/7/2000	1.0 to 1.416	Salt-crust slough 1.0 to 1.04 feet; salt-crust slough & tan clay 1.04 to 1.416 feet; algal mat in bottom of core tip
	NB-ST-02C-2	4/7/2000	2.0 to 2.666	Slough (mix of salt, some oolites, carbonate fragments, and traces of gypsum) 2.0 to 2.333; tan clay 2.333 to 2.666
	NB-ST-03A-1	4/13/2000	0.0 to 0.416	Salt crust; lost underlying sediments; attempted to recover lost core with new sample liner but unsuccessful (STWL at 0.0 inches BGL)
	NB-ST-03B-1	4/13/2000	0.416 to 1.416	Tan clay
	NB-ST-03B-2	4/13/2000	0.416 to 1.333	Wet tan clay with few scattered gypsum crystals (up to 0.5 X 0.5 inches)
	NB-ST-03C-2	4/13/2000	1.333 to 2.0	Wet tan plastic clay with few scattered gypsum crystals (less than 0.5 X 0.5 inches)
	NB-ST-05A-1	4/8/2000	0 to 1.75	Salt crust 0.0 to 1.666 feet; gray-green clay and salt 1.66 to 1.75 feet (note – winter pond depth at 0.5 to 0.75 inches)
	NB-ST-05B-1	4/8/2000	1.75 to 2.83	Tan clay
	NB-ST-05A-2	4/8/2000	0 to 1.33	Salt crust
	NB-ST-05B-2	4/8/2000	1.33 to 2.33	Salt crust with tan clay & some gypsum
	NB-ST-05C-2	4/8/2000	2.4 to 3.5	Tan clay matrix with fine gypsum crystals; note, bottom of core in 0.125 to 0.25-inch gypsum crystals loosely aggregated with dark organic clay
	NB-ST-05D-2	4/8/2000	3.5 to 4.25	Sugary gypsum "sand" with slight clay matrix

UTTR = Utah Test and Training Range, Hill Air Force Base, UT; Yellow highlight indicates depth to first occurrence of ground water; blue highlight identifies first occurrence of possible anaerobic conditions.

APPENDIX A2

Laboratory Analysis Methods

Quality Assurance

To ensure the analytical quality of the data generated during this project, it was imperative that all analysis strictly followed a Quality Assurance Program (QAP). This QAP consists of several important components: (i) Use of approved methods including instrument maintenance. (ii) Routine analysis of analytical blanks, (iii) Routine analysis of replicate samples, (iv) calculation of the cation-anion balance, and (v) Routine analysis of standard reference materials (SRM).

Instrument Parameters

Quality assurance and quality control of the laboratory analysis were continuously carried out through a series of approved methods. Each instrument used for sample analysis was maintained and operated per manufacturer's instructions. The quality assurance directly related to instrument analysis included the following: daily calibration, verification of the calibration and running blanks and SRM periodically during the analysis run. For each analyte at least a four point standard concentration (including blank) curve with an r^2 value of 0.999 or better was constructed. Prior to, and at the end of, each analytical session the standard calibration was verified by running additional standard solutions and SRM. During the analysis known standard solutions and SRM were run periodically to verify the accuracy of the analysis and to monitor instrument drift.

Blanks

To determine the type and amount of potential contamination, blanks were analyzed routinely during each stage of analysis. The blanks for cation analysis were DI water acidified to 0.5% v/v with Fisher Optima[®] double-distilled HNO₃; blanks for anion analysis were DI water. Analytical blanks were used to evaluate the potential contamination associated with the laboratory processing and the instrument analysis of the samples.

Replicate Analysis

Triplicates were created in the laboratory as separately diluted sub-samples that were treated as individual samples. Therefore, the percent standard deviation includes possible error

in dilution as well as laboratory contamination and instrument analysis. Table A2.1 summarizes the analytical error as average and range of the percent standard deviation.

Table A2.1. The summary of the average, and range of the standard deviation of laboratory triplicate samples for major cation and anion analysis.

	Average % RSD	Range % RSD
Na	2%	<1 -6%
K	5%	<1 -8%
Mg	3%	<1 -6%
Cl⁻	2%	<1 -6%
SO₄⁻²	1%	<1- 2%
Br⁻	7%	5- 9%

Cation-Anion Balance

The calculation of a simple cation-anion balance was conducted as an independent check for the accuracy of the analysis. More than 96% of all samples balanced within 100% +/- 10%, with the outliers being within +/- 15%. After re-dilution and analysis the outliers also had a calculated ion balance within the acceptable analytical error of +/- 10%.

Standard Reference Materials

The third component of our QAP was the routine analysis of SRM. Care was taken to choose SRM that were similar in both concentration and analytical matrix to the expected range of the samples. The following reference materials were used: **SLRS-3**; National Research Council of Canada, Ottawa, Ontario, Canada; **CRM-ES**, **CRM-soil**, **ICP-WS-6** and **CWW-TM-d**; High Purity Standards, Charleston, SC, USA; **PW-34-c**, **PW-34-d** and **WW-11-d**; Environmental Resource Associates, Arvada, Colorado, USA; **QC-SPEX-AL**; SPEX Industries, Edison, N.J. The results of the SRM analysis are listed in Table A2.3 and A2.4.

Table A2.3. List of SRM (Standard Reference Materials) used during Inductively Coupled Plasma- Optical Emissions Spectroscopy (ICP-OES) accuracy checks the literature value and the mean and standard deviation results of the SRM analysis. Data are listed in milligrams per Liter (mg/L).

<u>CRM-ES</u>	Mg	Ca	Na	K	
	mg/L	mg/L	mg/L	mg/L	
mean	86	70	168	135	
std dev	2.1	1.7	6.9	4.6	
Lit Value	100	80	200	150	
<u>CRM soil</u>	Mg	Ca	Na	K	Ba
	mg/L	mg/L	mg/L	mg/L	mg/L
mean	60.5	314	59	177	4.52
std dev	1.9	6.4	0.65	1.15	0.08
Lit Value	70	350	70	200	5.0
<u>CWW-TM-d</u>	B	Ba	Sr		
	mg/L	mg/L	mg/L		
mean	1.85	1.78	1.83		
std dev	0.04	0.02	0.03		
Lit Value	2.0	2.0	2.0		
<u>SLRS-3</u>	Mg	Ca	Na	K	
	mg/L	mg/L	mg/L	mg/L	
mean	1.63	6.08	3.15	0.85	
std dev	0.07	0.10	0.14	0.15	
Lit Value	1.6	6.0	2.3	0.7	
<u>ICP-WS-6</u>	Na	K			
	mg/L	mg/L			
mean	10	49			
std dev	0.16	1.7			
Lit Value	10	50			

Table A2.4. List of SRM (Standard Reference Materials) used during Ion Chromatograph (IC) accuracy checks the literature value and the mean and standard deviation results of the SRM analysis. Data are listed in milligrams per Liter (mg/L).

<u>PW-34-c</u>	Cl	Br	NO3	SO4
	mg/L	mg/L	mg/L	mg/L
mean	14.7	1.45	20.4	57.4
std dev	0.48	0.04	1.1	1.4
Lit Value	14.5	1.48	20.3	56.6

<u>PW-34-d</u>	Cl	Br	NO3	SO4
	mg/L	mg/L	mg/L	mg/L
mean	32.3	3.16	27.6	28.8
std dev	0.73	0.04	1.2	1.15
Lit Value	32.1	3.14	27.0	29.9

<u>QC-SPEX-AL</u>	Cl	Br	NO3	SO4
	mg/L	mg/L	mg/L	mg/L
mean	19.6	2.45	45.1	19.7
std dev	0.57	0.04	0.85	0.79
Lit Value	20.0	2.5	44.3	20.0

<u>WW-11-d</u>	Cl	SO4
	mg/L	mg/L
mean	90.7	61.7
std dev	1.2	1.3
Lit Value	85	60.9

Sample Analysis

Density

The brines and pore fluid samples were analyzed for salinity upon receipt of the sample. The density was analyzed using a Mettler/Parr DMA40, Digital Density Meter. Readings for air and laboratory deionized water (DI) were used to calibrate the instrument. After every five samples DI water was read to check for instrument drift, which was calculated as a “percent error.” The percent error in the density analysis ranged from 0 – 0.056% with a mean value of 0.016% and a standard deviation of 0.018%.

The density was converted to specific gravity using the following conversion factor:

$$\text{Density} / 0.99823 = \text{Specific Gravity.}$$

Cations

Due to the extremely high concentrations of Cl in the brines and pore fluids it was necessary to dilute the samples prior to analytical determination. The samples were volumetrically diluted (1:2,000) with DI water. A 50-milliliter (mL) aliquot was prepared for each cation and anion analysis. A pH less than 2 will increase the stability of the cations in solution, therefore, the sub-sample for major and minor cation analysis was acidified to 0.5% volume/volume (v/v) with Fisher Optima[®] double-distilled HNO₃ (0.25 mL of acid per 50 mL).

The major (Na, K, Ca and Mg) and minor (B, Ba, Sr and P) cation concentrations for the brine and pore fluid samples were determined on the diluted samples using a Perkin Elmer P-2 ICP-OES (Inductively Charged Plasma –Optical Emissions Spectroscopy). The results of the cation analysis are listed in table A2.5 – A2.15.

Anions

The sub-sample for analysis of the major and minor anions was preserved by refrigeration. Concentrations of the anions; chloride, sulfate, bromide and nitrate (Cl⁻, SO₄²⁻, Br⁻, NO₃⁻) were also determined on the diluted samples using a Dionex DX-120 ion chromatograph (IC). Samples for which the concentration of the constituents was below the analytical detection limit are shown as “less than” (<) the detection limit, samples for which the constituent was not

analyzed due to an insufficient volume for analysis are designated as "ISA" in the tables. The results of the anion analysis of the samples are listed in tables A2.5 – A2.15.

Table A2.5. The concentrations of the major cations and anions of the pore fluids recovered from the first set of BLM core samples.

Results are listed in percent (%) based on volume of the analyte in solution.

Core name	Core position	Depth inches	density g/mL	Cl %	SO ₄ %	Na %	Mg %	K %
NB6	Atop	0-2.5	1.2033	17.4	1.0	9.5	0.50	0.37
NB6	Abot	2.5-5	1.1978	16.9	0.9	9.6	0.45	0.38
NB6	B	5-10	1.1909	14.3	0.8	7.7	0.38	0.30
NB6	C	10-14	1.2042	16.3	1.0	8.8	0.52	0.48
NB6	D	14-18	1.2011	16.0	1.1	8.7	0.58	0.51
NB6	E	18-23.25	1.2042	15.4	1.1	8.5	0.61	0.55
NB6	F	23.25-28.5	1.2022	16.0	1.2	8.2	0.69	0.57
NB6	G	28.5-32.5	1.2029	16.0	1.2	8.4	0.70	0.55
NB6	H	32.5-36.5	1.1953	13.4	1.0	7.7	0.45	0.45
NB6	ltop	36.5-42.25	1.1993	15.5	1.3	8.2	0.61	0.55
NB6	J	42.25-48	1.1961	15.5	1.3	8.3	0.63	0.57
NB6	K	48-54	1.1984	15.2	1.3	8.6	0.65	0.52
NB6	Ltop	54-60	1.1910	14.9	1.3	7.8	0.65	0.55
NB6	Ntop	60-63.5	1.1754	13.4	1.2	7.3	0.60	0.51
NB6	Nbot	63.5-76	1.1722	14.4	1.2	7.5	0.61	0.46
NB7	Atop	0-2.5	1.2016	16.3	1.1	9.1	0.65	0.47
NB7	Abot	2.5-5	1.2038	16.4	1.0	8.8	0.60	0.55
NB7	B	5-10	1.2028	16.5	0.8	8.7	0.55	0.57
NB7	D	15-20	1.1793	14.6	0.7	7.8	0.47	0.51
NB7	E	20-25	1.1768	13.8	0.6	7.4	0.44	0.48
NB7	F	25-30	1.1800	14.0	0.6	7.4	0.45	0.49
NB7	G	30-34.5	1.1674	12.9	0.6	7.0	0.37	0.39
NB7	H	34.5-39	1.1917	15.8	0.6	8.6	0.49	0.55
NB7	ltop	39-44	1.2096	17.4	0.6	8.9	0.55	0.61
NB7	J	44-49	1.1834	15.1	0.6	8.0	0.44	0.52
NB7	K	49-54	1.1677	13.5	0.6	7.6	0.42	0.52
NB7	Ltop	54-56.5	1.1586	13.0	0.6	7.0	0.39	0.53
NB7	Lbot	65.5-72	1.1545	11.9	0.5	6.4	0.31	0.39

Core positions that indicate "top" or "bot" identify positions in the recovered core where pore fluid was obtained. Where depth intervals for "top" and "bot" are the same, "top" pore-fluid sample is from the upper portion of the interval, and "bot" pore-fluid sample is from the lower portion of the interval.

