IDENTIFICATION OF A NATURAL SOIL-WATER TRACER
AT AN
ANCIENT INDIAN MIDDEN

by

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Abstract

An interdisciplinary effort of hydrology and archaeology is currently under way to use an ancient Indian midden as a natural analogue for low-level radioactive waste sites in semi-arid regions. As part of this effort, investigations were conducted to determine a natural soil-water tracer and the recharge rate at a semi-arid site in central New Mexico. Archaeologists associated with the project determined the age and length of occupation of the pueblo, two key criteria upon which the site was chosen. Location, abundance of midden deposits, and depth to bedrock and/or ground water were also important factors in choosing the study area. Archaeologic excavations were conducted to determine locations of thickest midden deposits and midden content. It is within such locations the Cl/Br tracer was found at depth. Cl/Br was chosen as a tracer due to several limiting factors. Chief among these is that the tracer had to occur naturally, a result of the leaching of midden materials. High sulfate content in the soils at the site prevented the use of sulfate as a tracer, and chloride was not deposited in sufficient amounts to detect a peak higher than background soil-water chloride concentrations. However, a source of high Cl/Br ratios could be found in the salt used by the occupants of the pueblo, and in their excrement. Salt collected from two locations of known pre-historic use were analyzed for Cl/Br. The analyses indicate Cl/Br ratios range from 12,000 to 32,000. Cl/Br ratios in modern human excrement vary from approximately 200 to 3000 depending upon the diet of the individual. Excrement ratios of pueblo occupants would likely vary as well depending upon their diet. Assuming a source of high Cl/Br ratios, soil boring samples were collected at 14 locations and analyzed via high pressure liquid chromatography to determine the depths to which a Cl/Br tracer had moved in the subsurface.

At two locations, the Cl/Br tracer had peak ratios of 130 to 160 in the subsurface, higher than precipitation and soil background Cl/Br ratios of 63 ± 14.7 and 86 ± 14.3. The results of the investigations indicated the Cl/Br tracer had moved to a depth of approximately 1.1 to 1.3 m below the surface of deposition over a period of approximately 545 to 695 years (time since pueblo occupation). This results in a mean recharge rate of 6.6×10^{-3} m/yr based on Cl/Br profiles. This is approximately double the recharge rate of 3.2×10^{-3} m/yr calculated using the chloride mass balance method. Recharge rates were calculated using estimates of precipitation and chloride concentration in precipitation, therefore, some error is associated with the calculation. These uncertainties will be addressed in the next phase of the investigation.

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Okay Mom, you can get that new car now.

1.0 INTRODUCTION

Determination of recharge rates in arid and semi-arid environments has long been a focus of attention. The popularity of these environments as settings for various types of landfills has revealed a dearth of information regarding several hydraulic characteristics, including recharge rates. The most popular method for determining long-term (on the order of hundreds to thousands of years) recharge rates is the use of chloride as a soil-water tracer and the application of the chloride mass balance method. However, this method may be subject to error. The chloride mass balance method assumes chloride is a conservative tracer, and that the most significant source of chloride is that found in precipitation. Chloride from sources other than rainfall may be added to the system, thereby introducing uncertainty regarding chloride depositional rates. Chloride could perhaps also be retarded by anionic forces associated with high-surface area clays, or passed through larger pores at a faster rate than percolating soil-water (M. Ankeny, personal communication, 1995). Additional soil-water tracers such as atomic-bomb produced isotopes have also been used to estimate recharge rates. However, these are reliable only insomuch as they can be applied over the past 30 to 40 years. A more accurate estimate of recharge rates may be found by locating a system in which a soil-water tracer has been introduced to the system and has moved to a depth determined naturally by the system, over an extended period of time. Such a site may also be used as an analogue for modern day solute transport.

Currently, there is no natural analogue for low-level radioactive waste sites in which solute flow and transport predictions are made over an intermediate time range (several hundreds of years). Vadose-zone flow and transport models are used to make predictions for these sites, but without an analogue there is no real-life example for these models to be calibrated against and verified. Therefore, the worst-case and more expensive scenarios are often used in the design and construction of low-level waste sites. By providing a natural analogue for low-level waste sites of intermediate time scale solute flow and transport, against which these models can be calibrated and verified, a more accurate outcome of solute transport could be predicted. At the same time, validation and establishment of confidence in vadose-zone and solute transport models can be established.

From August 1993 to August 1995, soil samples were collected and analyzed to determine the identity of a natural soil-water tracer generated by an ancient Indian midden. The midden and adjoining pueblo are collectively known as Fernandez Pueblo (Socorro County, NM). Samples were collected from hollow-stem auger, air-rotary, and hand-auger boreholes, and during archaeologic excavations. These samples were analyzed for the presence of chloride, bromide, and ultimately nitrate, soil-water tracers that would likely be present in the refuse deposited in the midden. The ratio of chloride to bromide proved to be the most reliable natural tracer.

Chloride and bromide deposition occurs from various sources including precipitation, dryfall, release from decaying flora and/or fauna, and anthropogenic or animal sources. For the pueblo occupants, salt is most likely the main (and perhaps only) source of chloride and bromide, and salt has a high Cl/Br ratio associated with it. Salt had a variety of uses among the inhabitants of the pueblo. It was used in drying meal, preparing jerky and curing animal hides, but mostly it was used to provide flavoring in cooking (D. Chapman, personal communication, 1995). As salt was a valuable commodity, it is likely that not much salt would have been wasted or thrown into the midden. Thus, the appearance of this distinctive Cl/Br ratio would be subtle. It was also possible that, in the midden deposits, human excrement would provide an alternate source of chloride and bromide. If a latrine location which the inhabitants used could be located, this location could be sampled and the movement of the chloride/bromide peak could be traced. The Cl/Br ratio in urine may vary from 200 to 3000, depending on the modern individual's diet (Sangster et. al., 1983). There is no method of determining whether these ratios would be valid for inhabitants of the pueblo, however it would probably be not far wrong to say the Cl/Br ratio in the excrement of the pueblo inhabitants was also higher than a measured rainfall ratio of 63. It was necessary to determine the influence of cattle at the site as well, as any excrement left by the cattle may have affected the ratio seen in the subsurface. Given the differences in the ages of deposition, any influence from the cattle should be seen at a shallower depth in the subsurface.

At an "uncontaminated" location where the only source for chloride and bromide in the subsurface is assumed to be rainwater chloride and bromide, a decrease or increase in the chloride/bromide ratio away from that found in rainwater would indicate other sources of input for chloride or bromide. Conversely, it could indicate sinks for one ion relative to the other. At Fernandez Pueblo, it was determined that subtle increases in the Cl/Br ratio at two locations in relatively dense midden deposits were most likely the result of midden materials (salt and/or excrement) and their subsequent leachate. By analysis of samples collected throughout the soil profile, the depth to which the tracer had traveled could be identified, and the recharge rate determined. Once the recharge rate was determined, the site could be used as a natural analogue for low-level waste sites.

Dryfall measurements of chloride and bromide were not made at the site. Given the remoteness of the site, chloride and bromide sources found in metropolitan areas would likely contribute negligible amounts. However, the effects of windblown particulates is also not known, but on the basis of results for several hand-auger holes the effects appear negligible.

1.1 Related Research

There has been little use of natural analogues for the validation of intermediate time scale vadose-zone and solute transport models. Most of the analogue studies conducted have been toward validating large time-scale (on the order of thousands of years) ground-water models. There have been investigations using chloride and bromide or a combination of the two as tracers. Some of these studies have involved the use of Br/Cl ratios in assessing the extent of brackish-water intrusion (Fleck, 1990), or the use of Cl/Br ratios in tracking irrigation return flow (Hess, 1992). Br/Cl ratios are being used to assess the validity of the chloride mass balance approach in determining recharge rates at the Yucca Mountain site (J. Fabryka-Martin, personal communication, 1995). Cl/Br ratios are also being used to study the effects of "ultrafiltration" on anions in the vadose zone (M. Ankeny, personal communication, 1995). Altman and Kump (1994) studied the movement of chloride, bromide, and nitrate in the riparian zone. They determined that bromide, chloride and nitrate exhibit non-conservative behavior in the near surface zone that fluctuates between saturation and unsaturation.

1.2 Project Background

Winograd (1987) stated that the task of predicting the effects of buried wastes on the environment is a transscientific one. While mathematical models and short term field and laboratory experiments can be used to predict the fate of buried wastes, the archaeologic record provides an actual, tangible record in which the ability of the unsaturated zone in arid and semi-arid regions to isolate solidified wastes can be examined. To use Fernandez Pueblo as a natural analogue for low-level waste sites therefore required interdisciplinary cooperation between archaeologists and hydrogeologists.

Separate goals were therefore associated with this project. The original and present-day mass and composition of the midden had to be ascertained (the source term of the tracer could then be defined), and the age of the midden had to be established. This task was the responsibility of archaeologists associated with the University of New Mexico Office of Contract Archaeology and Department of Anthropology. The physical, hydraulic and geochemical properties of the subsurface had to be characterized by the hydrogeologists. Solute distribution in the subsurface (i. e., the tracer) and the recharge rate had to be determined as well. Using these properties attempts to simulate solute movement in the given time frame, i.e., the age of the pueblo, would be completed using a variety of flow and transport models such as SWMS2D and/or SWAP (D. Dolmar, personal communication, 1995). Finally, in an effort to validate the model, the model predictions would be compared to real-life solute distributions. Objective model validation strategies would then be employed to identify useful predictive models for performance assessment (J. McCord, personal communication, 1993).

1.3 Research Objectives

The goal of the research described in this paper was two-fold. The first task was to determine what could be used as a soil-water tracer. Once a potential soil-water tracer was identified through laboratory analyses, a distribution of that tracer was sought in the subsurface. When and if the proposed tracer was found in the subsurface, the second task was to determine a recharge rate based upon the depth at which the peak concentration of the tracer was found and the elapsed time since deposition of the source material.

Identifying a suitable soil-water tracer and locating this tracer in the subsurface were performed in conjunction with one another. Conversations with the OCA archaeologists would determine that the location of an urinal used by the pre-historic occupants was unknown. Therefore, the biggest hurdle to overcome was locating a tracer in the subsurface, as nothing was known about the site or location of the midden deposits. It is in the location of the thickest midden deposits that the tracer was finally located in the subsurface. Once the tracer was located, the recharge rate was determined.

Determination of a suitable soil-water tracer is discussed in Appendix A. What follows is a discussion of the site itself, the field and laboratory methods applied in this project, and the results of our work.

2.0 FIELD SITE CHARACTERISTICS

2.1 Site Selection

There were several factors to be considered in the selection of a study area. To have sufficient build-up of leachable material, the site had to have undergone long-term and intensive occupation. The period of occupation at the pueblo had to have a relatively definite beginning and end, which would allow archaeologists to accurately date the age of the midden deposits and the length of occupation. The pueblo and midden deposits also had to be geologically located above unsaturated, unconsolidated deposits, allowing for vertical flow. Depth to groundwater and/or depth to bedrock had to exceed the depth any potential tracer may have traveled since the time of occupation. Finally, the site had to be relatively inaccessible to the public, so there would be no influence of their activity. At the same time, however, the site had to be relatively accessible for research and field work.

Several sites were considered for investigation. Fernandez Pueblo was chosen as the study area as it was the only site which appeared to meet the requirements listed above. For additional information on the inhabitants of Fernandez Pueblo, the reader is referred to Appendix B.

2.2 Fernandez Pueblo

Fernandez Pueblo, also known as LA 781 in the New Mexico Laboratory of Anthropology numbering system (W. Doleman, personal communication, 1995), is located in the SE 1/4, NW 1/4, SW 1/4 & SW 1/4, NE 1/4, SW 1/4 of Section 27, T3S, R5E, (Section 27, Orndorff Ranch, NM, 7 1/2 minute quadrangle) Socorro County, New Mexico. The midden and adjoining pueblo are collectively known as Fernandez Pueblo, and are located in Socorro County, NM (Figure 2-1). Cattle freely graze over the area, which is administered by the Bureau of Land Management (BLM). The site elevation is approximately 1650 m above mean sea level.

Fernandez Pueblo consists of a large masonry pueblo made up of four large house mounds with northern and southern village areas (Doleman, 1995). Room blocks (i.e. floors and walls) are constructed of adobe, sandstone and conglomeratic blocks and slabs. Figure 2-2 provides a more detailed map of the pueblo and the estimated extent of midden deposits. The masonry of the pueblo itself is covered, being exposed only where four bulldozer trenches were created in the early 1970's during a pothunting expedition (D. Siegal, personal communication, 1993). In 1994 and 1995 archaeologic investigations were conducted at Fernandez Pueblo by the OCA archaeologists. Hand auger holes and test pit excavations revealed substantial midden deposits flanking the northeastern portion of the pueblo mound. Midden deposits are up to 1.3 m thick in this area, and appear to be thinnest east and southeast of the pueblo mound. Thickness of midden deposits vary as some midden material appears to have been re-deposited at locations further downslope from the pueblo. At a distance of 50 to 100 m from the pueblo, from south to north, intact midden is absent (Doleman, 1995) and appears to consist of re-worked materials. The midden surface is located approximately 20 to 40 cm below ground surface (bgs). Midden deposits contain waste and cultural material created during occupation of the pueblo, just as any modern-day landfill would contain wastes from a modern city. Bone fragments from various species of mammals, ceramic potsherds, charred remains of corn, beans, squash, fuel wood, and various

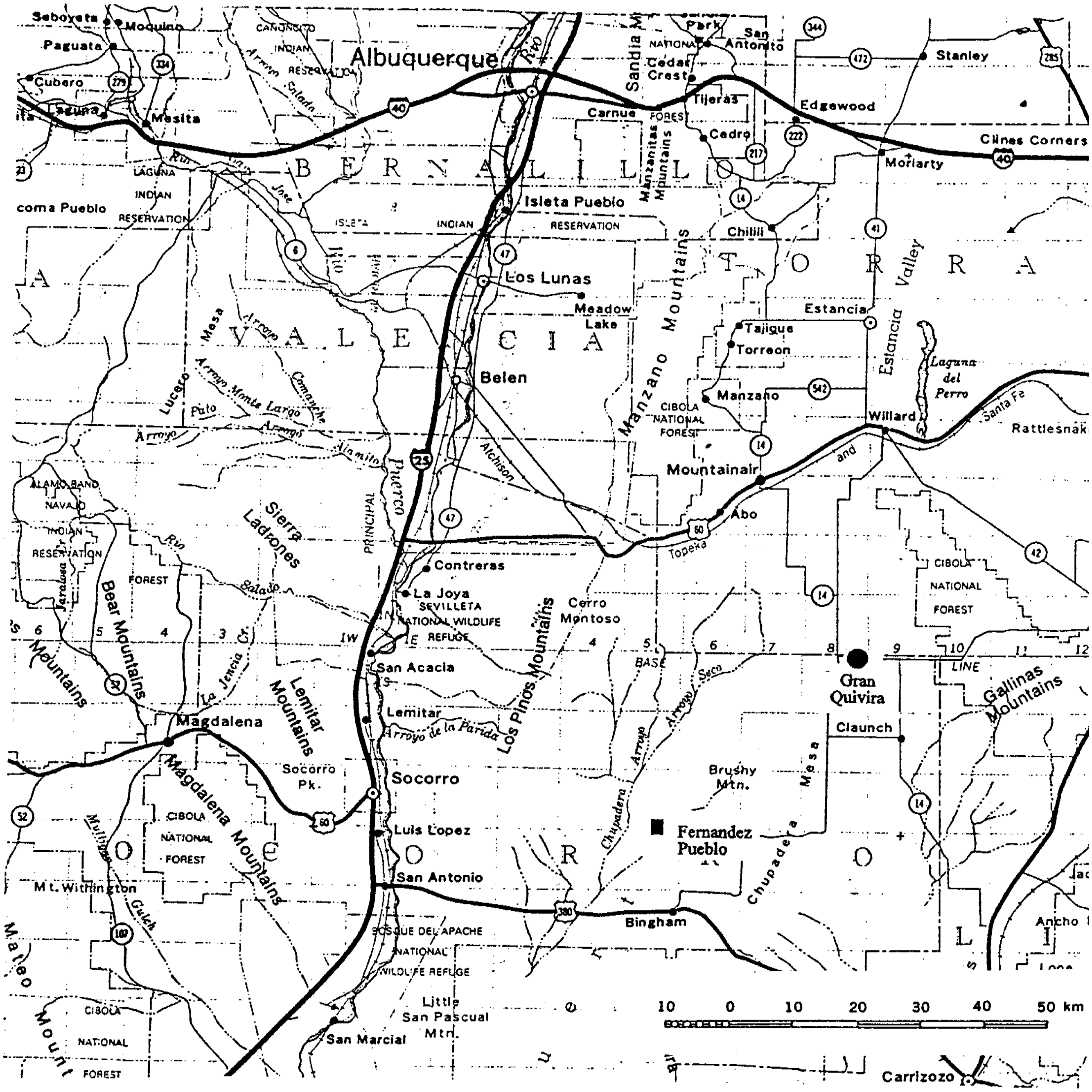

Figure 2-1. Location Map of Fernandez Pueblo and Gran Quivira

NMBMMR Resource Map
New Mexico Topographic Map, 1983 ed.

Figure 2-2. Detail Map of Fernandez Pueblo and Midden Extent

▨ Pueblo/Exposed Room Blocks

☐ Midden Material/ Cultural Debris

lithic fragments such as arrowheads and building stone are present. It is possible that human remains may also be interred in the midden, a common practice of the Anasazi culture.

Ages of occupation are quite often established on the basis of potsherds littering the surfaces of these sites. At Fernandez Pueblo the presence of two types of these, solid Glaze A Pueblo IV and Chupadero black-on-white, indicate that Fernandez Pueblo was occupied from about AD 1300-1450. Pithouse structures buried underneath midden deposits were revealed when two backhoe trenches were dug at the site. These structures represent earlier Anasazi occupation of the region, dating perhaps as early as AD 900 (D. Chapman, personal communication, 1995).

2.3 Geology

2.3.1 Structural Geology

The topography of the study area is characterized by rolling hills, shallow playa basins, and low ridges. Fernandez Pueblo sits atop one of these low ridges between two playa basins, on the western flank of the Torres Syncline. The Torres Syncline is part of a series of north-northeast trending folds created during the Laramide Orogeny and includes the Prairie Springs Anticline to the west, and the Oscura Anticline to the east of the study area (C. Treadwell, personal communication, 1995). The Torres Syncline is the northern extension of the large syncline that lies beneath the Jornada del Muerto, a graben basin which drains primarily to the south and west. Within the Jornada are a series of ephemeral lakes or playas which are fed by intermittent drainage carrying surface run-off (Shelley et al, 1989). The Los Pinos Mountains to the west, and Chupadera Mesa and the Oscura Mountains to the east form the boundaries of the Jornada del Muerto in this area. The Capitan Lineament is located south of the study area and is an alignment of faults and outcrops, and may affect the regional flow of groundwater. Intrusive material may also be present in the study area as part of a series of Tertiary dikelets which run parallel to the Capitan Lineament.

2.3.2 Stratigraphy

Stratigraphy in the area of Fernandez Pueblo consists of three units: the upper unit of the Triassic non-marine Dockum Formation (correlable to Triassic Chinle Formation west of the study area, C. Smith, personal communication, 1995), lacustrine Eocene Baca Formation, and Quaternary alluvial sands and local colluvium. The units are unconformably associated, and dip generally to the east, indicating the axis of the Torres syncline is to the east of the pueblo (opposite that shown in Figure 2-3).

As shown in Figure 2-3, predominantly Quaternary aeolian deposits overlie the Dockum Formation in the study area. At Fernandez Pueblo, the upper (degraded) shale unit of the Dockum Formation is present, and consists of purple to reddish-purple clays with lenses of coarse to medium grained purple sandstones and conglomerates (C. Treadwell, personal communication, 1995), and rare lenses of green clays. It is within this unit that a confined aquifer underlying the study area appears. Not shown in Figure 2-3 is an apparent outcrop located in the central portions of the pueblo mound. The surface of the pueblo mound is littered with several types of rock material: sandstones, mudstones, and conglomerates. The sandstones, mudstones and conglomerates are likely representative of the Dockum Formation, which underlies the site. The lacustrine/non-marine Baca Formation is characterized by pinkish and yellow-orange sands, and reddish silty and sandy clays interbedded with evaporite (gypsum) layers. The sands and possibly the clays associated with

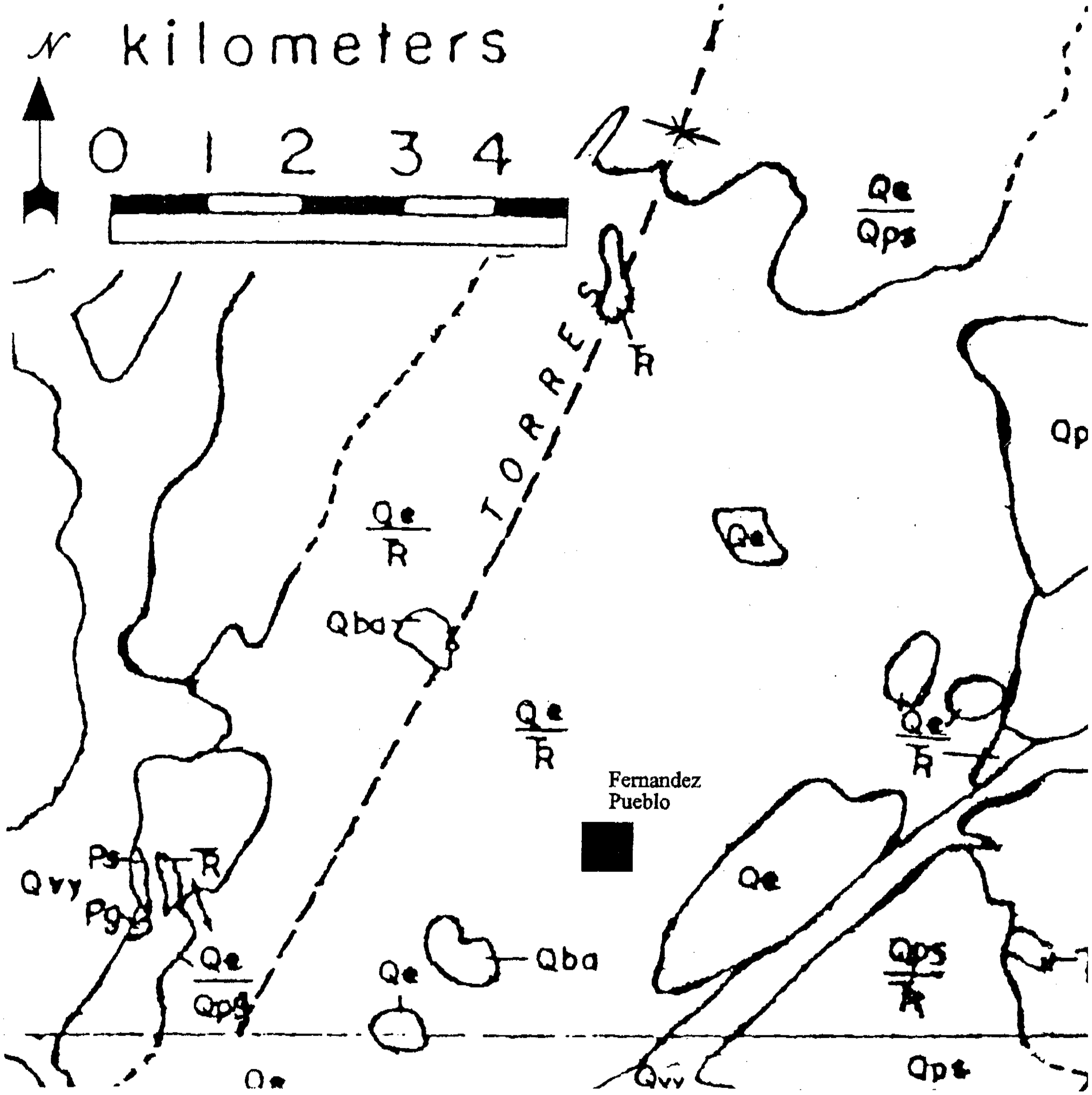

Figure 2-3. Local Geologic Map

Qba - Basin floor sediments
Qe - Eolian sand
Qvy - Alluvial and colluvial deposits of major stream valleys
Qps - Undivided piedmont-slope alluvium
T_R - Triassic rocks consisting of mudstones, siltstones and red to purple mudstones
Ps - San Andres Limestone
Pg - Glorieta Sandstone

Source: NMBMMR Open File Report #238

the Baca Formation thin and disappear as one moves towards the outcrop from the east. Red aeolian sands cover the study area today, and were most likely deposited after the time of occupation at the pueblo. Since that time, these sands have mixed with underlying midden material, and in some cases washed down the slopes of the pueblo, forming local colluvium. The sand and colluvium layer is thickest near the eastern slopes of the pueblo, then thins to the east away from the pueblo, leaving Baca Formation at the near-surface.