Table A2.6. The concentrations of the major cations and anions of the pore fluids recovered from the first set of BLM core samples, continued.
Results are listed in percent (%) based on volume of the analyte in solution.

Core name	Core position	Depth interval inches	Density g/mL	Cl %	SO ₄ %	Na %	Mg %	K %
NB10	Btop	30-36	1.2300	14.1	4.3	5.4	2.28	1.22
NB10	Bbot	30-36	1.2551	15.5	4.6	6.1	2.63	1.51
NB10	Ctop	36-45	1.2488	15.8	4.4	6.2	2.56	1.52
NB10	Dbot	36-45	1.2426	15.9	4.2	6.4	2.41	1.45
NB10	Etop	45-54	1.2300	16.3	3.3	6.8	2.03	1.38
NB10	Fbot	45-54	1.2300	14.6	2.3	6.4	1.54	0.98
NB10	G&H	54-64	1.2202	14.3	2.0	6.2	1.39	0.90
NB10	ltop	72-78	1.2162	16.9	1.5	8.3	1.07	0.90
NB10	lbot	72-78	1.1918	15.2	1.2	7.7	0.80	0.67
NB11	A	0-7.5	1.2103	9.7	0.8	5.5	0.36	0.33
NB11	B	7.5-15	1.2106	16.9	1.4	9.1	0.66	0.58
NB13	A	0-6	1.1933	14.2	1.1	7.5	0.54	0.50
NB13	B	6-12	1.2092	16.5	1.9	8.4	1.07	0.90
MW01B	1	67-76	1.1940	15.3	1.7	7.9	1.01	0.59
MW01B	2	117-123	1.0998	7.9	0.6	4.2	0.18	0.27
SB04	1	59-63	1.1312	9.8	1.0	5.1	0.31	0.27
SB04	2	108-112	1.1386	10.6	1.3	5.8	0.55	0.47
SB04	3	156-160	1.0984	7.8	0.6	4.6	0.25	0.27
SB04	4	204-208	1.0865	6.6	0.5	3.9	0.15	0.18
SB04	5	252-256	1.0891	7.2	0.6	4.2	0.21	0.25
SB04	6	300-304	1.0921	7.3	0.5	4.3	0.21	0.26
SB04	7	348-352	1.0917	6.9	0.5	4.0	0.15	0.18
SC-7	NB13	salt crust	1.2590	15.3	4.8	5.4	2.38	1.39

Core positions that indicate "top" or "bot" identify positions in the recovered core where pore fluid was obtained. Where depth intervals for "top" and "bot" are the same, "top" pore-fluid sample is from the upper portion of the interval, and "bot" pore-fluid sample is from the lower portion of the interval.

Table A2.7. The concentrations of the minor cations and anions of the pore fluids recovered from the first set of BLM core samples.

Results are listed in parts per million (ppm) based on volume of the analyte in solution.

Core Name	Core position	Depth interval inches	Br ppm	NO ₃ ppm	Ca ppm	Ba ppm	Sr ppm	B ppm	P ppm
NB6	Atop	0-2.5	50	<40	470	120	75	610	350
NB6	Abot	2.5-5	60	<40	430	120	76	530	380
NB6	B	5-10	60	160	400	120	76	550	350
NB6	Cb	10-14	60	<40	450	100	42	<500	<200
NB6	D	14-18	80	<40	420	100	42	<500	<200
NB6	E	18-23.25	70	<40	380	100	40	<500	<200
NB6	F	23.25-28.5	80	<40	390	100	40	<500	<200
NB6	G	28.5-32.5	60	<40	410	100	40	<500	<200
NB6	H	32.5-36.5	80	<40	400	120	74	580	340
NB6	It	36.5-42.25	70	<40	410	100	40	<500	<200
NB6	J	42.25-48	80	<40	420	100	40	<500	<200
NB6	K	48-54	80	<40	420	100	40	<500	<200
NB6	Lt	54-60	80	<40	420	100	40	<500	<200
NB6	Nt	60-63.5	70	<40	560	100	42	<500	<200
NB6	Nb	63.5-76	50	<40	390	120	78	610	500
NB7	Atop	0-2.5	50	<40	430	120	75	500	280
NB7	Abot	2.5-5	80	<40	460	100	43	<500	<200
NB7	B	5-10	70	<40	560	100	46	<500	<200
NB7	D*	15-20	70	<40	900	100	49	<500	<200
NB7	E	20-25	70	<40	870	100	50	<500	<200
NB7	F	25-30	51	<40	1025	100	52	<500	<200
NB7	G	30-34.5	<50	<40	640	120	80	500	330
NB7	H	34.5-39	80	<40	830	100	55	<500	<200
NB7	It	39-44	70	<40	610	100	54	<500	<200
NB7	J	44-49	50	<40	970	100	55	<500	<200
NB7	K	49-54	50	<40	1200	100	56	<500	<200
NB7	Ltop	54-56.5	50	<40	1100	100	54	<500	<200
NB7	Lbot	65.5-72	<50	<40	760	120	90	780	380

Core positions that indicate "top" or "bot" identify positions in the recovered core where pore fluid was obtained. Where depth intervals for "top" and "bot" are the same, "top" pore-fluid sample is from the upper portion of the interval, and "bot" pore-fluid sample is from the lower portion of the interval.

Table A2.8. The concentrations of the major cations and anions of the pore fluids recovered from the first set of BLM core samples, continued.

Results are listed in parts per million (ppm) based on volume of the analyte in solution.

Core Name	Core position	Depth interval inches	Br ppm	NO ₃ ppm	Ca ppm	Ba ppm	Sr ppm	B ppm	P ppm
NB10	Btop	30-36	230	<40	<60	110	65	500	340
NB10	Bbot	30-36	270	<40	100	100	30	<500	<200
NB10	Cb	36-45	260	<40	110	100	31	<500	<200
NB10	D	36-45	260	<40	120	100	31	<500	<200
NB10	E	45-54	236	<40	285	99	142	<500	<200
NB10	F	45-54	203	<40	439	98	104	<500	<200
NB10	G	54-64	170	<40	<60	120	70	510	60
NB10	ltop	72-78	160	<40	330	100	45	<500	<200
NB10	lbot	72-78	100	<40	140	120	80	490	400
NB11	A	0-7.5	60	<40	<60	120	69	420	260
NB11	B	7.5-15	70	<40	50	120	72	410	220
NB13	A	0-6	80	<40	100	120	74	340	380
NB13	B	6-12	120	<40	<60	120	70	320	340
MW01B	1	67-76	100	<40	90	120	75	320	210
MW01B	2	117-123	<50	<40	600	130	85	300	380
SB04	1	59-63	40	<40	460	120	81	260	300
SB04	2	108-112	60	<40	770	100	47	<500	<200
SB04	3	156-160	60	<40	110	110	50	<500	<200
SB04	4	204-208	70	<40	490	130	85	280	350
SB04	5	252-256	<40	<40	850	110	51	<500	<200
SB04	6	300-304	<40	<40	830	110	50	<500	<200
SB04	7	348-352	<50	<40	400	130	85	330	300
SC-7	NB13	salt cryst	270	<40	<60	60	44	<500	<200

Core positions that indicate "top" or "bot" identify positions in the recovered core where pore fluid was obtained. Where depth intervals for "top" and "bot" are the same, "top" pore-fluid sample is from the upper portion of the interval, and "bot" pore-fluid sample is from the lower portion of the interval.

Table A2.9. The concentrations of the major cations and anions in the brine samples collected by Papadopolus, Corp. The concentration of the analyte is reported in percent (%) based on the volume of analyte in solution.

ISA indicates that there was insufficient volume for analysis.

Date Collected	Sample Identification	Density g/mL	Cl %	SO ₄ %	Na %	Mg %	K %
12/3/1999	Canal Seep (end) 1503	1.218	14	1.6	6.82	0.90	0.54
12/3/1999	Canal Surface (end) 1520	1.204	15	1.9	7.73	1.00	0.78
12/4/1999	Canal Seep (near) 1446	1.205	16	1.3	8.71	0.75	0.48
12/4/1999	Canal Seep (mid-east) 1651	1.136	10	1.2	5.54	0.56	0.33
12/4/1999	Canal Seep (mid-west) 1615	1.141	11	1.2	6.13	0.43	0.22
12/4/1999	Canal Surface (near) 1310	1.207	16	1.3	7.87	0.70	0.45
12/4/1999	Pond Surface 1538	1.209	16	1.2	7.36	0.73	0.41
12/4/1999	MW 01 1419	ISA	13	1.2	8.19	0.71	0.48
12/3/1999	MW 01A 1320	1.118	17	1.4	5.19	0.30	0.30
12/4/1999	MW 01B 1425	1.100	9.6	0.6	4.37	0.18	0.14
12/4/1999	MW 01C 1435	1.088	7.1	0.6	3.86	0.16	0.09
12/4/1999	MW 02C 1518	1.087	6.7	0.6	3.95	0.16	0.11
12/3/1999	MW 03A 1555	1.135	10	1.1	5.55	0.36	0.21
12/3/1999	MW 03B 1811	1.090	6.9	0.6	4.40	0.19	<0.05
12/3/1999	MW 03C 1808	1.094	7.7	0.5	4.21	0.18	0.05
12/4/1999	MW 04A 1015	1.138	11	1.1	5.71	0.32	0.26
12/4/1999	MW 04B 1030	1.098	7.1	0.6	3.92	0.18	0.05
12/4/1999	MW 04C 1050	1.092	7.2	0.6	4.21	0.18	0.14
12/4/1999	MW 05A 1216	1.148	11	1.3	5.84	0.44	0.28
12/4/1999	MW 05B 1210	1.111	8.2	0.8	4.41	0.28	0.15
12/4/1999	MW 05C 1228	1.094	6.9	0.5	4.39	0.20	0.16
12/3/1999	MW 09A 1448	1.160	13	1.4	5.60	0.67	0.56
12/3/1999	MW 09B 1430	1.113	9.0	0.5	4.85	0.27	0.34
12/3/1999	MW 10A 1335	1.171	13	1.3	6.40	0.68	0.61
12/3/1999	MW 10B 1320	ISA					
12/1/1999	MW 12A 1605	1.231	17	2.3	6.58	1.79	1.14
12/1/1999	MW 12B 1526	1.221	15	3.0	6.55	1.64	0.90
12/1/1999	MW 12C 1550	1.144	12	0.5	6.12	0.35	0.48
12/1/1999	MW12 Seep 1625	1.230	16	2.3	6.34	1.87	1.14

Table A2.10. The concentrations of the minor cations and anions in brine samples collected by S.S. Papadopolus, Corp. The concentration of the analyte is reported in parts per million (ppm) based on the volume of analyte in solution. ISA indicates that there was insufficient volume for analysis.