Outcrops of Pennsylvanian San Andres gypsum are located to the northwest, west and southwest of the Pueblo. They are extensive and it is possible this unit contributes the sulfate that exists in the subsurface (B. Colpitts, personal communication, 1993), however it is more likely that sulfate found underlying the site is related to the evaporite layers associated with the Baca Formation. In the general region, there are also efflorescing salts which "grow" on shale and mudrock. There is no relation between these salts and the gypsum from the Pennsylvanian San Andres (B. Colpitts, personal communication, 1993), but may perhaps be genetically related to the subsurface evaporite layer.

With respect to the chloride/bromide tracer, Bowen (1979) states that while evaporites and marine formations may contain significant amounts of chloride and/or bromide, non-marine siliceous formations usually do not contain significant amounts of either ion. This does not preclude the possibility that formations may contribute whatever chloride and bromide they contain to the soil-water content. It is therefore necessary to determine background chloride and bromide concentrations at Fernandez Pueblo. This aspect is discussed further in Section 4.0.

2.4 Climate, Flora and Fauna

Shelley et. al., (1989) provide an excellent description of climate, flora and fauna in the region of Fernandez Pueblo. They describe the region as experiencing relatively hot summers and moderately cold winters, based upon data recorded from 1931-1952. Mean maximum temperature in July is 34.4° C, and mean minimum temperature in January is -5.6° C. There are no average annual precipitation measurements recorded in this area, but precipitation data for Gran Quivira (Figure 2-1) from 1930-1983 indicate an average rainfall of 36 cm (Kunkel, 1984). Average rainfall in Socorro for the same period is approximately 23 cm. Fernandez Pueblo lies between the two areas; therefore the average rainfall at the site is estimated as 30 cm. There have been no significant climatic changes since the Indians last inhabited the Pueblo (F.M. Phillips, personal communication, 1995).

Grasses and shrubs dominate the vegetation at Fernandez Pueblo. Sparse gramas such as blue, black and sideoats gramas (*Bouteloua*) are found on sandy slopes. Sand sage (*Artemisia filifolia)*, various yuccas (*Yucca*), and an occasional juniper (*Juniperus monosperma*) are interspersed with prickly pear cactus (*Opuntia macrocentra*), and creosote bushes (*Larrea tridentata*). At higher elevations denser stands of juniper and pinyon pine (*Pinus edulis*) are present.

Various species of mammals, reptiles, and birds are present in the study area. After heavy precipitation events, several varieties of amphibians are also present. Representative species include the pronghorn antelope (*Antilocarpa americana*), black-tailed jackrabbit (*Lepus californicus*), red-tailed hawk (*Buteo jamaicensis*), common crow (*Corvus *brachyrhynchos*), and whiptail lizard (*Cnemidophorus* sp.). The domestic cow and horse (*Bos* sp. and *Equus caballus*) are common grazers in the area.

3.0 METHODS

3.1 Field Work

From August 1993 through August 1995 field investigations were conducted at Fernandez Pueblo and the surrounding area. Additional field work included the collection of salt from known sources which may have been visited by the inhabitants of Fernandez Pueblo. For salt collection and Cl/Br information, the reader is referred to Appendix C. Field work and destructive sampling (disturbance of surface and subsurface soils) was conducted in basically three stages: (1) An initial site investigation and collection of background samples, (2) an initial archaeologic investigation from which several hand-samples were collected and analyzed, investigative boreholes to determine the influence of cattle excrement in the subsurface, and the installation of a monitoring well at Fernandez Pueblo; and (3) destructive sampling within the midden. Borehole drilling was conducted using two methods, hollow-stem auger and air-rotary. Additional samples were collected by hand augers or Veihmeyer tubes (SoilTest, Carlsbad, CA). All samples were analyzed for chloride, bromide, and gravimetric water content. Samples collected from within the midden were analyzed for nitrate-N as well. Locations for all boreholes and hand-auger holes are shown in Figure 3-1. For clarification, Table 3-1 presents an inventory of destructive sampling by New Mexico Tech personnel at Fernandez Pueblo. Lithologic logs from all boreholes and midden hand-auger holes are provided in Appendix D.

3.1.1 Hand and Hand Auger Samples

A number of samples were collected by hand. These included samples collected during initial hydrologic and archaeologic characterizations at the site, and subsequent hand

Table 3-1

Inventory of Destructive Sampling at Fernandez Pueblo and Surrounding Areas

Drilling Rig Boreholes:

Hollow-Stem Auger:

BH- 1
BH-2
BH-3
BH-4
North Windmill
South Windmill

Air-Rotary Boreholes:

MW-1
TP-B-103
TP-B-106
TP-B-107
TP-B-118
TP-B-123
TP-B-71
TP-B-72

Hand Auger Holes

10 cm bucket:

AH-1
AH-2
AH-3
TP-A-103
SU 72 NE
TP-A-106A
TP-A-106B
TP-A-107
TP-A-118
SU 72 SE
TP-A-123
TP-A-71
TP-A-72
EM-1
SU 72 Pit

Veihmeyer tube:

Cl-1
Cl-2
Cl-3

auger samples collected at the test pits cleared by the archaeologists. Hand auger samples were collected using a 10 cm diameter bucket in 15 cm intervals. Veihmeyer samples were collected using a 2.1 cm tube in 15 cm intervals. Samples were stored in labeled, double-bagged one quart plastic bags. Samples contributed by OCA archaeologists were gathered from five of the most artifact-abundant "strats" or levels in three 1 m by 1 m test pits at the site. These samples were stored in labeled paper sacks.

Background soil samples were collected using a Veihmeyer sampling tube in October 1993. Three random sampling locations were chosen on the west side of the midden, the preponderance of midden material being found on the east side of the pueblo. These hand auger holes are known as Cl-1, Cl-2, and Cl-3. Approximately 60-80 grams of intact soil were collected during each sampling interval. The amount of soil collected varied with depth due to the hardness of the soil and the compaction occurring within the tube. Depths of each hole varied and was controlled by the hardness and thickness of the evaporite layer. Cl-1 was sampled to a depth of 183 cm. Cl-2 and Cl-3 were drilled to depths of 228 cm and 175 cm, respectively.

Thirteen hand-auger holes were drilled using a 10 cm-diameter bucket auger. Three were drilled as background holes, as inconclusive laboratory results from the Veihmeyer samples necessitated collection of further background samples. These hand auger holes were completed in July 1994 and are known as AH-1, AH-2, and AH-3. They were drilled at three separate locations on the west side of the pueblo, each to a depth of 198 cm bgs. Hardness of the evaporite layer prevented further penetration.

Three investigative hand-auger holes were drilled near or in Test Pit 72 (shown as TP 72 in Figure 3-1) to determine if Cl/Br ratios were significantly different than those found in background holes off-site. The auger holes were drilled during the archaeologic investigation in May 1994. Hand auger holes were drilled in locations cleared by the archaeologists at points north and south of the test pit. These holes, known as SU 72 NE and SU 72 SE, are relatively shallow, drilled to depths of 59.7 cm and 43.3 cm. An additional auger hole, known as SU 72 Pit, was drilled at the bottom of the cleared pit once sterile soil was reached, over an interval of 137 to 244 cm bgs. These samples were collected in irregular intervals, presumably at the change in lithology.

The remaining seven hand auger holes were drilled in February 1995, just outside the boundaries of seven excavated 1 m by 1 m test pits. These locations are known as TP-A-71, TP-A-72, TP-A-103, TP-A-106, TP-A-107, TP-A-118 and TP-A-123. These auger holes were actually drilled just outside each pit as the objective was to collect undisturbed samples in the first one to one-and-a-half m bgs. Depth at each hand auger hole varied, depending on the hardness of the evaporite and whether or not boulders were encountered in the subsurface. Deepest hand auger holes were TP-A-71 and TP-A-103 with depths of 305 cm. TP-A-72 was drilled to a depth of 264 cm, TP-A-118 to a depth of 259 cm, and TP-A-107 to a depth of 221 cm. TP-A-123 was drilled to a depth of 137 cm. Two auger holes were drilled at TP-A-106. Penetration to a depth of 130 cm for the first auger hole, TP-A-106A, prompted a second hole, TP-A-106B. TP-A-106B was drilled to a depth of 175 cm. Two auger holes drilled in such close proximity, less than 30 cm apart, allowed spatial comparisons of chloride and bromide to be made.

3.1.2 Hollow-Stem Auger Boreholes

Six boreholes were drilled using the hollow-stem auger method. Four were drilled during the initial investigation of the site. Two were drilled at locations known as North and South Windmill for the investigation of Cl/Br ratios associated with cattle excrement. An A-2 Acker, hollow stem auger rig with a 15-cm diameter bit was used to drill these boreholes. The hollow-stem auger method allowed collection of intact samples at depths just above the water table during the initial investigation. Borehole samples were collected in approximately 1.5-m intervals or at the change in lithology. All samples were stored in labeled, double-bagged one gallon plastic bags for future analyses. During the initial site investigation, intact samples were collected by means of shelby tubes. Split-spoon sampling was not possible due to the hardness of clays encountered in the subsurface. Shelby-tube samples were returned to New Mexico Tech, opened, and the contents were retrieved and analyzed.

3.1.2.1 Initial Investigation Boreholes BH-1, BH-2, BH-3 and BH-4

After Fernandez Pueblo was chosen as the study area, it was necessary to determine the depth to bedrock and/or groundwater, and subsurface lithology. At the time, nothing was known with regards to these factors. It was necessary to obtain permits from the BLM before any work could be conducted at the site. One of the conditions of conducting destructive field work at Fernandez Pueblo was to minimize damage to the surface and any pueblo or midden/cultural material. Therefore, boreholes BH-1, BH-2, and BH-3, shown in Figure 3-1, were located along a pathway on the eastern and southeastern side of the pueblo. If the pueblo was built on an outcrop, then it was important to determine depth to groundwater and/or bedrock in these areas. At the same time, collection and analysis of borehole samples could perhaps provide a clue as to what we could or could not use as a tracer. The fourth drill site, known as BH-4 (Figure 3-1), is believed to have been drilled in a location not impacted by midden deposits, and served as a "background" borehole. The exploratory boreholes were drilled in August 1993.

Drilling using the hollow stem auger method took a considerable amount of time. Much of the subsurface formation encountered was a very dense, thick, red to purple grey clay. A considerable amount of steam was created during drilling, leading to soil moisture loss via volatilization and subsequent condensation. This condensation occasionally caused the clays to "pack" or stick to the flights of the auger, preventing the cuttings at depth from coming up from the flights of the augers. At this point drilling was stopped, the augers were removed from the borehole and the sticky clays were dislodged. Borehole BH-2 is a prime example of the difficult drilling conditions. Two bits were ruined, owing to the intense heat and pressures created as the augers ground against the unyielding clays. Two and a half days were required to drill the borehole to apparent ground water.