Date Collected	Sample Identification	Density g/mL	Ca ppm	Ba ppm	Sr ppm	Br ppm	B ppm	NO ₃ ppm
12/3/1999	Canal Seep (end) 1503	1.218	<40	63	51	90	180	<50
12/3/1999	Canal Surface (end) 1520	1.204	91	64	56	116	<100	<50
12/4/1999	Canal Seep (near) 1446	1.205	91	62	55	91	170	<50
12/4/1999	Canal Seep (mid-east) 1651	1.136	430	69	61	57	<100	<50
12/4/1999	Canal Seep (mid-west) 1615	1.141	540	65	62	<50	<100	<50
12/4/1999	Canal Surface (near) 1310	1.207	157	60	56	91	190	<50
12/4/1999	Pond Surface 1538	1.209	50	64	54	74	130	<50
12/4/1999	MW 01 1419	ISA	80	60	55	236	<100	<50
12/3/1999	MW 01A 1320	1.118	734	64	70	205	125	<50
12/4/1999	MW 01B 1425	1.100	755	65	65	122	<100	<50
12/4/1999	MW 01C 1435	1.088	588	66	64	244	<100	<50
12/4/1999	MW 02C 1518	1.087	653	66	64	85	<100	<50
12/3/1999	MW 03A 1555	1.135	608	64	62	132	<100	<50
12/3/1999	MW 03B 1811	1.090	633	66	66	143	<100	<50
12/3/1999	MW 03C 1808	1.094	539	66	65	100	<100	<50
12/4/1999	MW 04A 1015	1.138	641	64	62	<50	<100	<50
12/4/1999	MW 04B 1030	1.098	583	66	62	<50	<100	<50
12/4/1999	MW 04C 1050	1.092	641	66	66	<50	<100	<50
12/4/1999	MW 05A 1216	1.148	427	63	59	73	<100	<50
12/4/1999	MW 05B 1210	1.111	765	65	63	<50	<100	<50
12/4/1999	MW 05C 1228	1.094	631	66	66	138	<100	<50
12/3/1999	MW 09A 1448	1.160	379	62	60	81	<100	<50
12/3/1999	MW 09B 1430	1.113	638	65	67	70	<100	<50
12/3/1999	MW 10A 1335	1.171	342	62	61	<50	<100	<50
12/3/1999	MW 10B 1320	ISA						
12/1/1999	MW 12A 1605	1.231	<40	58	50	<50	150	<50
12/1/1999	MW 12B 1526	1.221	<40	60	48	78	120	<50
12/1/1999	MW 12C 1550	1.144	1400	63	69	63	100	<50
12/1/1999	MW12 Seep 1625	1.230	<40	59	49	220	160	65

Table A2.11. The concentrations of major cations and anions of pore fluids recovered from sediment cores collected by S.S. Papadopolus, Corp. The concentration of the analyte is reported in percent (%) based on the volume of analyte in solution. ISA indicates that there was insufficient volume for analysis.

Core Sample ID	Depth interval Feet	Density g/mL	Cl %	SO₄ %	Na %	Mg %	K %
MW10A	0.5-1.5 ft top	1.2	15.2	2.16	8.22	0.99	0.71
MW10A	0.5-1.5 ft bot	1.17	12.4	1.22	6.43	0.69	0.68
MW10A	2.5-3.5 ft top	1.19	10.4	1.08	5.81	0.54	0.53
MW10A	2.5-3.5 ft bot	1.18	9.6	1.02	5.36	0.54	0.54
MW10A	5.0-6.0 ft top	1.15	10.8	0.85	6.01	0.42	0.62
MW10A	5.0-6.0 ft bot	1.13	8.6	0.61	5.12	0.24	0.69
MW10B	10.0-11.0 ft top	1.13	7.1	0.68	4.35	0.25	0.33
MW10B	10.0-11.0 ft bot	1.12	8.9	0.65	5.19	0.26	0.45
MW10B	16.0-17.0 ft top	1.11	8.9	0.66	5.38	0.28	0.34
MW10B	16.0-17.0 ft bot	1.11	9.2	0.66	5.20	0.27	0.41
MW12	0-1.0 ft	1.23	14.9	1.90	6.50	1.71	1.22
MW12	3.0-4.0 ft top	1.24	15.3	2.77	7.12	1.78	0.97
MW12	3.0-4.0 ft bot	1.20	16.3	2.60	7.50	1.75	0.92
MW12	6.0-7.0 ft top	1.23	15.8	2.13	8.07	1.30	0.90
MW12	6.0-7.0 ft bot	1.14	10.9	0.94	6.22	0.42	0.49
MW12	15.0-15.5 ft top	1.15	10.9	1.24	5.92	0.65	0.49
MW12	15.0-15.5 ft bot	1.13	10.1	1.00	6.11	0.42	0.35
MW12	17.5-18.5 ft top	1.13	10.1	1.10	5.30	0.46	0.42
MW12	17.5-18.5 ft bot	1.13	9.4	1.01	5.42	0.39	0.42

Core positions that indicate "top" or "bot" identify positions in the recovered core where pore fluid was obtained. Where depth intervals for "top" and "bot" are the same, "top" pore-fluid sample is from the upper portion of the interval, and "bot" pore-fluid sample is from the lower portion of the interval.

Table A2.12. The concentrations of minor cations and anions of pore fluids recovered from sediment cores collected by S.S. Papadopolus, Corp. The concentration of the analyte is reported in parts per million (ppm) based on the volume of analyte in solution. ISA indicates that there was insufficient volume for analysis.

Core Sample ID	Depth interval Feet	density g/mL	Br mg/g	NO ₃ mg/g	Ca mg/g	Sr mg/g	Ba mg/g
MW10A	0.5-1.5 ft top	1.2	99	<50	<40	50	64
MW10A	0.5-1.5 ft bot	1.17	65	<50	300	60	67
MW10A	2.5-3.5 ft top	1.19	58	<50	93	54	64
MW10A	2.5-3.5 ft bot	1.18	60	<50	187	54	65
MW10A	5.0-6.0 ft top	1.15	53	<50	679	66	68
MW10A	5.0-6.0 ft bot	1.13	<50	<50	715	67	68
MW10B	10.0-11.0 ft top	1.13	<50	<50	631	65	69
MW10B	10.0-11.0 ft bot	1.12	<50	<50	805	70	69
MW10B	16.0-17.0 ft top	1.11	<50	<50	691	71	70
MW10B	16.0-17.0 ft bot	1.11	<50	<50	646	69	69
MW12	0-1.0 ft	1.23	195	<50	<40	50	63
MW12	3.0-4.0 ft top	1.24	194	<50	<40	46	62
MW12	3.0-4.0 ft bot	1.20	<50	<50	<40	50	64
MW12	6.0-7.0 ft top	1.23	139	<50	<40	49	63
MW12	6.0-7.0 ft bot	1.14	78	<50	762	68	68
MW12	15.0-15.5 ft top	1.15	84	<50	470	64	67
MW12	15.0-15.5 ft bot	1.13	68	<50	851	73	69
MW12	17.5-18.5 ft top	1.13	62	<50	609	68	68
MW12	17.5-18.5 ft bot	1.13	64	<50	728	71	68

Core positions that indicate "top" or "bot" identify positions in the recovered core where pore fluid was obtained. Where depth intervals for "top" and "bot" are the same, "top" pore-fluid sample is from the upper portion of the interval, and "bot" pore-fluid sample is from the lower portion of the interval.

Table A2.13. The concentrations of the major cations and anions of the second set of BLM brine samples. Results are listed in percent (%) based on volume of the analyte in solution. Filtered (filt) and unfiltered (uf) samples are designated, as are field replicates collected in two different sized bottles (250 mL and 1 L).

Sample ID	Collection Time	Collection date	density g/mL	Cl %	SO ₄ %	Na %	Mg %	K %
MC 52A	1530	3/7/00	1.1527	11.0	1.32	7.43	0.15	0.34
MC 53A	1230a	3/9/00	1.2013	15.1	1.27	9.99	0.38	0.43
MC 53A	1230b	3/9/00	1.2013	15.0	1.27	9.82	0.37	0.42
MC 53A	1230c	3/9/00	1.2013	15.0	1.25	9.82	0.37	0.42
MC 54A	1400	3/9/00	1.2014	15.0	1.26	9.91	0.37	0.41
MC 55E	1600	3/24/00	1.2148	15.6	1.23	9.47	0.68	0.94
MC 56E	1630	3/24/00	1.2108	15.4	1.37	9.42	0.65	0.88
MC 57A	1630	3/31/00	1.1393	12.1	1.47	6.55	0.39	0.32
MW 09A	1442	12/3/99	1.1607	8.3	1.35	6.99	0.52	0.67
MW 09B	1430	12/3/99	1.1128	13.3	0.48	5.31	0.24	0.38
MW 10A	1335	12/3/99	1.1717	12.6	1.23	7.50	0.48	0.67
MW 10B	1320	12/3/99	1.1182	9.0	0.55	5.63	0.25	0.46
MW 12C	1550	12/1/99	1.1456	11.7	0.49	7.09	0.07	0.37
MW 12C	1550	9/13/00	1.1243	9.4	0.48	5.94	0.18	0.40
NBST 01W, L	1710	4/7/00	1.2157	16.0	1.15	10.45	0.30	0.47
NBST 01W,250	1710	4/7/00	1.2158	16.2	1.23	10.45	0.39	0.55
NBST 05SW,L	1945	4/8/00	1.2090	16.2	0.61	11.00	0.08	0.31
NBST 05SW,250	1945	4/8/00	1.2088	16.1	0.61	10.92	0.07	0.36
NBST 05W,L	1915	4/8/00	1.2323	15.7	2.51	7.86	1.68	1.35
NBST 05W,250	1915	4/8/00	1.2318	15.4	2.51	7.79	1.70	1.40
NBW 16 filt	1825	6/24/00	1.1711	12.9	1.00	8.18	0.26	0.34
NBW 16 uf	1825	6/24/00	1.1712	12.9	1.02	10.93	0.26	0.35
NBW 17, a	1635	9/13/00	1.2114	16.3	0.79	10.40	0.26	0.43
NBW18	1950	9/13/00	1.0755	6.5	0.30	0.97	1.60	1.06

MC-52A – 54A, and 57A: ground water-seep samples from walls of inlet canal (southern periphery)

MC-55E and 56E: ground water-seep samples from low-relief mounds (central basin topographic low)

MW-09, 10, and 12: brine samples from monitoring wells (intermediate and central basin topographic low)

NBST-01W and NBST 05W: ground water-seep samples from cavernous upwelling structures in halite crust (intermediate and central basin topographic low)

NBST 05SW: surface-water samples from 0.5 to 0.75-inch deep surface brine pond (central basin topographic low)

NBW-16: brine samples from open borehole NB#14 (western periphery)

NBW-18: brine samples from open borehole NB#15 (western periphery)

Table A2.14. The concentrations of the minor cations and anions of the second set of BLM brine samples. The concentration of the analyte is reported in parts per million (ppm) based on the volume of analyte in solution. Filtered (filt) and unfiltered (uf) samples are designated, as are field replicates collected in two different sized bottles (250 ml and 1 L). ISA indicates that there was insufficient volume for analysis.

Sample ID	Collection time	Collection date	density g/mL	Br ppm	NO ₃ ppm	Ca %
MC 52A	1530	3/7/2000	1.1527	<50	<50	0.029
MC 53A	1230a	3/9/2000	1.2013	67	<50	0.013
MC 53A	1230b	3/9/2000	1.2013	75	<50	0.013
MC 53A	1230c	3/9/2000	1.2013	67	<50	0.013
MC 54A	1400	3/9/2000	1.2014	58	<50	0.013
MC 55E	1600	3/24/2000	1.2148	115	<50	0.013
MC 56E	1630	3/24/2000	1.2108	116	<50	0.013
MC 57A	1630	3/31/2000	1.1393	158	<50	0.037
MW 09A	1442	12/3/1999	1.1607	86	<50	0.028
MW 09B	1430	12/3/1999	1.1128	<50	81	0.052
MW 10A	1335	12/3/1999	1.1717	111	<50	0.023
MW 10B	1320	12/3/1999	1.1182	<50	<50	0.057
MW 12C	1550	12/1/1999	1.1456	131	70	0.14
MW 12C	1550	9/13/2000	1.1243	<50	<50	ISA
NBST 01W, L	1710	4/7/2000	1.2157	74	<50	0.013
NBST 01W,250	1710	4/7/2000	1.2158	<50	<50	0.013
NBST 05SW,L	1945	4/8/2000	1.2090	50	<50	0.025
NBST 05SW,250	1945	4/8/2000	1.2088	50	<50	0.031
NBST 05W,L	1915	4/8/2000	1.2323	211	73	0.013
NBST 05W,250	1915	4/8/2000	1.2318	203	56.8	0.013
NBW 16 filt	1825	6/24/2000	1.1711	68	<50	0.028
NBW 16 uf	1825	6/24/2000	1.1712	68	<50	0.025
NBW 17, a	1635	9/13/2000	1.2114	66	<50	0.020
NBW18	1950	9/13/2000	1.0755	<50	74	0.030

MC-52A – 54A, and 57A: ground water-seep samples from walls of inlet canal (southern periphery)

MC-55E and 56E: ground water-seep samples from low-relief mounds (central basin topographic low)

MW-09, 10, and 12: brine samples from monitoring wells (intermediate and central basin topographic low)

NBST-01W and NBST 05W: ground water-seep samples from cavernous upwelling structures in halite crust (intermediate and central basin topographic low)

NBST 05SW: surface-water samples from 0.5 to 0.75-inch deep surface brine pond (central basin topographic low)

NBW-16: brine samples from open borehole NB#14 (western periphery)

NBW-18: brine samples from open borehole NB#15 (western periphery)

Table A2.15. The concentrations of the major and minor cations and anions of the pore fluids recovered from the second set of BLM core samples. The concentration of the analyte is reported in percent (%) or parts per million (ppm) based on the volume of analyte in solution. ISA indicates that there was insufficient volume for analysis.

Sample ID	Sample depth	density g/mL	Cl %	SO ₄ %	Na %	Mg %	K %	Ca %	Sr %	Br ppm
#1, NB ST 01A 1	0-1 ft	1.2168	16.1	3.48	10.85	0.68	0.58	0.033	0.003	ISA
#2, NB ST 01A 2	0-1 ft	1.2051	15.5	1.21	10.37	0.52	0.51	0.033	0.002	ISA
#3, NB ST 01B 1	1-2 ft	1.2098	16.0	1.07	10.58	0.55	0.63	0.041	0.003	ISA
#4, NB ST 01B 2	1-2 ft	1.2186	16.0	1.49	10.26	0.71	0.71	0.049	0.002	140
#5, NB ST 02A 1	0-1 ft	1.2179	16.0	1.59	ISA	ISA	ISA	ISA	ISA	156
#7, NB ST 02B 1	1-2 ft	1.2138	16.1	1.76	10.05	0.97	0.68	0.025	0.002	189
#8, NB ST 02B 2	1-2 ft	1.2162	16.0	1.77	9.70	0.99	0.72	0.041	0.002	ISA
#9, NB ST 02C 2	2-3 ft	1.2193	16.0	1.61	9.76	0.89	0.67	0.025	0.002	ISA
#11, NB ST 05B 2	16-28 in	1.2294	15.5	2.77	10.25	0.75	0.70	0.016	0.003	171
#13, NB ST 05D 2	42-51 in	1.2136	16.0	1.61	10.05	0.77	0.74	ISA	0.003	173
#14, NB ST 05A1	0-20 in	1.227	16.5	2.18	9.37	1.12	0.98	0.024	0.002	196
#15, NB ST 05A 1	20-21 in	1.252	14.2	4.47	8.39	1.40	1.40	0.008	0.002	216
#16, NB ST 05A 2	0-16 in	1.2168	16.3	1.33	10.03	0.74	0.69	0.033	0.004	131
#16, NB ST 05A 2	0-16 in	1.2164	16.2	1.32	ISA	0.81	ISA	ISA	0.003	148
#16, NB ST 05A 2	0-16 in	1.2173	16.2	1.31	10.02	0.81	0.74	ISA	0.004	156
#17, NB ST 05B 2	16-28 in	1.2535	14.7	5.15	8.70	1.74	1.24	0.008	0.002	199
#18, NBST 05B C2	29-42 in	1.2303	15.5	3.08	8.94	1.52	0.83	0.016	0.002	219

APPENDIX A3

Table A3.1. Pore-water brine chemistry from borehole core samples, western periphery of Newfoundland Basin. ISA = insufficient volume for analysis.

USGS Site Identifier	BLM Sample Number	BLM Borehole ID	Sample Interval, ft	Brine Chemistry, g/L (unless otherwise indicated)								
				Density, g/mL	Na	Mg	K	Ca	Cl	SO ₄	TDS	Mole Bal
NB-BH-3	NB-6At	NB#6	0 to 0.21	1.203	115.52	6.02	4.45	0.57	209.37	12.03	347.96	-0.0205
NB-BH-3	NB-6Ab		0.21 to 0.42	1.198	114.99	5.39	4.55	0.54	202.43	10.78	338.68	-0.0144
NB-BH-3	NB-6B		0.42 to 0.83	1.191	94.08	4.64	3.57	0.48	169.11	9.53	281.41	-0.0159
NB-BH-3	NB-6Cb		0.83 to 1.17	1.204	105.97	6.26	5.78	0.54	196.28	12.04	326.88	-0.0202
NB-BH-3	NB-6D		1.17 to 1.50	1.201	104.50	6.97	6.13	0.50	192.18	13.21	323.48	-0.0164
NB-BH-3	NB-6E		1.50 to 1.94	1.204	102.36	7.35	6.62	0.46	185.45	13.25	315.48	-0.0107
NB-BH-3	NB-6F		1.94 to 2.38	1.202	98.58	8.30	6.85	0.47	192.35	14.43	320.98	-0.0231
NB-BH-3	NB-6G		2.38 to 2.71	1.203	101.04	8.42	6.62	0.49	192.46	14.43	323.47	-0.0186
NB-BH-3	NB-6H		2.71 to 3.04	1.195	92.04	5.38	5.38	0.48	160.17	11.95	275.40	-0.0067
NB-BH-3	NB-6It		3.04 to 3.52	1.199	99.54	7.32	6.60	0.49	185.89	15.59	315.43	-0.0185
NB-BH-3	NB-6J		3.52 to 4.0	1.196	99.28	7.54	6.82	0.50	185.40	15.55	315.08	-0.0174
NB-BH-3	NB-6K		4.0 to 4.5	1.198	103.06	7.79	6.23	0.50	182.16	15.58	315.32	0.2343
NB-BH-3	NB-6Lt		4.5 to 5.0	1.191	94.09	7.74	6.55	0.50	177.46	15.48	301.82	-0.0170
NB-BH-3	NB-6Nt		5.0 to 5.30	1.175	85.80	7.05	5.99	0.66	157.50	14.10	271.12	-0.0101
NB-BH-3	NB-6Nb		5.30 to 6.33	1.172	87.92	7.15	5.39	0.46	168.80	14.07	283.78	-0.0205
NB-BH-5	NB-7At	NB#7B	0 to 0.21	1.202	109.35	7.81	5.65	0.52	195.86	13.22	332.40	-0.0096
NB-BH-5	NB-7Ab		0.21 to 0.42	1.204	105.93	7.22	6.62	0.55	197.42	12.04	329.79	-0.0174
NB-BH-5	NB-7B		0.42 to 0.83	1.203	104.64	6.62	6.86	0.67	198.46	9.62	326.87	-0.0205
NB-BH-5	NB-7C		0.83 to 1.25	ISA	ISA	ISA	ISA	ISA	ISA	ISA	ISA	ISA
NB-BH-5	NB-7D		1.25 to 1.67	1.179	91.99	5.54	6.01	1.06	172.18	8.26	285.04	-0.0154
NB-BH-5	NB-7E		1.67 to 2.08	1.177	87.08	5.18	5.65	1.02	162.40	7.06	268.39	-0.0135
NB-BH-5	NB-7F		2.08 to 2.5	1.180	87.32	5.31	5.78	1.21	165.20	7.08	271.90	-0.0154
NB-BH-5	NB-7G		2.5 to 2.88	1.167	81.72	4.32	4.55	0.75	150.59	7.00	248.94	-0.0141
NB-BH-5	NB-7H		2.88 to 3.25	1.192	102.49	5.84	6.55	0.99	188.29	7.15	311.31	-0.0128
NB-BH-5	NB-7It		3.25 to 3.67	1.210	110.07	6.65	7.38	0.74	210.47	7.26	342.57	-0.0218
NB-BH-5	NB-7J		3.67 to 4.08	1.183	95.86	5.21	6.15	1.15	178.69	7.10	294.16	-0.0159
NB-BH-5	NB-7K		4.08 to 4.5	1.168	88.75	4.90	6.07	1.40	157.64	7.01	265.77	-0.0044
NB-BH-5	NB-7Lt		4.5 to 4.71	1.159	81.10	4.52	6.14	1.27	150.62	6.95	250.61	-0.0118
NB-BH-5	NB-7Lb		5.46 to 6.0	1.155	73.89	3.58	4.50	0.88	137.39	5.77	226.01	-0.0142

Table A3.2. Pore-water brine chemistry from borehole core samples, central basin topographic low of Newfoundland Basin. ISA = insufficient volume for analysis.