Moisture condensation also made it difficult to determine when and if groundwater was encountered. Shelby-tube samples were collected at locations believed to be just above the water table. As the water table elevation appeared to vary from borehole to borehole, collection sometimes fell short of the target depth. Generally, drilling was stopped at the depth where clays coming up the flights of the auger were very liquid and ropy. Having no other subsurface information, it was assumed this indicated an aquifer. It is possible that these apparent saturated conditions were the result of condensation of moisture accumulated in the clays. Subsequent boreholes drilled in nearby locations would encounter truly saturated conditions at greater depths. Regardless, the ropy clays made it impossible to continue drilling as they prevented deeper cuttings from coming up the borehole. All boreholes were drilled to depths were apparent saturation occurred. BH-1 was drilled to a total depth of 15.2 m below ground surface (mbgs). BH-2 was drilled to 11.9 m bgs. BH-3 was drilled to a depth of 8.8 m, and BH-4 to a depth of 12.2 m. At the completion of drilling, all boreholes were backfilled with native material.

An apparent area of recharge exists approximately 2 km northeast of the site, at Fernandez Ranch. Heavy rains during the summer months of 1994 resulted in a considerable amount of surface water in a shallow depression just south of the ranch house and east of the dirt access road, shown in Figure 3-2. Conversations with Matt Williams, of Williams Windmills, Lemitar, NM, revealed that depth to ground water in the area of the ranch house was no more than six meters.

3.1.2.2 North and South Windmill Boreholes

The North and South Windmill drilling locations were chosen due to the heavy cattle traffic they receive. Both locations are approximately 1 km from the site, as shown in Figure 3-2, and were drilled in June 1994. At each location a stock tank is present which provides cattle with water. Evidence of cattle excrement is abundant in these areas. Stock tanks have been in use for at least 50 to 100 years, according to the owner, Mary Weathers (personal communication, 1994). Lithologies were markedly different in the two locations. At the North Windmill, lithologies were the same as those previously seen at Fernandez Pueblo, i.e., purple clays with surface sands. South Windmill sediments consisted of yellowish clays, gravels and sands. Drilling conditions were the same as those at the previous four hollow-

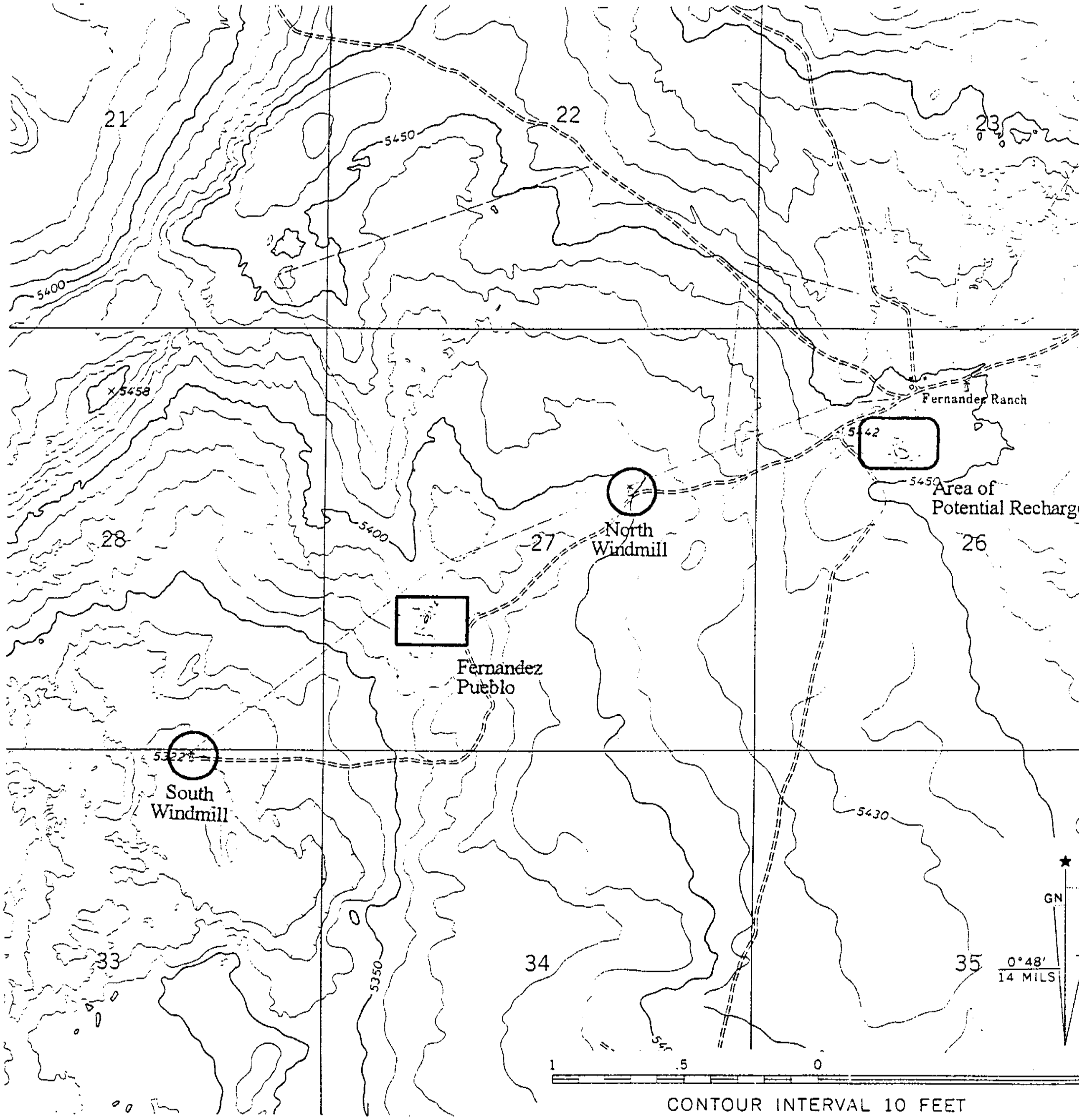

Figure 3-2. Locations of North and South Windmill and Area of Potential Recharge at Fernandez Pueblo

Orndorff Ranch Quadrangle, New Mexico - Socorro Co.
7.5 Min. Series (Topographic)

stem auger boreholes. As before, these boreholes were to be drilled to groundwater. Again, this depth was difficult to determine. The South Windmill borehole was drilled to a depth of 14.6 m, the North Windmill borehole was drilled to a depth of 10 m, depths at which apparent saturation was encountered.

3.1.3 Air-Rotary Boreholes

Eight boreholes were drilled using the air-rotary method. The air-rotary method was used for several reasons. It was no longer necessary to collect intact samples, and it was a much quicker method of drilling, even through the tight subsurface clays. It was also much easier to move the air-rotary rig over the surface of the midden and pueblo than the hollow-stem auger rig.

Boreholes were drilled using a CP 650 air-rotary drilling rig with a 16-cm mill tooth bit. Sampling intervals were every 1.5 m or at the change in lithology, and samples were stored in double bagged 1-gallon plastic bags. Samples were collected by placing a container at the point of exit of the borehole cuttings. This container was emptied into a sample bag at measured time intervals, determined by the speed of drilling, to ensure a representative sample was collected. At a change in lithology, or at the end of the 1.5 m interval, the bag was sealed and sample collection for the next interval began.

3.1.3.1 Monitoring Well MW-1

In September 1994 a monitoring well was drilled and installed at Fernandez Pueblo. The monitoring well would allow collection of piezometric levels and aquifer water quality analyses. Monitoring well MW-1 was to be drilled and installed at BH-4. However, BH-4 could not be located. Based upon the surface disturbance created during the drilling of BH-4, it appears that MW-1 was drilled approximately 1 m east of BH-4. Ground water at MW-1 was encountered at a depth of 17.4 m bgs. The aquifer appears to be confined as tight, dry clay layers were penetrated prior to reaching water. Sloughing of surface sands made it necessary to stop drilling at 18.3 m bgs. The well was left to sit overnight to allow the water level to equilibrate. The next morning the water level was measured at 13.4 m bgs.

A 5-cm (2- in.) inner diameter PVC casing was installed to a total depth of 18.3 m. Six meters of 20-slot (0.05-cm or.020-inch slots) screen was installed at the base of the borehole with an additional 12.2 m of blank casing to the surface. The casing was installed with a cap at the bottom and PVC glue was used to glue the sections of casing together. The annular space was backfilled using perlite (Dica-Perl, Socorro, NM) from a depth of 18.3 m to 0.75 m bgs, then Enviroplug (Wyo-Ben Inc., Billings, MT) from a depth of approximately 0.5 m to the surface. A 0.6 m by 0.6 m cement pad and protective steel casing were installed at the surface. A schematic diagram of the well casing is provided in Appendix E.

3.1.3.2 Test Pit Boreholes

In March 1995 seven air-rotary boreholes were drilled at locations with known midden/cultural deposits. These locations were chosen based upon the relatively high amounts of midden/cultural material and would allow sampling directly beneath the source of the "plume" created by leaching materials in the midden. Due to the restrictions placed upon us by site permits, we could only drill within test pit locations already excavated and cleared by the OCA archaeologists. At the completion of excavation and removal of cultural and midden material, the pits were backfilled with mixed soils. Therefore, the first one to one-and-a-half meters of material were not collected during drilling. As before, these boreholes were to be drilled to ground water. As before, depth to ground water varied from borehole to borehole. There were lithologic variations in the top 5 m of the subsurface in each borehole due to the erosion of the Baca Formation. There was severe sloughing of surface sands at TP-B-71 and TP-B-72. The drilling rate slowed as we encountered tighter sections of clay, increased drilling depths, and sloughing of surface sands. Dense clays encountered deeper in the subsurface were much harder to bring to the surface, so at times cuttings were irretrievable. In those cases the boreholes were completed at these depths. To continue further would have required adding water to the borehole. This would have defeated the purpose of trying to collect in situ samples which were to to be analyzed for soil-water chloride and bromide, nitrate-N.

Drilling was uneventful at TP-B-106, TP-B-123, and TP-B-107. These were the shallowest of the seven wells. At TP-B-103, drilling was slower as tighter clays were encountered at depth, but there were still no difficulties in bringing up cuttings. At TP-B-118, located approximately 25 m north of TP-B-103, cuttings were unable to be retreived from the bottom of the hole at 19.8 m bgs. Repeated efforts to "pressure up" and blow cuttings up from the bottom of the hole was unsuccessful; attempting to blow cuttings up from the bottom of TP-B-118 succeeded only in blowing water up from the bottom of TP-B-103. Although ground water had not yet been reached, drilling was stopped at TP-B-118 at this point.

TP-B-71 and TP-B-72 are located nearest the pueblo, in an area defined to have the thickest midden deposits. Thickness of the surface sands also increases towards the pueblo. These sands caused sloughing, or caving at the top of the boreholes of TP-B-71 and TP-B-72.

It quickly became necessary to add DDF Foamer (Denver, CO) to the hole. DDF Foamer, also known as "drillfoam" is an anionic surfactant. It adheres to the soil particles on the sides of the borehole, forming a sort of wallcake which prevents further sloughing and controls dusting. Drillfoam was applied at selected depths within the first 5.3 m of the boreholes, predominantly in the sands which were causing the trouble. The foaming agent was mixed with water, then circulated throughout the borehole through the air-circulation system. Circulation was continued until the drillfoam was dry and in place, then drilling was resumed. A sample of the drill foam was collected for future analyses. The addition of drill foam did not completely stop the sloughing sands, but did allow drilling to continue. The surface sand content in samples varies from 10 to 30% by volume. This mixing was considered when preparing samples for laboratory analyses.

Sloughing sands were a somewhat more severe problem at TP-B-72. At 3.8 m bgs, sloughing was threatening the base of the rig, even with the addition of the drillfoam. A 3-m section of casing was then installed as a conductor. The conductor secured the upper portions of the borehole and also shut off those portions of the borehole in which drill foam had been added, thus decreasing the amount of mixing that could occur. It was necessary to ream the borehole and blow out all cuttings before the conductor could be installed. This reaming would have mixed any cuttings in the hole from 0 to 4.6 m bgs. Drilling was resumed, but a sample from 3.8 to 4.6 m could not be collected. Drilling continued until a depth of approximately 19.2 m, when cuttings were no longer coming up the borehole.

Water levels were collected where possible at the completion of drilling. A table of air-rotary borehole and water level elevations is given in Appendix F.

3.1.4 Additional Field Work

Water samples were collected at the North and South Windmill locations on the date of drilling described above. Samples were collected from storage (stored water pumped from the well) and stock tanks (actual drinking tanks for the cattle) for chloride and bromide analyses. No samples could be collected from the wells themselves as the windmill pumps were not active on those days.

Water samples for chloride and bromide analyses were collected in August 1995 from MW-1. A 0.79 cm (2-in) submersible pump (Grundfos Corporation, Clovis, CA) used to pump the well for one-half hour at a rate of 2 gallons per minute. Three samples were then collected in 15 min. intervals, and samples were stored in 500 ml polypropylene bottles for future chloride and bromide analyses.

Electromagnetic inductance (EM) surveys were conducted at Fernandez Pueblo as well. One hand auger hole was drilled in association with the EM survey. For further information on the EM surveys and laboratory results of analyses conducted on the hand auger hole, the reader is referred to Appendix G.

3.2 Laboratory Analyses

3.2.1 Soil Moisture Content

Gravimetric water contents were measured for each sample. Mass measurements were made to 0.01 g using a Mettler balance. All samples were thoroughly mixed within their bags then 20 grams (30 grams of homogenized soil were used for moisture analyses on Cl-1, the author's first attempt at such analyses) of the homogenized sample were placed in a soil moisture tin. Moist weights were recorded, then the sample was placed in a 105°C oven for a period not less than 24 hours. At the end of this period the soil moisture tins were removed from the oven and weighed to determine soil moisture loss. Gravimetric water content was then determined by dividing the weight of water by the dry weight of the sample.

3.2.2 Extraction

As samples were prepared for soil moisture tests, samples were also prepared for anion extraction. One hundred grams of the mixed soil were placed in a 500-ml polyethylene bottle, to which 100 ml of Type-I (de-ionized, de-aerated) water was then added for the leaching process. Boreholes in which suspected mixing of surface sands with deeper clays were sieved with a No. 200 U.S. Standard sieve to remove the surface sand grains. One hundred grams of the resulting pan fraction was collected and analyzed. For boreholes TP-B-72, TP-B-23, TP-B-118, and TP-B-106 it was not always possible to collect 100 g of soil due to the high rock content in the sample. In these instances, a corresponding amount of Type I water was added to the soil sample, preserving the 1:1 dilution. Bottles were sealed with Teflon tape and capped, then placed on a shaker table for not less than 24 hours. Bottles were then removed and centrifuged. The leachate was collected and stored in pre-rinsed 150-ml polypropylene bottles. At the time of analysis, samples were placed in 2-ml sampling vials. Where necessary, the leachate was filtered using 0.45 micron PFTE syringe filters (Alltech Associates, Inc., Deerfield, IL) prior to its placement in the vial. Blank samples were processed at the same time. Type I water was alternately filtered or not filtered and placed in 2-ml vials to check for chloride, bromide, or nitrate-N contamination. The process of placing the Type I water in the vials involved using the same materials as those used in placing leachate in the vials.

3.2.3 High Pressure Liquid Chromatography

High pressure liquid chromatography (HPLC) analyses were conducted to quantify chloride, bromide, and nitrate-N concentrations. Initially, only bromide was analyzed for in samples collected from boreholes BH-1, -2, -3, and -4, and SU 72 NE, SU 72 SE and SU 72 Pit. With the exception of the seven test pit boreholes (known as TP-B) and the seven test pit hand auger holes (known as TP-A), all other samples were analyzed for chloride and bromide by New Mexico Bureau of Mining and Mineral Resources (NMBMMR) laboratory personnel. The NMBMMR ion chromatography (IC) procedure is discussed in the following section.

Quantitation of chloride, bromide and nitrate-N was carried out to a detection limit of 0.01 mg/l for chloride, 0.02 mg/l for bromide, and 0.03 mg/l for nitrate-N. The HPLC system consisted of a 501 HPLC pump, a Perkin-Elmer Advanced LC Sample Processor ISS 200 (the autosampler), and a Lambda-Max Model 481 LC Spectrophotometer (the detector), all by Waters Associates (Milford, MA). Signal output was processed by an HP 3396A Integrator (Avondale, PA) and actual computer outputs were created using ChromPerfect software version 6.0 (Justice Innovations, Mountain View, CA). The wavelength was set to 205 nm for bromide only, then lowered to 195 nm for the detection of chloride. Nitrate-N absorbance was determined at both wavelengths. Two Vydac (Hesperia, CA) 302IC4.6 low capacity anion exchange columns were used. The dimensions of the columns are 4.6 mm by 250 mm. The detection method used was one based on the work by Gerritse and Adeney (1985). The column was equilibrated using a 0.1M K_2HPO_4/H_3PO_4 solution, pH=5.5, for 72 hours. The eluent used during analysis was a 0.02M KH_2PO_4/H_3PO_4 solution, pH=3.8, run at a flow rate of 2 ml/min. The pH of the eleunt was adjusted in each case using phosphoric acid of the same molarity as the eluent.

Anion concentrations in the leachate were determined by comparison to standards prepared from reagent grade chemicals. Three standards of chloride, bromide and nitrate-N were run every 10 samples. Bromide standards ranged from 5, 1, and 0.1 mg/l to 1, 0.4 and 0.04 mg/l. Chloride standard ranges also varied, depending on the concentrations present in the samples. Chloride standards ranged from 500, 300, 100 mg/l, 400, 200, 100 mg/l, and 300, 100, 50 mg/l to measure high chloride concentrations. For lower concentrations, combinations of 50, 25, 10, 5, 1, 0.1 and 0.01 mg/l standards were used. Nitrate-N standard ranges were 10, 2, and 0.2 mg/l. Lower standard ranges included 2, 1, 0.8, and 0.08 mg/l, and 0.03 mg/l.

During HPLC analysis, an unknown peak appeared. The occurrence of this peak was intermittent, but while retention times decreased during usage of the column, the appearance of the unknown peak only varied slightly in time. The peak did not interfere with the determination of chloride, bromide, or nitrate-N concentrations.

Samples collected from TP-A-71 and TP-A-72, and a few from TP-B-71 and TP-B-72, required diluting. These samples were analyzed once, at which time the nitrate-N concentrations were found to be overwhelmingly high. Chloride and bromide were also out of the standard range, or nearing the upper calibration limit. Samples were diluted using the phosphate eluent. Precision volume measurements were made using an Oxford 1 to 5 ml pipettor and Kimax 10 and 20 ml glass pipettes. It was necessary to dilute samples to one-tenth or one-twentieth of their original concentration. Blank eluent samples were also prepared for HPLC analyses at the same time. These were used to determine if there were any chloride, bromide, or nitrate-N contamination occurring via the dilution process.

As discussed in Section 3.1.3.2, the DDF foaming agent used at TP-B-71 and TP-B-72 contaminated all samples collected from these boreholes. HPLC analyses conducted on the drillfoam sample collected in the field revealed significant amounts of chloride, bromide and nitrate-N. It was therefore necessary to calculate the true concentrations of the sample. The presence of an unknown peak associated with the drill foam was consistent in all contaminated samples, and present in no other samples except these. These samples required a run time of 85 min., compared to the standard 11 min. run by all other samples. By comparing the heights of this unknown drill foam peak in the drillfoam sample with that found in the soil sample, a ratio was calculated and then applied to the chloride, bromide, and nitrate-N peaks detected in the sample. In this manner the true concentrations of chloride, bromide and nitrate-N were calculated. This method assumes that the drillfoam absorbs to all samples equally. Appendix H contains chromatograms of the drill foam sample and representative chromatograms of drillfoam-contaminated samples from TP-B-71 and TP-B-72. The method used to back-calculate HPLC concentrations to soil-water concentrations and the uncertainty associated with this method is also included in Appendix H.

3.2.4 Ion Chromatography

Ion chromatography (IC) analyses were conducted on all samples initially collected from the site. All the hollow-stem auger boreholes, storage and stock tank water samples, and samples collected from SU 72 NE, SU 72 SE, SU Pit, and MW-1 were analyzed by NMBMMR personnel. Unless requested, analysis was only for chloride and bromide. BH-4 was analyzed for major cations and anions. A DIONEX 4000i ion chromatograph instrument (Sunnyvale, CA) with autosampler, gradient pump, and detectors which include conductivity, ultraviolet/visible wavelength and electrochemical were used for these analyses. The integrator was a DIONEX 4270, and the column was a DIONEX AS4A with the corresponding AS4G guard column. Dimensions of the DIONEX AS4A column are 4 x 250 mm The eluent was 1.8mM/1.7mM carbonate/bicarbonate, and the injection volume was 55 µl. Flow rate was 2 ml/min. Three standards were run and twice daily calibration checks in the low range of the standards and the high range of the standards were run. The calibration checks were acceptable for continuation of the run if within ± 10%. Standards for chloride ranged from 0.2 mg/l to 200 mg/l, while the bromide standards range from 10 µg/l to 1000 µg/l. The calibration standards and the calibration checks were made separately by different people as a check for accuracy and precision of instrument, solutions, and the analyst (Sandy Schwartz, personal communication, 1995).

The detection of bromide was often susceptible to interference by nitrate. To determine the accuracy of the NMBMMR analyses, three samples of known chloride and bromide concentrations were sent for analysis. The results are shown in Table 3-2. Some discrepancy is present. In order to obtain a better control over the analysis of samples, it was decided that all subsequent samples would be analyzed by the author via HPLC.

3.2.5 Other Laboratory Work

Clay mineralogy analyses were performed on samples collected at BH-4 to determine the types of clays present in the subsurface. These samples were analyzed by the Clay Laboratory at NMBMMR. The results may be found in Appendix I.

Table 3-2. Bromide Spike IC Analyses

Spike Name	Spiked Chloride, mg/l	Spiked Bromide, mg/l	Measured Chloride, mg/l	Measured Bromide, mg
AH-1, 78-84	0.3	0.1	0.47	0.114
AH-2, 78-84	20	0.5	22	0.690
AH-3, 78-84	150	1	150	1.1
SU 74, 60-66	200	5	190	5.2
SU 74, 66-72	1500	10	1500	11

Randomly selected rainwater samples were analyzed for chloride and bromide analyses. These samples were collected by Dr. Gerardo Gross of the NMT Hydrology Program at various times in 1978 and 1979 (R. Bowman, personal communication, 1995) and Dr. Robert Bowman in October 1994, on the roof of Workman Center at New Mexico Tech. Results are discussed in Section 4.1. Analyses were performed at Los Alamos National Laboratory by IC.

4.0 RESULTS AND DISCUSSION

4.1 Rainwater, Stock, and Storage Tank Analyses

Results of the rainwater analyses are shown in Table 4-1. The mean chloride, bromide and Cl/Br concentrations are shown. The average rainwater Cl/Br ratio is 63 ± 14.7. Average chloride values are reported as 5.44 ± 6.46 mg/l and average bromide values are reported as 0.09 ± 0.12 mg/l. Chloride values may be higher in Socorro than at Fernandez Pueblo, as chloride can be enriched by a variety of sources in a metropolitan area. The same may be said of bromide, however bromide enrichment sources are much less common than those for chloride (Bowen, 1979). If this is true, then Cl/Br ratios in rainwater at the site may be somewhat lower than those values reported in Socorro. J. Fabryka-Martin reports an average rainfall chloride/bromide ratio of 74 ± 38 at the Yucca Mountain area (personal communication, 1995).