USGS Site Identifier	BLM Sample Number	BLM Borehole ID	Sample Interval, ft	Brine Chemistry, g/L (unless otherwise indicated)								
				Density, g/mL	Na	Mg	K	Ca	Cl	SO ₄	TDS	Mole Bal
	NB8-A1	NB#8	0 to 0.542	1.2248	90.64	17.15	14.70	0.34	194.74	22.05	339.61	-0.00839
	NB8-A2		0 to 0.542	1.2496	69.98	17.49	17.49	0.12	148.70	44.99	298.78	-0.00775
	NB8-B1		0.542 to 1.0	1.2246	90.62	19.59	17.14	0.28	198.39	29.39	355.42	-0.0082
	NB8-B1		0.542 to 1.0	1.2302	67.66	14.76	12.30	0.20	148.85	22.14	265.92	-0.0072
	NB8-B1		0.542 to 1.0	1.2308	59.08	13.54	11.82	0.18	132.93	20.92	238.47	-0.00771
	NB8-B3		0.875 to 1.25	1.2349	75.33	18.52	14.82	0.20	171.65	30.87	311.39	-0.01193
	NB8-B3		0.875 to 1.25	1.2343	88.87	19.75	17.28	0.23	191.32	34.56	352.01	-0.00694
	NB8-B3		0.875 to 1.25	1.235	82.75	18.53	17.29	0.23	182.78	32.11	333.68	-0.00998
	NB8-C2		1.542 to 2.5	1.2491	73.70	18.74	19.99	0.16	161.13	46.22	319.93	-0.00963
NB-BH-7	NB-10Bt	NB#10A	2.5 to 3.0	1.230	66.42	28.04	15.01	0.07	173.43	52.89	335.86	-0.0166
NB-BH-7	NB-10Bb		2.5 to 3.0	1.255	76.56	33.01	18.95	0.13	194.54	57.73	380.92	-0.0060
NB-BH-7	NB-10Cb		3.0 to 3.75	1.249	77.43	31.97	18.98	0.14	197.31	54.95	380.77	-0.0087
NB-BH-7	NB-10D		3.0 to 3.75	1.243	79.53	29.95	18.02	0.15	197.57	52.19	377.40	-0.0108
NB-BH-7	NB-10E		3.75 to 4.5	1.230	83.64	24.97	16.97	0.35	200.49	40.59	367.01	-0.0145
NB-BH-7	NB-10F		3.75 to 4.5	1.230	78.72	18.94	12.05	0.54	179.58	28.29	318.13	-0.0137
NB-BH-7	NB-10G		4.5 to 5.33	1.220	75.65	16.96	10.98	0.07	174.49	24.40	302.56	-0.0188
NB-BH-7	NB-10H		4.5 to 5.33	ISA	ISA	ISA	ISA	ISA	ISA	ISA	ISA	ISA
NB-BH-7	NB-10It		6.0 to 6.5	1.216	100.94	13.01	10.95	0.40	205.54	18.24	349.09	-0.0171
NB-BH-7	NB-10Ib		6.0 to 6.5	1.216	91.77	9.53	7.99	0.17	181.15	14.30	304.91	-0.0172
NB-MW12A	MW12	MW12A	0 to 1.0	1.23	79.95	21.03	15.01	0.05	183.27	23.37	322.6782	-0.00249
NB-MW12B	MW12-t	MW12B	3.0 to 4.0	1.24	88.04	22.07	12.03	0.05	189.72	34.35	346.26	-0.00445
NB-MW12B	MW12-b	MW12B	3.0 to 4.0	1.2	90.00	21.00	11.04	0.05	195.60	31.20	348.89	-0.00996
NB-MW12B	MW12-t	MW12B	6.0 to 7.0	1.23	99.63	15.99	11.07	0.05	194.34	26.20	347.28	-0.00374
NB-MW12B	MW12-b	MW12B	6.0 to 7.0	1.14	70.68	4.79	5.59	0.87	124.26	10.72	216.89	-0.00322
NB-MW12C	MW12-t	MW12C	15.0 to 15.5	1.15	67.85	7.48	5.64	0.54	125.35	14.26	221.11	-0.00413
NB-MW12C	MW12-b	MW12C	15.0 to 15.5	1.13	68.93	4.75	3.96	0.96	114.13	11.30	204.023	0.003699
NB-MW12C	MW12-t	MW12C	17.5 to 18.5	1.13	59.89	5.20	4.75	0.69	114.13	12.43	197.08	-0.0128
NB-MW12C	MW12-b	MW12C	17.5 to 18.5	1.13	61.02	4.41	4.75	0.82	106.22	11.41	188.63	-0.0024

Table A3.3. Pore-water brine chemistry from borehole core samples, adjacent to Inlet Canal, southern peripheral portion of Newfoundland Basin.

USGS Site Identifier	BLM Sample Number	BLM Borehole ID	Sample Interval, ft	Brine Chemistry, g/L (unless otherwise indicated)								
				Density, g/mL	Na	Mg	K	Ca	Cl	SO ₄	TDS	Mole Bal
NB-MW01B	MW01-B1	MW01	5.58 to 6.33	1.194	94.33	12.06	7.04	0.11	182.68	20.30	316.51	-0.01233
	MW01-B2		9.75 to 10.25	1.0998	46.19	1.98	2.97	0.66	86.88	6.60	145.28	-0.01396
NB-MW04	SB04-1	MW04	4.92 to 5.25	1.1312	57.69	3.51	3.05	0.52	110.86	11.31	186.94	-0.02034
	SB04-2		9.0 to 9.33	1.1386	66.04	6.26	5.35	0.88	120.69	14.80	214.02	-0.00632
	SB04-3		13.0 to 13.33	1.0984	50.53	2.75	2.97	0.12	85.68	6.59	148.62	-0.00219
	SB04-4		17.0 to 17.33	1.0865	42.37	1.63	1.96	0.53	71.71	5.43	123.63	-0.00377
	SB04-5		21.0 to 21.33	1.0891	45.74	2.29	2.72	0.93	78.42	6.53	136.63	-0.00248
	SB05-6		25.0 to 25.33	1.0921	46.96	2.29	2.84	0.91	79.72	5.46	138.18	-0.00006
	SB04-7		29.0 to 29.33	1.0917	43.67	1.64	1.97	0.14	75.33	5.46	128.19	-0.0067
NB-BH-10	NB-13A	NB#13	0 to 0.5	1.193	89.50	6.44	5.97	0.12	169.45	13.13	284.60	-0.0197
NB-BH-10	NB-13B		0.5 to 1.0	1.209	101.57	12.94	10.88	0.07	199.52	22.97	347.96	-0.0141
NB-BH-11	NB-11A	NB#11B	0 to 0.625	1.210	66.57	4.36	3.99	0.07	117.40	9.68	202.07	-0.0063
NB-BH-11	NB-11B		0.625 to 1.25	1.211	110.16	7.99	7.02	0.06	204.59	16.95	346.78	-0.0203
NB-BH-11	NB-11C&D											
NB-BH-11	NB-11E&F											
NB-BH-15	NB-16A	NB#16	0 to 1.0	1.161	82.43	8.24	8.82	0.92	135.84	13.93	250.18	0.017824
NB-BH-15	NB-16B		1.0 to 2.0	1.1369	68.21	3.87	4.32	0.84	111.42	12.51	201.16	0.001529
NB-BH-15	NB-16C		2.0 to 3.0	1.1397	69.52	3.99	3.87	1.14	119.67	13.68	211.87	-0.00666
NB-BH-15	NB-16D		3.0 to 4.0	1.1402	79.81	4.56	4.56	0.80	135.68	29.65	255.06	-0.01933
NB-BH-17	NB-18A	NB#18	0 to 1.0	1.1898	95.18	6.78	6.31	0.40	168.95	16.66	294.29	-0.00977
NB-BH-17	NB-18B		1.0 to 2.0	1.1858	96.05	8.66	7.59	0.55	175.50	15.42	303.75	-0.00672
NB-BH-17	NB-18C		2.0 to 3.0	1.22	79.30	9.03	7.93	0.84	153.72	14.64	265.46	-0.00834

APPENDIX A4

Table A4.1. Brine chemistry from open borehole ground-water samples, western peripheral portion of Newfoundland Basin.

USGS Site Identifier	BLM Sample Number	BLM Borehole ID	Sample Interval, ft	Brine Chemistry, g/L (unless otherwise indicated)								
				Density, g/mL	Na	Mg	K	Ca	Cl	SO ₄	TDS	Mole Bal
NB-BH-2	NBW-5	NB#5	N/A	1.156	72.10	5.50	3.90	1.11	133.20	8.30	224.11	-0.0076
NB-BH-3	NBW-6	NB#6	N/A	1.183	86.30	7.60	5.55	0.47	152.70	7.69	260.31	0.0034
NB-BH-5	NBW-11	NB#7B	N/A	1.151	78.00	3.90	5.10	1.20	132.10	6.48	226.78	0.0019
NB-BH-13	NBW-16	NB#14	N/A	1.166	86.59	4.46	0.50	0.77	144.04	13.91	250.30	-0.0071
NB-BH-14	NBW-18	NB#15	N/A	1.073	47.00	1.00	2.80	0.53	69.86	3.12	124.30	0.0089
NB-BH-21	NBW-32A&B	NB#22	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND
NB-BH-23	NBW-21A&B	NB#24	N/A	1.022	9.91	0.31	0.60	0.29	16.56	1.01	28.70	-0.0001

N/A Not applicable

ND No data, not analyzed

Table A4.2. – Brine chemistry from open borehole ground-water samples, central basin topographic low of Newfoundland Basin.

USGS Site Identifier	BLM Sample Number	BLM Borehole ID	Sample Interval, ft	Brine Chemistry, g/L (unless otherwise indicated)								
				Density, g/mL	Na	Mg	K	Ca	Cl	SO ₄	TDS	Mole Bal
NB-BH-4	NBW-9	NB#8	N/A	1.224	79.40	20.00	16.60	0.18	167.60	35.03	318.81	0.0032
NB-BH-6	NBW-12	NB#9	N/A	1.236	76.80	20.60	20.60	0.34	177.68	35.84	331.90	-0.0071
NB-BH-7	NBW-14	NB#10	N/A	1.236	76.10	20.87	19.00	0.31	177.68	30.57	324.50	-0.0048

N/A Not applicable

Table A4.3. Brine chemistry from open borehole ground-water samples, adjacent to Inlet Canal, southern peripheral portion of Newfoundland Basin.

USGS Site Identifier	BLM Sample Number	BLM Borehole ID	Sample Interval, ft	Brine Chemistry, g/L (unless otherwise indicated)								
				Density, g/mL	Na	Mg	K	Ca	Cl	SO ₄	TDS	Mole Bal
NB-BH-*	MC-19B	NB#2	N/A	1.173	76.50	7.30	7.25	0.42	128.90	25.60	245.97	-0.0014
NB-BH-1	MC-22B	NB#3	N/A	1.158	74.50	3.70	4.15	0.64	120.40	15.45	218.84	-0.0014
NB-BH-8	MC-28B	NB#12	N/A	1.159	75.80	6.76	6.50	0.60	141.45	10.27	241.40	-0.0066
NB-BH-10	MC-44C	NB#13	N/A	1.178	82.90	7.49	8.40	0.54	151.80	12.55	263.70	-0.0033
NB-BH-12	MC-45C	NB#11B	N/A	1.174	78.60	9.20	8.60	0.44	146.28	14.69	257.80	-0.0005
NB-BH-16	NBW-20A	NB#17	N/A	1.173	76.67	7.86	8.40	0.40	138.00	24.85	256.20	-0.0082
NB-BH-18	NBW-27A	NB#19	N/A	1.146	76.67	3.14	4.60	0.82	126.96	12.52	224.70	-0.0038

* No identifier assigned

N/A Not applicable

APPENDIX A5

Table A5.1. X-ray diffraction-derived mineralogy of shallow sediments obtained from open borehole and monitoring-well cores. Monitoring wells and open boreholes are prefixed with “MW” and “NB,” respectively (monitoring well SB-04 is the exception). UID = unidentified sulfate; mineral presence or absence indicated by “N” (no) and “Y” (yes); Tr trace; ? uncertain identification due to overlap of diagnostic peaks.