Results of chloride and bromide analyses for the stock and storage tank samples are shown in Table 4-2. The results were not collected from pristine sources. Generally speaking, chloride and bromide are higher in the stock tanks, where enrichment of chloride and/or bromide may have occurred via cattle or windblown material. Storage tanks are enclosed and would seem to be the more uncontaminated environment, depending upon how clean these tanks (presumably steam-cleaned underground storage tanks) were prior to use. Higher ratios at the North Windmill storage tank relative to those at the South Windmill are counter-intuitive, especially as higher Cl/Br ratios were found in soil samples at the South Windmill. It is possible there is some laboratory error associated with these analyses that were completed by NMBMMR personnel.

Table 4-1. Rainwater Analyses

Sample Name	Cl, mg/l	Br, mg/l	Cl/Br
R192	2.56	.0487	53
10/14/94	.718	.0111	65
R&DD Roof Date 8/21/78	4.18	.0498	84
R&DD Roof Date 9/22/78	.232	.0051	45
R235	7.44	.0981	76
R237	17.5	.315	56
Mean:	5.44 ± 6.46	0.09 ± 0.12	63 ± 14.7

Table 4-2 Stock and Storage Tank Water Analyses

	South Windmill			North Windmill		
Location	Cl, mg/l	Br, mg/l	Cl/Br	Cl, mg/l	Br, mg/l	Cl/Br
Stock Tank	180	1.80	100	170	2.2	77.3
Storage Tank	74	1.3	57.8	87	0.73	119

4.2 Chloride Mass Balance

Of the four deepest TP-B boreholes, two seem to indicate background conditions. These are TP-B-103 and TP-B-118. Based upon Cl/Br ratios found in all seven TP-B-boreholes, these wells do not show significant changes in their ratios due to midden influences. Cl/Br ratios are discussed further in Sections 4.4.3.2.5. Using the chloride concentration results from these wells, a chloride mass balance was performed (after Phillips, 1994) to estimate the recharge rate in the study area. The equation:

$$R_{Cl} = P(C_p/C_{Sw})$$

where

R_{Cl} = Annual recharge rate estimated by chloride mass balance, in m/yr
P = Average annual precipitation rate at site, m/yr
C_p = Chloride concentration of precipitation at the site, mg/l
C_{sw} = Average chloride concentration of soil water below the rooting depth, mg/l

was used. The application of the chloride mass balance method assumes vertical, one-dimensional flow in the downward direction, and that chloride in the subsurface is due principally to chloride in rainfall. The chloride in precipitation and precipitation itself are assumed to represent long-term averages. The system is also assumed to be at steady state, in which "[t]he mass rate of chloride input to the soil from precipitation is equal to the mass rate of chloride output of water percolating below the root zone" (Stephens and Coons, 1994). No data was collected to question the assumption of downward flow. Thus the author accepts this assumption as essentially valid, although she realizes that heterogenous lithologies found in the near subsurface of the boreholes may affect percolating soil water in any number of ways. Based upon the results of chloride and bromide analyses of borehole samples (discussed below), it appears that chloride (and bromide) in the subsurface is due principally to chloride in rainfall.

Two numbers were initially used for C_p, the chloride concentration in precipitation at the site. A value of 5.44 mg/l is the average of chloride concentration of rainwater collected at New Mexico Tech. This value is much higher than the following reported values. Phillips (1994), measured chloride concentrations as 0.375 mg/l in the Sevilleta National Wildlife Refuge, Socorro County, NM. Stephens and Coons (1994) used a chloride concentration of 0.34 mg/l in their estimate of recharge for an area near Sunland Park, NM. J. Fabryka-Martin reports an average rainfall chloride concentration of 0.55 ± 0.36 mg/l at the Yucca Mountain area (personal communication, 1995). Why the value at Socorro is so much higher is not known at the present time. It may be evaporation had occurred after collection of rainwater samples. Evaporation would increase the concentration of the chloride and bromide, yet the Cl/Br ratio would be preserved.

The precipitation rate at Fernandez Pueblo has been estimated as 0.305 m/yr. Chloride precipitation values of both 0.375 mg/l and 5.44 mg/l have been used in the calculation of recharge and percolation rates for boreholes TP-B-103 and TP-B-118. Results are shown in Table 4-3. There is little variation in the calculated percolation rates between the two boreholes, indicating relatively little differences in soil-water chloride concentration. Percolation rates differ by an order of magnitude between the two chloride precipitation values of 0.375 and 5.44 mg/l. Using a chloride content of 0.375 mg/l, the average recharge rate is 3.2×10^{-4} m/yr. If an estimated porosity of 30% is used, the percolation rate is 1.1 x

Table 4-3. Estimation of Recharge Rate at TP-B-103 and TP-B-118

TP-B-103				TP-B-118			
Depth, m	Soil water Cl, mg/l	[1]Rate m/yr	[2]Rate m/yr	Depth, m	Soil water Cl, mg/l	[1]Rate m/yr	[2]Rate m/yr
1.2	141	8.1e-04	1.2e-02	1.2	60.5	1.9e-03	2.7e-02
1.7	68.9	1.7e-03	2.4e-02	2.1	684	1.7e-04	2.4e-03
2.3	2141	5.3e-05	7.7e-04	3.2	3483	3.3e-05	4.8e-04
2.9	3231	3.5e-05	5.1e-04	4.1	4377	2.6e-05	3.8e-04
3.4	3305	3.5e-05	5.0e-04	5.3	3348	3.4e-05	5.0e-04
4.0	5585	2.0e-05	3.0e-04	6.9	1759	6.5e-05	9.4e-04
4.6	5960	1.9e-05	2.8e-04	8.2	726	1.6e-04	2.3e-03
5.6	3428	3.3e-05	4.8e-04	9.1	219	5.2e-04	7.6e-03
7.0	1918	6.0e-05	8.7e-04	9.8	216	5.3e-04	7.7e-03
8.0	1058	1.1e-04	1.6e-03	10.4	202	5.7e-04	8.2e-03
8.9	274	4.2e-04	6.0e-03	11.4	199	5.8e-04	8.3e-03
9.6	186	6.1e-04	8.9e-03	13.0	179	6.4e-04	9.3e-03
10.1	235	4.9e-04	7.1e-03	14.5	281	4.1e-04	5.9e-03
10.5	219	5.2e-04	7.6e-03	15.9	362	3.2e-04	4.6e-03

Table 4-3. Estimation of Recharge Rate at TP-B-103 and TP-B-118 (cont'd)

TP-B-103				TP-B-118			
Depth, m	Soil water Cl, mg/l	[1]Rate m/yr	[2]Rate m/yr	Depth, m	Soil water Cl, mg/l	[1]Rate m/yr	[2]Rate m/yr
11.4	265	4.3e-04	6.3e-03	16.9	278	4.1e-04	6.0e-03
13.0	306	3.7e-04	5.4e-03	17.8	325	3.5e-04	5.1e-03
14.3	221	5.2e-04	7.5e-03	18.7	230	5.0e-04	7.2e-03
15.7	161	7.1e-04	1.0e-02	19.5	377	3.0e-04	4.4e-03
17.2	282	4.1e-04	5.9e-03				
18.6	314	3.6e-04	5.3e-03				
19.5	423	2.7e-04	3.9e-03				
Estimated Recharge Rate[3]:		3.0e-04	4.4e-03			3.4e-04	4.9e-03
Estimated Percolation Rate[4]:		1.0e-03	1.5e-02			1.1e-03	1.6e-02

Notes:
1) Chloride conc.= .375 mg/l, ppt = .305 m/yr
2) Chloride conc.= 5.44 mg/l, ppt = .305 m/y
3) Rates calculated using chloride concentrations below the rooting depth (~3 m)
4) Calculated using 30% porosity

10^{-3} m/yr. For a chloride concentration of 5.44 mg/l, the average recharge rate is 4.7 x 10^{-3} m/yr, and the percolation rate is then 1.6 x 10^{-2} m/yr.

Using the known age of the pueblo, AD 1300-1450, the estimated travel distances have been calculated. Using a velocity of 1.1 x 10^{-3} m/yr, the estimated travel distance of the solute ranges from 0.76 m to 0.60 m below the surface of deposition. The estimated travel distance using the higher velocity of 1.6 x 10^{-2} m/yr ranges from 11 to 8.7 m below the surface of deposition. The latter distances and travel velocities are obviously in error. As previously discussed, the chloride concentration in precipitation at Socorro is anomalously high when compared to other concentrations. Therefore, it was decided to use the chloride concentration measured by Phillips as it appears to be a more reasonable number. The recharge rate has therefore been estimated as 1.1 x 10^{-3} m/yr and potential travel distances as 0.8 to 0.6 m below the surface of deposition.

4.3 Chloride Age Dating

Chloride ages were calculated using the chloride mass balance as described by Phillips (1994). The equation

$$t_z = \frac{\int_0^z \theta C_{Cl}\, dz}{D_{Cl}}$$

was used, where

t_z = Transport time, yrs

θ = Volumetric Water Content (estimated, $L^3\ L^{-3}$)

C_{Cl} = Cumulative soil water chloride content ($M\ L^{-3}$)

D_{Cl} = Chloride deposition rate, (M L^{-2} T^{1})
dz = change in depth (L)

It was necessary to estimate volumetric water contents. This was done by using density estimates of 1.68 g/cm^3 for clay, and 2.16 g/cm^3 for sand. These estimates are based upon the Proctor density for well compacted materials (D.L. Hughson, personal communication, 1995). Using the lithologic logs as guides, estimates of compaction were made and the density adjusted accordingly. For example, clays appearing well compacted (i.e. clods of clay versus loose, disseminated clays) were assigned a density of 1.51 g/cm^3, or approximately 90% of the total compaction density. Surface sands were extremely uncompacted, and thus were assigned a value of 1.73 g/cm^3, or 80% of the Proctor density for sand. There is a potential 20% to 30% error associated with these estimates of volumetric water content which would be propagated to the calculated ages. Cumulative soil water chloride contents were obtained from the measured values in samples. The chloride deposition rate was determined using a chloride concentration in rainfall of 0.375 mg/l (Phillips, 1994) and an estimated yearly rainfall of 0.305 m/yr. The change in depth corresponds to the depth over which the sample was collected.

This chloride-age dating method is sensitive to the concentration of soil-water chloride. Boreholes with large cumulative chloride concentrations will have greater ages than those boreholes having lesser chloride. Chloride ages are discussed further in Sections 4.4.1.3 and 4.4.3.2.3.

4.4 Destructive Sampling Results

Results of chloride, bromide, nitrate-N, Cl/Br, gravimetric water content, and soil-water age for all samples are provided in Appendices J through L. Using the data provided in the tables, profiles of gravimetric water content, chloride, bromide, Cl/Br, and nitrate-N vs. depth were prepared for the seven TP-A hand auger holes, the hollow-stem auger boreholes, and the air-rotary boreholes. These are provided in Appendices M through O.

It should be noted that during the course of drilling, some moisture was lost due to the drilling process. This was especially true in the case of the hollow-stem auger holes. This loss of moisture may cause an apparent increase in soil water ion concentration. However, it should not affect the ratio of chloride to bromide.

4.4.1 Archaeologic and Hand Auger Sample Results and Discussion

Laboratory results of hand samples collected from test pits during archaeologic excavations are provided in Appendix J, Table J-1, page 177. The results indicate a variation in Cl/Br ratios in the samples. The ratios vary and in some cases are either very low or higher than precipitation ratios. Ratios are lower than rainwater in cases where charcoal was present in the sample. This low ratio may indicate a release of bromide originally bound in the cells of the vegetation. High ratios indicate a decrease in bromide or an increase in chloride, which may be due to some midden material influence. Tables of results for the SU 72 samples are found in Tables J-2 through J-4, pages 177 and 178. Cl/Br ratios in samples known as SU 72 show a general increase in the Cl/Br ratio with depth. Chloride and bromide concentrations are generally higher than those found in samples from Cl-1, -2, and -3, and AH-1, -2, and -3, discussed below.

The initial background hand auger holes, known as Cl-1, -2, and -3, yielded insufficient data. Tables of results are found in Appendix J, Tables J-5 through Table J-7, pages 179 to 181. Bromide concentrations often fell below the detection limits of the IC. Cl/Br ratios that were identifiable generally were low, ranging from 17 to 55. Chloride concentrations are less than 70 mg/l. The highest bromide concentration detected is 1.5 mg/l. Insufficient amount of soil collected did not allow for re-analysis of bromide. It was this lack of data which prompted us to drill three more auger holes to obtain background data.

The hand auger holes AH-1, -2, and -3 were also analyzed by the NMBMMR for both chloride and bromide concentrations, and were analyzed a second time for bromide concentrations using high pressure liquid chromatography (HPLC). Tables of results are also found in Appendix J, Tables J-8 through J-10, pages 182 to 184. Again, bromide concentrations were low, often below the detection limit. Bromide concentrations ranged from non-detectable to 28 mg/l. Cl/Br ratios varied from 2 in AH-2 to 2200 in AH-3. The latter number is most likely erroneous, as there are no corresponding values at depths above or below this value. Other Cl/Br values are within the range of meteoric water.

The remaining hand auger holes, those collected adjacent to test pit locations and prefixed as TP-A, were analyzed by HPLC. Tables of results for these analyses may be found in Appendix J, Tables J-11 through J-18. Profiles based upon these results are found in Appendix M, Figures M-1 through M-7. TP-A-71, (Figure M-1A and M-1B, pages 211 and 212) bears the consistently highest anion concentrations of all the auger holes. This is most likely due to the fact that Test Pit (TP) 71, as excavated by the archaeologists, yielded one of the largest volume of artifacts from the test pits at Fernandez Pueblo. TP 72 had the highest volume of artifact material of the excavated test pits. Excerpts from a progress report on archaeologic testing at Fernandez Pueblo include the following descriptions of the seven test pits:

> TP 71: 1.0 m of stratified midden deposits, including a refuse-filled adobe borrow pit and ash lens. Charcoal from upper levels (20-40 cm) yielded a radiocarbon date of 400 BP ± 70 years (recall the estimated pueblo occupation is AD 1300-1450).
>
> TP 72: At least 0.70 m of stratified midden deposits: possible borrow pit near bottom.
>
> TP 103: Apparent eolian deposits with high artifact density. A pocket of charcoal-bearing deposits yielded charred corn and beans.
>
> TP 118: 5 m north of TP 103 in apparently stratified eolian deposits. Middle levels contained an organic stain and high artifact density. Either intact or redeposited midden.
>
> TP 106: 70-80 cm of cultural deposits, including at least 20 cm of apparently intact, stratified midden.
>
> TP 107: 40-50 cm of stratified deposits, including 20-30 cm of partially intact to somewhat eroded midden.
>
> TP 123: Stratified eolian sequence, possibly partially redeposited midden.

Of these test pits, TP 71, TP 72 and TP 106 were definite midden. The remaining are described as possible/probable (intact and/or redeposited) midden (Doleman, 1995). Composition of the midden includes bone fragments, ceramic sherds, eggshell fragments, pelecypod and gastropod shells, lithic debitage, muscovite fragments, and at TP 72, coprolites (fossil feces, most likely recent). Non-cultural rock assemblages include arkosic sandstone and conglomerate, quartz, sandstone, siltstone, mudstone/shale, micrite and micrite fragments, albite fragments, carbonates, gypsum, quartzite, chert, petrified wood, and potassium feldspar (Doleman, 1995).

4.4.1.1 Gravimetric Water Content

Gravimetric water contents ranged from 3% to 23% at the auger holes. Variations in water content are most likely due to differences in subsurface lithology and to a smaller extent, moisture uptake by plant roots. Vegetation cover at the site is sparse but fairly consistent from sampling location to location, compared to the larger spatial variations in subsurface lithology. TP-A-106A and TP-A-106B (Figure M-4A, page 217) moisture content distributions track each other very well, demonstrating small spatial variability at this particular sampling localities.

4.4.1.2 Nitrate-N

The most striking thing about nitrate-N deposition in the subsurface is that unlike chloride, bromide, and moisture content, there is no consistent pattern between auger holes. This is most likely due to different processes which affect nitrate concentration in the soil.

TP-A-71 and TP-A-72 (Figures M-1B and M-2B, pages 212 and 214) exhibit an increase in nitrate-N with depth. Nitrate-N concentrations at TP-A-71 are overwhelmingly high, greater than 2000 mg/l, compared with nitrate-N concentrations from other test pit locations. TP-A-106A&B and TP-A-123 (Figures M-4B and M-7B, pages 218 and 224) exhibit high nitrate-N concentrations near the top of the auger hole, but these concentrations are approximately 60 and 350 mg/l and decrease with depth. It is seems likely these concentrations indicate some recent insect or animal activity at the surface in these locations. The remaining test pit auger holes contain nitrate-N in concentrations less than 20 mg/l. The high nitrate-N concentrations at TP-A-71 and TP-A-72, and the relatively lower concentrations present in other holes appear to indicate a source of nitrate-N is associated with the thick midden deposits in the areas of TP-A-71 and TP-A-72.

4.4.1.3 Chloride

Chloride concentration in the subsurface are generally low at depths from 0 cm bgs to 100 or 150 cm bgs, reflecting the low chloride concentrations in rainwater. There is a gradual increase in chloride over the next 100 to 200 cm, perhaps reflecting a gradual accumulation of chloride due to evapotranspiration. The exception is TP-A-118 (Figure M-6A, page 221) in which chloride concentrations do not appear to increase with depth, but rather appear to remain relatively constant with the exception of a chloride peak at 175 cm depth. Given the corresponding bromide peak also present at this depth, and a Cl/Br ratio within the range of rainwater, it would appear this data point reflects a true value and is not due to contamination or analytical error. A thick layer of sand present in this hole may be allowing soil-water to percolate at a comparatively rapid rate. The cause of the sharp chloride spike is not known, but its depth suggests either a peak due to release from midden material, a perturbation in the system by roots or more likely an association with limonite staining found at this depth (the reader is referred to the Lithologic Log for TP-A-118 in Appendix D, p. 126). Limonite is a field term used to describe a natural hydrous oxide of uncertain identity (Hurlbut and Klein, 1977).

Chloride ages were determined in the eight TP-A holes and are provided in Tables J-11 through J-18. Strictly speaking, the method of determining ages should be applied to depths below the root zone. However in this instance rough generalizations were made. Chloride ages are largest in TP-A-71 and TP-A-72 (Tables J-11 and J-12), where the largest chloride concentrations are found. Chloride ages are lowest in shallow holes and in TP-A-118 (Table J-17), where not much chloride was found. These hand auger holes were drilled in locations of known midden deposits. If the deposits were discharging chloride leachate equally, there should be more equitable ages, however this is not the case. The jump in chloride age at TP-A-71 may indicate a source of chloride in the midden deposits at this location. Chloride ages at TP-A-72 that are relatively higher than other hand auger holes may also indicate a source of chloride in the midden deposits at this location.

4.4.1.4 Bromide

The distribution of bromide in the subsurface closely follows the pattern of chloride distribution in the subsurface. As with chloride, bromide concentrations are also low the first 100 to 150 cm below ground surface, then gradually increase in concentration with depth. As with chloride, a sharp bromide peak is found at 175 cm depth at TP-A-118. The reasons for the presence of this peak would be the same as those listed above. However, bromide is preferentially taken up by plants; therefore, the presence of this peak at this depth would strongly suggest plant activity is not the cause of the peaks.

4.4.1.5 Chloride/Bromide

Meteoric Cl/Br values range from approximately 40 to 80 (Table 4-1). Cl/Br ratios in the TP-A holes exhibit ratios much less than those of rainfall. These low values may be due to the preferential uptake and ultimate release of bromide by organic matter (Gerritse and George, 1988). Chloride is also taken up, but the relatively higher background concentrations are not as influenced by uptake and subsequent release (Gerritse and George, 1988). Given the semi-arid setting and relatively sparse vegetation, organic matter is most likely not very abundant nor distributed equally in space. Once vegetation dies some of it is likely spread over the vicinity that it occupies. As the organic matter decays, bromide is released, thus enriching bromide already present in the subsurface and causing the generally low Cl/Br ratios in the near subsurface. Rainfall chloride and bromide then mixes with chloride and bromide present in the subsurface. It is hypothesized that this mixing over depth causes a gradual increase of low Cl/Br ratios back to those seen in rainfall.

Alternative sources of chloride and/or bromide enrichment in the subsurface may be due to dryfall or the soils themselves. It does not seem likely that dryfall would enrich bromide relative to chloride as sources of chloride are more abundant than those of bromide (Bowen, 1979). The soils themselves may be contributing chloride to the soil water, thus increasing the Cl/Br ratio with depth. With the exception of TP-A-71, in which the Cl/Br ratio peaks and then decreases, and TP-A-118, which has no consistent Cl/Br pattern, an increase in Cl/Br ratios with depth is seen in the hand auger holes. Lithologic variations between holes, and variations in the rate of increase, make it difficult to determine if particular lithologies are contributing to the Cl/Br ratio. At TP-A-71 and TP-A-72, where the highest ratios are found, there are no apparent differences in lithologies associated with these peaks relative to holes in which these lithologies are found but peaks in ratios are not. The potential contribution of chloride and bromide from the soil is discussed further in Section 4.4.3.2.5.

Cl/Br values vary from a low of 4 to anomalously high values of 1500 in TP-A-123. At TP-A-123 the ratio of 1500 is unfortunately found in the deepest sample at the bottom of the borehole, so there is no other data to validate this ratio. It may be an anomaly whose origin is unknown at the present time. A ratio of 160 is found at the surface of TP-A-118, perhaps due to a passing animal or insect. TP-A-118 exhibits relatively constant ratios that do not appear to increase with depth. A slight peak at 175 cm depth is present and mimics those seen in chloride and bromide. However it is well within the range of rainwater and thus obfuscates the question of the cause of its origin. With the exception of TP-A-118, all auger holes exhibit a relative increase in the Cl/Br ratio with depth

TP-A-71 and TP-A-72 exhibit the largest Cl/Br ratios of all the holes drilled at the site. Ratios reach maximums of 160 at TP-A-72 and 182 in TP-A-71 at a depth of 2.36 m in both holes (Figures M-1A and M-2A, page 211 and 213). The thickness of midden deposits at TP 71 was determined to be 1.3 m and 1.1 m at TP 72. A travel distance of 1 to 1.2 m correlates somewhat well with the calculated travel distance of 0.6 to 0.8 m as discussed in Section 4.2. These peaks may be significant in terms of our tracer deposition, as it is likely they are due to residue from the midden.

The arithmetic mean and standard deviation were calculated for the Cl/Br ratios found in the subsurface. They are 60 ± 52.9 mg/l (the high Cl/Br ratio of 1500 from TP-A-123 was not included in the calculations). The average Cl/Br ratio measured in rainwater is 63 ± 13.4 (Table 4-1). The large increase in deviation is due to the low Cl/Br ratios as discussed above, and higher Cl/Br ratios which may be due to midden influence.

4.4.2 Hollow-Stem Auger Holes

4.4.2.1 BH-1, BH-2, BH-3 and BH-4

Questionable laboratory results for chloride and bromide have made the results of the IC analyses for the following boreholes suspect. The results are reported as is, but re-analysis using HPLC is pending. Modifications will be made when new results are obtained. Tables of results for BH-1, -2, -3, and -4 are found in Appendix K, Tables K-1 through K-4. Solute and gravimetric water content profiles vs. depth are found in Appendix N, Figure N-1 through N-4.

4.4.2.1.1 Gravimetric Water Content

Gravimetric water content was affected by the intense heat created during drilling. This intense heat caused condensation and subsequent vaporization of the soil water, decreasing water content in the subsurface. While this water loss may cause an apparent increase in soil-water chloride and bromide concentration, it should not affect the Cl/Br ratio. Subsequent air-rotary boreholes may reflect a more accurate gravimetric water content profile, as they most likely did not lose as much moisture.