BLM Sample number	Sample depth, ft BGL	Halite	Quartz	Aragonite	Calcite	Dolomite	Total Clay	UID Sulfate	Gypsum
SBO4-1	4.92 to 5.25	8.4	43.3	43.3	3.8	0.7	40.3	N	1.8
SBO4-2	9.0 to 9.33	2.1	8.8	18.2	10.4	2.6	40	N	
SBO4-3	13.0 to 13.33	2.8	5.1	38.3	10.6	4.5	36.5	Y? or F-spar?	TR?
SBO4-4	17.0 to 17.33	1.8	3.6	59.7	4.2	1.8	27.9	Y	1.6
SBO4-5	21.0 to 21.33	2.4	2.5	49.5	5.1	2.4	38.3	N	TR?
SBO4-6	25.0 to 25.33	3.4	3.1	51.9	4.6	3.7	33.4	N	TR?
SBO4-7	29.0 to 29.33	1.8	2.5	55.7	4.9	3.2	30.1	Y? or F-spar?	1.8
NB6-A t	0.0 to 0.21	9.7	8.6	29.3	18.9	0.9	32.7	N	0
NB6-A b	0.21 to 0.42	5.3	16.4	0	20.6	2.5	55.3	Y	0
NB6-B	0.42 to 0.83	8.3	20.2	0	25.8	4.4	25.4	N	0
NB6-C b	0.83 to 1.17	9.4	18.9	0	20.6	10.8	40.2	Y	0
NB6-D	1.17 to 1.5	11.9	17.3	0	20.9	3.7	46.2	Y	0
NB6-E	1.5 to 1.94	7.3	19.2	0	20.9	2.7	49.9	Y	0
NB6-F	1.94 to 2.38	6.8	13	18.7	16.9	3.1	41.6	Y	0
NB6-G	2.38 to 2.71	12.3	15.4	0	20.6	3.6	48.2	Y	0
NB6-H	2.71 to 3.04	8.1	9	36.2	12.7	1.9	32.2	Y	0
NB6-I t	3.04 to 3.54	12	9.5	30.2	9	2.7	36.7	N	0
NB6-J	3.52 to 4.0	4.7	13.2	32.8	3.8	1.7	43.9	N	0
NB6-K	4.0 to 4.5	4.4	6.1	51.3	4.2	1	33.2	Y	TR
NB6-L t	4.5 to 5.0	9.1	21.1	34.1	4	TR	31.6	Y	0
NB6-N t	5.0 to 5.29	6	16.7	36.3	4.6	3.3	33.2	Y	0
NB6-N b	5.29 to 5.58	8.3	6.1	47.5	3.6	0.9	31.6	Y	2
NB7-A t	0.066 to 0.21	6.8	12.8	18.4	10.9	1.7	49.5	N	0
NB7-A b	0.21 to 0.42	9.3	29.3	41.8	7.1	1.1	11.4	N	0
NB7-B	0.42 to 0.83	7.7	9.8	27	23.1	2.8	29.6	Y	0
NB7-C	0.83 to 1.25	4.8	20.6	34.9	11.4	0.6	27.7	Y	TR
NB7-D	1.25 to 1.67	18	15.5	16.5	10.1	0	40	Y	TR
NB7-E	1.67 to 2.08	5.4	1.8	14.3	5.4	15.6	19.7	N	37.9

Table A5.2. X-ray diffraction-derived mineralogy of shallow sediments obtained from open borehole and monitoring-well cores. Monitoring wells and open boreholes are prefixed with “MW” and “NB,” respectively (monitoring well SB-04 is the exception). UID = unidentified sulfate; mineral presence or absence indicated by “N” (no) and “Y” (yes); Tr trace; ? uncertain identification due to overlap of diagnostic peaks; - no data.

BLM Sample number	Sample depth, ft BGL	Halite	Quartz	Aragonite	Calcite	Dolomite	Total Clay	UID Sulfate	Gypsum
NB7-F	2.08 to 2.5	6.7	3.4	5.5	3.4	2.3	28.2	N	50.6
NB7-G	2.5 to 2.89	12.9	6.9	36.1	10.3	4.1	20.4	N	9.7
NB7-H	2.89 to 3.25	9.7	1.5	50.7	2.5	1	12.1	N	22.6
NB7-I t	3.25 to 3.67	5.6	2.6	36.8	2.9	2	27	N	23.1
NB7-J	3.67 to 4.08	6.1	0.8	66.8	2.4	0.6	18.6	N	4.7
NB7-K	4.08 to 4.5	4.1	1.3	44.8	1.7	1.1	22.2	N	24.8
NB7-L t	4.5 to 4.71	4.9	2.5	52.8	2.7	0.6	36.5	N	0
NB7-L b	4.71 to 4.91	7.8	3.9	51.2	5.2	1.1	30.8	N	TR
NB8-A 1	crust	98	0	0	0	0	2	—	0.3
NB8-A 2a	0.0 to 0.33	74	0	0	0	0	24	—	2
	red-brown								
NB8-A 2b	layer	85	0	0	0	0	13	—	2
NB8-A 2c	0.33 to 0.82	80	0	0	0	0	19	—	1
NB8-B 1	0.82 to 1.64	39	0	0	0	0	55	—	7
NB8-B 2a	0.82 to 1.31	63	0	0	0	0	36	—	1
NB8-B 2b	1.31 to 1.64	65	0	0	0	0	32	—	1
NB8-B 3	1.31 to 1.97	39	0	0	0	0	52	—	9
NB8-C 1a	1.97 to 2.79	46	0	0	0	0	50	—	4
NB8-C 1b	2.79 to 3.61	78	0	0	0	0	21	—	1
NB8-C 2a	2.30 to 3.28	73	1	0	0	0	26	—	1
NB8-C 2b	3.28 to 3.61	10	4	0	6	6	22	—	47
NB8-D 1a	3.94 to 4.27	11	1	0	0	0	46	—	42
NB8-D 1b	4.27 to 4.92	1	1	0	0	0	29	—	69
NB8-E 1a	4.92 to 5.25	50	2	0	0	0	11	—	37
NB8-E 1b	5.25 to 5.58	3	4	?	?	?	19	—	74
NB10-B t	2.5 to 3.0	1.7	2.8	0	5.6	2.9	54.7	Y	32.8
NB10-B b	2.5 to 3.0	1.5	3.8	0	4.3	1.9	34.3	Y	54.1
NB10-C t	3.0 to 3.75	2.2	1.3	0	TR?	TR?	33.3	Y	63.3
NB10-C b	3.0 to 3.75	33.9	3.6	0	2	TR?	18.8	Y	41.7
NB10-D	3.0 to 3.75	2.6	2.2	0	1.5	0.3	18.1	Y	75.4
NB10-E	3.75 to 4.5	26.8	2.3	0	2.3	0	24.2	Y?	44.5
NB10-F	3.75 to 4.5	0.7	0.5	0	0.5	0.3	22.5	Y?	75.5
NB10-G	4.5 to 5.3	2.1	0.4	0	1.8	TR	34.3	Y?	61.4
NB10-H t	4.5 to 5.3	2.1	0.7	0	2.1	0.9	24.7	Y?	69.4

Table A5.3. X-ray diffraction-derived mineralogy of shallow sediments obtained from open borehole and monitoring-well cores. Monitoring wells and open boreholes are prefixed with “MW” and “NB,” respectively (monitoring well SB-04 is the exception). UID = unidentified sulfate; mineral presence or absence indicated by “N” (no) and “Y” (yes) ; Tr trace; ? uncertain identification due to overlap of diagnostic peaks; - no data.

BLM Sample number	Sample depth, ft BGL	Halite	Quartz	Aragonite	Calcite	Dolomite	Total Clay	UID Sulfate	Gypsum
NB10-H b	4.5 to 5.3	24.3	0.8	0	0.8	3	25.1	Y?	46.7
NB10-I t	6.0 to 6.5	3.3	1.7	0	9.4	0.8	22.2	Y?	62.5
NB10-I b	6.0 to 6.5	3.9	0.9	0	1.6	2.6	41.4	Y	49.8
NB11-A	0.0 to 0.625	7.3	5.1	45	14.2	1.8	26.6	Y	TR?
NB11-B	0.625 to 1.25	16.5	?	17.1	4	1.3	24.8	Y?	36.3
NB13-A	0.0 to 0.5	7.7	1.2	3.2	5.2	0.8	28.7	N?	53.1
NB13-B	0.5 to 1.0	5.8	1.9	44.6	5.5	2.1	36.9	N	3.2
NB16-A 1	0.0 to 0.66	6	2	49	2	0	40	—	2
NB16-A 2	0.66 to 1.64	6	1	18	2	0	38	—	35
NB16-B 1	1.64 to 2.30	5	3	17	5	?	67	—	4
NB16-B 2	2.30 to 2.95	6	4	71	7	?	9	—	4
NB16-C 1	2.95 to 3.61	9	1	16	3	0	11	—	TR
NB16-C 2	3.61 to 4.59	11	2	38	4	0	45	—	0
NB16-D 1	4.59 to 5.41	5	2	31	3	0	60	—	TR
NB16-D 2	5.41 to 6.23	11	12	0	23	0	52	—	0
NB18-A 1	0.0 to 0.66	17	4	18	11	0	49	—	0
NB18-A 2	0.66 to 1.64	10	3	4	45	0	75	—	4
NB18-B 1	1.64 to 2.30	17	1	65	5	0	13	—	0
NB18-B 2	2.30 to 2.95	5	3	29	2	0	59	—	2
NB18-C 1	2.95 to 3.61	4	2	57	2	0	36	—	0
NB18-C 2	3.61 to 4.59	3	1	45	1	0	48	—	2
NBST01-A 1	0.0 to 1.0	100	0	0	0	0	0	N	0
NBST01-A 2	0.0 to 1.0	100	0	0	—	0	TR	N	0
NBST01-B 1t	1.0 to 2.0	92	0	0	0	0	TR	N	0
NBST01-B 1b	1.0 to 2.0	10.8	6	20.2	4.8	0	58.2	N	—
NBST01-B 2t	1.0 to 2.0	100	0	0	—	0	0	N	0
NBST01-B 2b	1.0 to 2.0	8	1.9	34.6	6.1	4.4	42.7	N	TR
NBST02-A 1t	0.0 to 1.0	100	0	0	—	0	0	N	0
NBST02-A 1b	0.0 to 1.0	82.4	0.3	0	0.8	0	14.8	N	0
NBST02-A 2t	0.0 to 1.0	100	0	0	—	0	0	N	0
NBST02-A 2b	0.0 to 1.0	93.1	0.2	0	0.2	0.2	7.3	N	0
NBST02-B 1t	1.0 to 2.0	100	TR	0	—	0	TR	N	0
NBST02-B 1b	1.0 to 2.0	38.8	1.2	23.3	6.9	0	28.2	N	0

Table A5.4. X-ray diffraction-derived mineralogy of shallow sediments obtained from open borehole and monitoring-well cores. Monitoring wells and open boreholes are prefixed with “MW” and “NB,” respectively (monitoring well SB-04 is the exception). UID = unidentified sulfate; mineral presence or absence indicated by “N” (no) and “Y” (yes); Tr trace; ? uncertain identification due to overlap of diagnostic peaks; - no data.

BLM Sample number	Sample depth, ft BGL	Halite	Quartz	Aragonite	Calcite	Dolomite	Total Clay	UID Sulfate	Gypsum
NBST02-B 2t	1.0 to 2.0	52.2	0	21.3	0.9	0	21.3	N	TR
NBST02-B 2b	1.0 to 2.0	11.2	1.2	52.1	0	TR?	32.1	N	TR?
NBST02-C 2t	1.0 to 2.0	88.2	0.3	1.8	0.3	0	9.2	N	TR?
NBST02-C 2b	1.0 to 2.0	7.9	5.5	12.8	4	15.8	52.1	N	TR
NBST05-B 1t	1.75 to 2.83	42.3	11	0	0	1.2	32.7	N	5.1
NBST05-B 1b	1.75 to 2.83	95.3	TR	0	0	0	3.2	TR?	0
NBST05-B 2t	1.3 to 2.3	62.1	0.3	0	1.4	0.8	33.8	N	TR
NBST05-B 2b	1.3 to 2.3	93.1	0	0	0	0	6.4	Y?	0
NBST05-C 2t	2.41 to 3.5	29.7	1.5	0	2.8	0	24.7	N	0
NBST05-C 2b	2.41 to 3.5	6	3.6	0	5.2	0	47.4	N	TR?
NBST05-D 2t	3.5 to 4.3	22.2	2.8	0	7.1	3.3	39.2	Y	TR
NBST05-D 2b	3.5 to 4.3	0.8	TR	0	0	1.1	15.6	TR or F-spar	0
NBST05-A 1 bagged	0.0 to 1.67	10	TR	0	0	0	TR	N	0
NBST05-A 1 bagged	1.67 to 1.75	20.3	3.9	TR	—	TR	44.8	N	0
NBST05-A 2 bagged	0.0 to 1.33	100	0	0	0	0	TR	N	0
NBST05-B 2 bagged	2.42 to 3.5	24	5.2	TR	—	TR	63.5	N	0
NBST05-C 2 bagged	2.42 to 3.5	5.2	2	4.1	0	1.2	TR	N	0
MW01-B 1	5.0 to 6.0	6.4	14.6	20.6	11.8	4.1	42.6	Y?	0
MW01-B 2	9.75 to 10.25	3	2	67.2	3.4	2.5	21.9	N	0
MW09-A	0.0 to 0.33	49.9	0	0	0	0	50.6	—	0
MW09-A	0.33 to 0.66	32.2	3.1	18.1	4.9	0	40.2	—	1.6
MW09-B	0.66 to 1.15	26.7	0	28.1	3.8	0	38.4	—	3
MW09-B	1.15 to 1.64	13.1	1.5	42.2	2.3	0	37.1	—	3.9
MW09-C	1.64 to 1.97	16.5	1.2	51.3	2.1	0	27.2	—	1.7
MW09-C	1.97 to 2.3	5.7	0	79.1	1	0	12.5	—	1.7
MW09-D	2.3 to 2.62	1	1.3	56.9	2.5	0	38.7	—	0
MW09-D	2.62 to 2.95	9.2	3.6	51.4	7	0	25.1	—	3.6
MW09-E	2.95 to 3.94	10.6	5.4	62.6	7.7	0	11.5	—	2.3
MW09-E	3.94 to 4.59	11.3	2.5	36.2	5	0	41.6	—	3.4

Table A5.5. X-ray diffraction-derived mineralogy of shallow sediments obtained from open borehole and monitoring-well cores. Monitoring wells and open boreholes are prefixed with “MW” and “NB,” respectively (monitoring well SB-04 is the exception). UID = unidentified sulfate; mineral presence or absence indicated by “N” (no) and “Y” (yes) ; Tr trace; ? uncertain identification due to overlap of diagnostic peaks.

BLM Sample number	Sample depth, ft BGL	Halite	Quartz	Aragonite	Calcite	Dolomite	Total Clay	UID Sulfate	Gypsum	Mica
MW10-A t	0.5 to 1.5	16.4	2.7	57.5	5.5	2	15.9	N	0	0
MW10-A b	0.5 to 1.5	15	1.9	41.1	3.6	1.7	35.6	N	1.1	0
MW10-A t	2.5 to 3.5	17.8	2	26.5	3.7	1.7	48.4	N	0	0
MW10-A b	2.5 to 3.5	8.3	9.1	50.9	5.8	2.8	23.4	N	TR?	0
MW10-A t	5.0 to 6.0	6.2	3	42.2	5.8	4.3	36.4	Y?	2	0
MW10-A b	5.0 to 6.0	4.5	3.1	72.8	4.9	1.3	11.6	Y	1.8	0
MW10-B t	10.0 to 11.0	7.1	2.9	54.9	5.5	2.6	27	N	TR?	0
MW10-B b	10.0 to 11.0	10.7	2.6	51.2	4.9	0.9	29.8	Y	0	0
MW10-B t	16.0 to 17.0	9	10.5	33.7	4.8	9	32.9	N	1.3	TR?
MW10-B b	16.0 to 17.0	10.1	4	51	6.3	2.5	25.3	N	0.9	0
MW12	0.0 to 1.0	100	0	0	TR?	0	0	N	0	0
MW12-t	30. to 4.0	7	2.1	0	TR?	1.6	13.6	Y	75.6	TR?
MW12-b	3.0 to 4.0	4.5	6.9	0	1.5	0.6	29	N	57.5	0
MW12-t	6.0 to 7.0	5.5	1.4	0	0.9	1.4	24.8	N	65.9	TR?
MW12-b	6.0 to 7.0	4.7	1.6	49.3	1.9	1	37.8	N	3.7	0
MW12-t	15.0 to 15.5	6.5	34.5	34.9	5	1.4	26.2	Y	23	TR?
MW12-b	15.0 to 15.5	7.2	2.8	54	3.5	1.4	31.2	N	0	0
MW12-t	17.5 to 18.5	9.9	5.7	19.9	9.9	12.1	40.8	N	1.8	TR?
MW12-b	17.5 to 18.5	11.5	4.7	37.2	8	9	28.7	N	1	TR?

APPENDIX A6

Table A6.1. SNORM-generated normative content (%) of chloride and sulfate salts of sodium, potassium, magnesium and calcium from pore fluids obtained from shallow-sediment cores. Core sites included two open boreholes (NB#7B and NB#16) from the west-central periphery and one monitoring well (MW-12) from the central basin topographic low.

Sample ID	Depth in ft	Na ₂ Cl ₂	K ₂ Cl ₂	MgCl ₂	CaCl ₂	CaSO ₄	MgSO ₄	K ₂ SO ₄
MW12a	0.3 to 1.6	64.1	8.3	18.4	0	0.5	8.7	0
MW12b	4.5 to 6.5	66	6.8	14.2	0	0.5	12.5	0
MW12c	15 to 17.5	72.4	4.3	6.4	13.5	3.5	0	0
MW12	0 to 1	63.6	8.9	18.5	0	0	0	0
MW12t	3 to 4	65.3	6.7	15.6	0	0	12.4	0
MW12b	3 to 4	66.8	6.1	15.9	0	0	11.1	0
MW12t	6 to 7	73.7	6.1	10.9	0	0	9.2	0
MW12b	6 to 7	76.4	4.5	7.6	4.8	6.7	0	0
MW12t	15 to 15.5	73.9	4.6	12.8	0	7.8	0.9	0
MW12b	15.5 to 17.5	76	3.3	7.7	5.1	7.9	0	0
MW12t	17.5 to 18.5	74	4.4	10.8	2.2	8.7	0	0
MW12b	18.5	74.6	4.4	8.5	4	8.5	0	0
NB7At	0.1 to 0.2	87.1	3.4	4.8	0	4.7	0	0
NB7Ab	0.2 to 0.4	86.1	4	5.5	0	4.4	0	0
NB7B	0.4 to 0.8	86.4	4.2	5.9	0	3.4	0	0
NB7D	0.8 to 1.3	83.8	4.1	7.8	0.3	4	0	0
NB7E	1.7 to 2.1	82.4	4.1	7.7	2.2	3.6	0	0
NB7G	2.1 to 2.5	87.8	3.7	5.9	0	2.7	0	0
NB7H	2.9 to 3.3	84.7	4.1	7.4	0.65	3.2	0	0
NB7I	3.3 to 3.7	86.6	4.4	6.8	0	2.2	0	0
NB7J	3.7 to 4.1	84.1	4	7	1.5	3.3	0	0
NB7K	4.1 to 4.5	81.6	4.2	7	3.5	3.7	0	0
NB7L	4.7 to 4.9	88.9	3.9	5	0	2.1	0	0
NB16a	0.0 to 1.0	79.3	5.8	7.2	0	1.1	5.9	0.7
NB16b	1.0 to 2.0	76.9	3.6	7.7	3.7	8.1	0	0
NB16c	2.0 to 3.0	75	3.1	6.6	6.1	9.1	0	0
NB16d	3.0 to 4.0	77.2	2.1	2.6	0	10.3	6.3	1.5

APPENDIX A7

Table A7.1. Borehole stratigraphy matched to cation/anion concentration extremes, western periphery of Newfoundland Basin. BGL = Below ground level.

USGS Site Identifier	BLM Sample Number	Logged Interval, ft BGL	Cation/Anion Species Concentration Extremes		Stratigraphic Description
			Max	Min	
NB-BH-3	NB-6A	0 to 0.21	Cl, Na	Mg, K SO ₄	Salt crust (0 to 0.5 inches); very-fine clastics and oolites in tan clay matrix (0.5 to 2.5 inches/0.21 feet)
	NB-6A	0.21 to 0.42			Very-fine clastics and oolites in tan clay matrix
	NB-6B	0.42 to 0.83	Very-fine clastics and oolites in tan clay matrix		
	NB-BH-3	NB-6C&D	0.83 to 1.5		Very-fine clastics and oolites in tan clay matrix (clay has blocky appearance)
	NB-BH-3	NB-6E	1.5 to 2.0		Very-fine clastics and oolites in tan clay matrix
	NB-BH-3	NB-6F	2.0 to 2.38		Mg, K
NB-BH-3	NB-6G&H	2.38 to 3.04	Cl, Mg	Cl, Mg	Very-fine clastics and oolites in tan clay matrix interbedded with zones dominated by oolites (first water at 2.38 ft BGL)
NB-BH-3	NB-6I	3.04 to 3.52			SO ₄
NB-BH-3	NB-6J	3.52 to 4.0	K, SO ₄	Cl, Na	Fine gypsum laths supported in white clay matrix (1.0 inches), and very-fine clastics and oolites in tan clay matrix (5 inches)
NB-BH-3	NB-6K&L	4.0 to 5.0	SO ₄		White clay interbedded with zones of oolites and fine-grained gypsum laths
NB-BH-3	NB-6N	5.0 to 5.58			Fine clastics with some gypsum laths and oolites in a dark gray to black clay
NB-BH-5	NB-7A	0.0 to 0.42	Na, SO ₄ , Mg Cl	K	Clay (1.5 inches) with sand and oolites (8.5 inches)
NB-BH-5	NB-7B	0.42 to 0.83			
NB-BH-5	NB-7C&D	0.83 to 1.66			Fine sand and oolites at top, bottom in white clay with gypsum laths and fine sand
NB-BH-5	NB-7E&F	1.66 to 2.5			Fine sand transitioning to gray green clay with gypsum crystals at 2.9 feet; oolites in clay matrix at 3.25 feet BGL
NB-BH-5	NB-7G&H	2.5 to 3.25			Oolites and fine clastics to 3.66 feet; carbonate-mat fragments, oolites, and fine clastics in clay matrix to 4.0 feet; brown clay with carbonate mat fragments from 4.0 to 4.08 feet
NB-BH-5	NB-7I&J	3.25 to 4.08	K		
NB-BH-5	NB-7K&L	4.08 to 4.92		SO ₄ , Mg, Cl, Na	Gray-green clay (no gypsum laths observed); clay is prismatic and moist

Yellow highlight indicates depth to first occurrence of ground water.

Table A7.2. Borehole stratigraphy matched to cation/anion concentration extremes, central basin topographic low of Newfoundland Basin. BGL = Below ground level.

USGS Site Identifier	BLM Sample Number	Logged Interval, ft BGL	Cation/Anion Species Concentration Extremes		Stratigraphic Description
			Max	Min	
NB-BH-4	NB-8A-1 & NB-8A-2	0 to 0.54	Cl	Cl, Na, SO ₄	0 to 0.25 ft, dense cemented halite with multiple "dust" layers in first 1 inch. Crystals grade from fine (0.125-inch) to coarse (0.25-inch) at 0.25 feet BGL. First water at 1.5 inches BGL. 0.25 to 0.54 ft, coarse, porous cemented halite
NB-BH-4	NB-8B-3	0.54 to 1.54		K	0.54 to 0.88 ft, coarse, porous cemented halite with crystals becoming larger (0.375 to 0.5 inch) with depth. 0.88 to 1.25 ft, coarse, porous poorly cemented halite with friable layering. 1.25 to 1.54 ft, coarse, porous poorly cemented halite
NB-BH-4	NB-8C-2	1.54 to 2.5	K	,	Fine-grained gypsum in clay matrix
NB-BH-4	NB-8D-1	2.5 to 3.16	K		Tightly-packed fine-grained gypsum crystals (0.0625 x 0.125 inches) in clay matrix
NB-BH-4	NB-8E	3.16 to 3.66	Na, SO ₄ , Mg, K		Tightly-packed fine-grained gypsum crystals (0.0625 x 0.125 inches) in clay matrix with very-fine black organic detritus
NB-BH-7	NB-10A	0.0 to 2.17			Salt crust (26 inches thick); first water at 1.0 inches BGL
NB-BH-7	NB-10B	2.17 to 3.0	SO ₄ , Mg	Cl, Na	Fine clastics, oolites, small gypsum laths in clay matrix
NB-BH-7	NB-10C&D	3.0 to 3.75	K		Fine-grained gypsum "sand"
NB-BH-7	NB-10E&F	3.75 to 4.5			Fine-grained gypsum "sand" - grades into black fetid clay containing fine-grained gypsum "sand" at 4.5 ft
NB-BH-7	NB-10G&H	4.5 to 5.33			Fine-grained gypsum "sand" in clay matrix - dark color due to fine-grained organic fragments
NB-BH-7	NB-10I	5.33 to 6.0			Gray-green clay with larger gypsum laths distributed in clay matrix; lath size ranged from 0.1875 to 0.375 in.
NB-BH-7	NB-10I	6.0 to 6.25	Cl, Na	SO ₄ , K	Gray-green clay with larger gypsum laths distributed in clay matrix; lath size ranged from 0.25 to 0.375 in.
NB-BH-7	NB-10I	6.25 to 6.5		Mg	Gray-green clay with larger gypsum laths distributed in clay matrix; lath size ranged from 0.25 to 0.375 in.

Yellow highlight indicates depth to first occurrence of ground water.

Table A7.3. Borehole stratigraphy matched to cation/anion concentration extremes, adjacent to inlet canal on southern periphery of Newfoundland Basin. BGL = Below ground level.

USGS Site Identifier	BLM Sample Number	Logged Interval, ft BGL	Cation/Anion Species Concentration Extremes		Stratigraphic Description
			Max	Min	
NB-BH-15	NB-16A	0 to 1.0	Cl, Mg, K		Top of core sample in wet clay; bottom of core sample in oolites with clay matrix
NB-BH-15	NB-16B	1.0 to 2.0		Na, SO ₄	Bottom of core in oolites with clay matrix
NB-BH-15	NB-16C	2.0 to 3.0		Mg, K	Bottom of core in alternating layers of oolites in clay matrix and layers of clay
NB-BH-15	NB-16D	3.0 to 4.0	Na, SO ₄	Cl	Top 9 inches of core in oolites with clay matrix; lower 3 inches of core in dirty, fine-grained sand with ostracods - has olive-gray clay matrix
NB-BH-17	NB-18A	0 to 1.0	SO ₄	Mg, K	Light-gray silty clay
NB-BH-17	NB-18B	1.0 to 2.0	Cl, Na, Mg		Light-gray silty clay with sandy oolites from 1.67 to 2.0 ft; Note: first water at 2.0 ft BGL
NB-BH-17	NB-18C	2.0 to 3.0	K	Cl, Na, SO ₄	Alternating light-gray sandy clay and oolites from 2.0 to 2.33 ft; olive-green to gray clay from 2.33 to 3.0 ft

Yellow highlight indicates depth to first occurrence of ground water.

Table A7.4. Borehole stratigraphy matched to cation/anion concentration extremes, SSP monitoring wells from north end of inlet canal to MW-12. BGL = Below ground level.

USGS Site Identifier	BLM Sample Number	Logged Interval, ft BGL	Cation/Anion Species Concentration Extremes		Stratigraphic Description
			Max	Min	
NB-MW09A	MW09	0.0 to 0.5	Mg, SO ₄		Salt crust 0.0 to 0.33 ft; light gray to white clay with zones of oolite "sand" 0.33 to 0.5 ft
NB-MW09A	MW09	0.5 to 1.0	Na		Light gray to white clay with zones of oolite "sand" 0.5 to 1.0 ft
NB-MW09A	MW09	1.0 to 1.5	Cl, K		Alternating light gray and oolite "sand" (brine saturated)
NB-MW09A	MW09	2.0 to 3.0			Light gray clay
NB-MW10A	MW10	0.0 to 0.0625	SO ₄ , Mg, K		Salt crust
NB-MW10A	MW10	0.0625 to 0.1	SO ₄ , Mg, K		Fetid organic clay (wet)
NB-MW10A	MW10	0.1 to 0.83	Cl, Na, SO ₄ , Mg, K		Tan clay with curd-like texture (wet)
NB-MW10A	MW10	0.83 to 1.0	Cl, Na		Carbonate fragments from algal mat material in clay matrix
NB-MW10A	MW10	1.0 to 1.1			Greenish-tan clay (damp)
NB-MW10A	MW10	1.1 to 1.33			Carbonate fragments, vuggy & angular in a matrix of oolites & minor clay (wet)
NB-MW10A	MW10	1.33 to 2.0			Tan clay with faint layering (damp)
NB-MW10A	MW10	5.0 to 6.0		Mg Cl, Na, SO ₄ , Mg, K	Gray and tan varved clay
NB-MW10B	MW10	10.0 to 11.0			Wet dark gray clay with toothpaste consistency
NB-MW12A	MW12	0 to 1.67	K		Salt crust
NB-MW12B	MW12	1.67 to 2.0			Fine clastics and oolites
NB-MW12B	MW12	2.0 to 2.67			Fine clastics (silty sand?) with some clay
NB-MW12B	MW12	2.67 to 3.17	SO ₄ , Mg		Fine clastics and abundant gypsum laths (0.125 X 0.25 inch)
NB-MW12B	MW12	3.17 to 3.42	SO ₄ , Mg		Coarse sand
NB-MW12B	MW12	3.42 to 3.5	SO ₄ , Mg		Gray-green clay
NB-MW12B	MW12	3.5 to 3.92	Mg		Fine clastics mixed with gypsum laths (0.125 X 0.25 inch)
NB-MW12B	MW12	3.92 to 4.08	Cl, Mg		Dominantly gypsum lath
NB-MW12B	MW12	6.0 to 7.0t	Na		Gray-green clay with abundant doubly-terminated gypsum laths; laths increasing in size (0.5 X 0.5 inch); clay difficult to cut with auger because of gypsum laths
NB-MW12C	MW12	15.0 to 15.5b		K	Wet dark gray clay with toothpaste consistency
NB-MW12C	MW12	17.5 to 18.5t		Cl, Na Mg	Wet dark greenish-gray clay with toothpaste consistency
NB-MW12C	MW12	17.5 to 18.5b		Cl, SO ₄	Wet dark greenish-gray clay with toothpaste consistency

APPENDIX A8

Table 8A.1. Time versus displacement of rising head from open borehole aquifer tests, and comparison of recovered head versus starting static water level (Rec/STWL).

NB#6		NB#7B		NB#2		NB#11B		NB#12		NB#13	
Time, min	Depth, ft	Time, min	Depth, ft	Time, min	Depth, ft	Time, min	Depth, ft	Time, min	Depth, ft	Time, min	Depth, ft
0.0	4.0	0.0	1.5	0.0	8.8	0.0	0.75	0.0	1.5	0.0	0.438
1.75	2.75	0.25	1.292	4.0	7.0	0.0833	0.708	0.25	1.291	0.166	0.417
2.25	2.4	0.5	1.083	7.5	5.1	0.166	0.646	0.5	1.25	0.25	0.375
3.0	2.05	0.75	1.042	9.0	4.42	0.25	0.563	0.75	1.166	0.33	0.354
3.25	1.97	1.0	0.958	10.5	3.95	0.333	0.5	1.0	1.104	0.417	0.354
3.5	1.87	1.25	0.917	11.8	3.68	0.417	0.479	1.25	1.083	0.5	0.333
3.75	1.83	1.5	0.875	13.3	3.48	0.5	0.438	1.5	1.083	0.583	0.333
4.0	1.77	1.75	0.875	14.5	3.37	0.583	0.417	1.75	1.083		
4.25	1.69	2.0	0.865	16.0	3.26	0.666	0.396	3.0	1.083		
4.5	1.62	2.25	0.865	17.5	3.20	0.75	0.375				
4.75	1.57	2.5	0.854	19.0	3.15	0.833	0.354				
5.0	1.51	3.0	0.833	20.3	3.10	0.917	0.333				
5.25	1.47	3.25	0.833	22.5	3.07	1.0	0.323				
5.5	1.43	4.0	0.833	23.7	3.05	1.166	0.313				
5.75	1.40			26.0	3.02	1.333	0.292				
6.0	1.36					1.5	0.292				
6.25	1.32										
6.5	1.28										
7.0	1.23										
8.0	1.12										
9.0	1.04										
10.0	0.97										
12.0	0.86										
14.0	0.77										
16.0	0.71										
20.0	0.62										
24.0	0.54										
STWL	0.583		0.875		3.05		0.25		1.0		0.333
Rec/STWL	0.93		0.95		0.99		1.17		0.92		1.0

APPENDIX A9

Table A9.1. Transmissivity and hydraulic conductivities of shallow sediments penetrated by five boreholes sited along the inlet canal on southern periphery, and one borehole (NB#7B) on western periphery of Newfoundland Basin. These shallow-brine aquifer properties were determined by analysis of specific capacities using TGUESS, version 1.2.

Input/Output	NB#2	NB#3	NB#7B	NB#11B	NB#12	NB#13
Input Data:						
Well diameter, in.	3	3	3.625	4.625	4.625	4.625
Static water level (STWL), ft	1.208	1.5	0.875	0.25	1.0	0.333
Depth to water during test (DTW), ft	1.333	1.96	1.5	0.75	1.5	0.4375
Test duration, h	0.4	0.05	0.066	0.025	0.05	0.0097
Pump rate, gpm	0.176	1.4	1.218	1.07	1.35	1.995
Aquifer thickness, ft	6.164	6.33	4.417	3.75	5.33	6.167
Screen length, ft	6.164	6.33	4.417	3.75	5.33	6.167
Storage coefficient	0.001	0.001	0.001	0.001	0.001	0.001
Well-loss coefficient	1	1	1	1	1	1
Output/Results:						
Specific capacity (Q/d), gpm/ft	1.408	3.044	1.949	2.140	2.700	19.095
Transmissivity (T), ft ² /sec	0.003357	0.006491	0.003949	0.003766	0.005242	0.03824
Hydraulic conductivity (K) ft/sec	0.0005446	0.001025	0.0008942	0.001004	0.0009835	0.006201
Number of iterations	4	4	4	4	4	5