BH-1, -2, -3 and -4 exhibit water contents ranging from 1% to 20%, indicating relatively dry subsurface conditions. The higher water contents seen in the profile of BH-2 (Figure N-2, page 227 and Table K-2, page 195) were collected from relatively saturated locations above and below the presumed aquifer at 11.3 m bgs. BH-1 (Figure N-1, page 226, and Table K-1, page 194) is the only borehole to exhibit a constant water content with depth. This occurs below 8.5 meters and moisture content averages 13%. Slight moisture peaks of 19% and 15% are found in BH-3 (Figure N-3, page 228 and Table K-3, page 196) and BH-4

BH-2 presents a puzzle. It exhibits much lower chloride concentrations than the other three boreholes. Assuming a constant chloride deposition rate over the entire study area, similar concentrations should be seen in all boreholes. One explanation may be that fractures in the clay are present in this area, and are allowing a more rapid rate of percolation. Any chloride present in the subsurface would therefore travel downward at a much quicker rate. At the present time there is no way to prove this hypothesis. It is also possible that an error occurred in the reporting of these results, however repeated conversations with NMBMMR personnel indicate this is not the case.

Chloride ages at the depth of the peaks and the base of the peaks described above were determined using the chloride mass balance method. At BH-1, these ages are 8905 and 16,222 years before present (yr bp) respectively. Peak and base ages at BH-2 are 1,730 and 5370 yr bp; at BH-3 they are 14,632 and 15062 yr bp. Finally these ages are 6,160 and 46,415 yr bp at BH-4. Generally speaking, chloride ages compare very well between BH-1 and BH-3, BH-2 and BH-4 are abnormally low and abnormally high in chloride.

4.4.2.1.3 Bromide

The pattern of bromide distribution in the four boreholes closely mimics that of chloride. Peaks are seen at the same depths. Of course, bromide concentrations are much lower, ranging from non-detectable to a high of 65 mg/l at BH-4. This peak occurs at the same depth as the high chloride peak found at BH-4. At BH-2, as with chloride, bromide concentrations are lower than those seen at the other three boreholes, ranging from non-detectable to 3.69 mg/l. The processes affecting the reported chloride concentrations in the subsurface at BH-2 are affecting bromide in the same manner.

4.4.2.1.4 Chloride/Bromide

Cl/Br ratios range from 6 to 245 in the four BH boreholes. High Cl/Br ratios, upwards of 120 occur, and Cl/Br peaks are present in each borehole. Peaks do not appear to be related to the Baca Formation/evaporite layer, as these peaks appear in BH-1, in which the evaporite layer is very thin or absent. The peaks do not appear to be influenced by structure, as they occur below the sand-clay interface of the Baca and Dockum Formations. The depth of the peak varies from 4.0 m at BH-1 and BH-4, to 5.2 m at BH-3 and 9.8 m at BH-2. Assuming the chloride ages discussed above are correct, it appears highly unlikely the Cl/Br peaks are due to any midden influence. The depth of the Cl/Br peak is consistent with the depth of the chloride and bromide peak for each borehole. Low Cl/Br ratios are found within the upper 2 m to 2.4 m of the subsurface, then increase with depth. The thickness of the base of the peak varies from 4 m to 7.5 m, as was seen with chloride. BH-1, -2 and -3 all show one large Cl/Br peak, then a general decrease in ratios and perhaps a slightly smaller peak at a lower depth. For reasons not entirely clear, BH-4 exhibits a more sawtooth sort of Cl/Br distribution. At BH-4, peaks occur at 4.0 m bgs, 8.5 m bgs, and perhaps a third at or below 12.2 m bgs. It is possible that a cyclic influx of recharge or partial fracture flow may be causing this pattern, however BH-4 does not sit in a topographic low where capture of overland flow could occur, and neither chloride nor bromide show such patterns of distribution. Subsequent boreholes near BH-4, such as MW-1, do not exhibit this pattern.

The Cl/Br mean and standard deviation for these four boreholes have been calculated as 106 ± 69.9. These values are much higher than those found in either the hand auger holes or in rainwater, discussed above. The unusually high Cl/Br ratios and their potential interpretation are discussed in Section 4.4.4.

4.4.2.2 South and North Windmill

Because these boreholes are each at least 1 km away from the site, and at least 2 km away from each other, they are discussed separately and no comparisons are made, except in the broadest sense, to the four hollow-stem auger holes drilled at the site. As noted previously, markedly different lithologies are found at the two sites. The effect of differing lithologies between the two locations is notable in water contents and in chloride and bromide distributions in the subsurface. Gravimetric water contents are markedly less in the yellow gravels and clays of the South Windmill. Higher water contents are noted in the purple clays in the near subsurface of South Windmill and in the purple clays at the North Windmill. For the convenience of the reader, tables of results for these boreholes are in Appendix K, Tables K-5 and K-6. Profiles are located in Appendix N, Figures N-5 and N-6.

As with the previous four BH boreholes, North and South Windmill samples were also analyzed by NMBMMR personnel, therefore the results are somewhat suspect. However based upon comparisons with BH bromide data analyzed via HPLC, the trend of the data, i.e., highs and lows in chloride and bromide distribution should remain consistent.

4.4.2.2.1 South Windmill

At South Windmill, chloride and bromide concentrations (Figure N-5, page 230, Table K-5, page199) were higher over a wider depth range (~ 10 m) than those found in the four BH boreholes and North Windmill. Chloride concentrations range from 1000 to 5700 mg/l. As with all cases, bromide distribution mimics the pattern of chloride distribution in the subsurface. Chloride and bromide bulges such as those seen in the previous boreholes are not present. Cl/Br ratios at South Windmill are the highest seen anywhere within the study area, ranging from a low of 45 at the surface, to a high of 485 at 7 m bgs. The average Cl/Br ratio is approximately 357. A tentative hypothesis as to the absence of the bulge, and the high Cl/Br ratios found at the site involves the lithology at the site. Below a depth of 2.4 m, the predominant lithology is a yellow clay and limestone gravel mix. As shown in Figure 2-4, the geologic map presents outcrops of Permian Glorieta Sandstone, a well indurated, well sorted, quartzose sand, and Permian San Andres Limestone, dominantly limestone and dolostone with abundant gypsum and minor mudstone and siltstone in the upper part (Osburn, 1984) in the area of South Windmill. Further geologic investigation would be necessary to determine which formation the borehole is in but it is most likely San Andres, given the limestone "gravels" found in the South Windmill samples. Bowen (1979) states that marine formations often contain relatively high amounts of chloride and/or bromide. It is possible chloride and bromide associated with the lithologies may be enriching soil water chloride relative to bromide, thus increasing the ratios.

An alternative hypothesis is a high Cl/Br source deposited at the surface followed by subsequent percolation. South Windmill lies in a topographic low which may serve as a catchment for runoff after rainfall. It may be that surface runoff is captured and chloride and bromide are concentrated as evaporation occurs. Unless enrichment of chloride relative to bromide occurs during overland flow, however, this hypothesis really does not explain the high Cl/Br ratios found at depth. Cattle activity at the surface may be a source of high chloride relative to bromide. Cattle defecating at the site for a period of 100 years could potentially contribute high Cl/Br ratios through their excrement. If this were true, however, the effect of this deposition should be seen less than 1 m below the surface of deposition, using the estimated travel velocity discussed in Section 4-2.

As mentioned earlier, these analyses were completed by the NMBMMR laboratory, therefore the results are somewhat suspect. If trends in data are valid, then Cl/Br ratios are high throughout the entire depth of the borehole, except at the surface, where the ratio is 46. While this ratio is also within the range of rainwater, it is also possible the Cl/Br ratio due to cattle. Low Cl/Br ratios may be attributed to the high organic matter content in cow pies. As the estimated travel distance below the surface of deposition is less than 1 m for deposition occurring within the last 100 yrs, the case for low Cl/Br ratios in excrement, and higher ratios at depths that are due to lithologic influences is strengthened.

4.4.2.2.2 North Windmill

Gravimetric water contents at North Windmill (Figure N-6, page 231, Table K-6, page 200) are within the range of those seen at the Fernandez Pueblo boreholes. As mentioned previously, the lithologies at North Windmill were characteristic of those seen at BH-1, -2, -3 and -4. A peak moisture content at 8.8 m depth may indicate the remnants of a perched aquifer. Like South Windmill, a chloride or bromide bulge is not present at the expected depth. A chloride peak is present at 2.4 m bgs with a chloride concentration of 850 mg/l. This concentration is the lowest peak concentration found in any borehole. A bromide peak at the same depth has a concentration of 5.54 mg/l, at least four times lower than the peak bromide concentration found in other boreholes. A second bromide peak is found at a depth of 8.53 m with a concentration of 10.3 mg/l. A discrete sample collected at this same depth revealed a bromide concentration of 0.20 mg/l. Thus it is likely that the first value of 10.3 mg/l, from a sample collected over an interval of 7.0 to 8.5 m bgs, may be erroneous.

In some respects, the pattern of chloride and bromide deposition resembles that of BH-2, in which no chloride peak and a depressed bromide peak were found. Unlike BH-2 however, a peak Cl/Br ratio occurs at approximately 5 m bgs and not at 10 m bgs. The pattern of Cl/Br distribution with depth closely resembles those of BH-1, -3, and -4.

A low chloride/bromide ratio of 1.75 is found at the depth of 8.5 m in this borehole. This is most likely an erroneous value. A low ratio such as this is not seen in any other borehole at this depth. The Cl/Br ratio in the discrete sample collected at 8.53 m bgs is 120, indicating the actual ratio may be higher.

The question of cattle Cl/Br ratios appears to remain unresolved at this site. Further chloride and bromide analyses conducted via HPLC on TP-B boreholes would indicate that high Cl/Br ratios obtained using IC are erroneous and NMBMMR laboratory results are suspect. If actual Cl/Br ratios are assumed to be lower than those reported in Table J-6, then the lack of a high Cl/Br spike in the subsurface at this location would seem to indicate low cattle excrement ratios as well.

4.4.3 Air-Rotary Boreholes

4.4.3.1 MW-1

Tables of results for laboratory analyses conducted on samples from MW-1 are given in Appendix L, Table L-1, page 196. Solute and gravimetric water content vs. depth profiles are shown in Appendix O, Figure O-1, page 233. Analyses were conducted by NMBMMR personnel.

Gravimetric water content distribution in the subsurface is much the same as seen in previous boreholes. Low moisture contents are seen close to the surface, associated with the sands of the Quaternary and Eocene formations. There is a gradual increase in water content with depth, in the clays of the Dockum Formation. Variations in water content below a depth of approximately 6 m may be due to variations in lithology, or indicative of paleoclimatic changes. Water contents in the vadose zone vary from 4% or 5% to a high of 20%, similar to what was seen in the previous four boreholes at the site. A very wet sample collected within the water bearing zone yielded a gravimetric water content of approximately 50%.

Chloride concentrations at MW-1 are also within the range of what was previously seen at BH-1, -2, -3, and -4. The omni-present chloride bulge again occurs at a depth of approximately 5 m bgs, and is almost 7.5 m in vertical thickness at its base. Peak chloride concentration is nearly 3900 mg/l at a depth of 4.57 m bgs. Chloride concentrations drop markedly below the bulge to an average value of 105 mg/l.

The pattern of bromide distribution in the subsurface closely mimics that of chloride. This mimicking is found in all boreholes and auger holes at Fernandez Pueblo. A bromide bulge appears approximately 5 m bgs. Bromide concentrations in MW-1 vary from 1 mg/l to 45 mg/l. Lower values are found in the near subsurface, and gradually increase with depth to a peak value of 45 mg/l at a depth of 4.57 m bgs. Below this depth, concentrations gradually decrease to an average concentration of 1.96 mg/l.

Cl/Br ratios at MW-1 vary little, from 42 to 87. The average ratios are 60 ± 12.8. These values are well within the measured range of precipitation. As stated above, samples from MW-1 were analyzed by NMBMMR personnel, therefore the results for MW-1 are also somewhat suspect. Samples collected from this borehole are also scheduled for re-analysis by HPLC. The average Cl/Br ratio at MW-1 is low compared to other TP-B boreholes, which may indicate an error in analyses. Based upon comparisons with other air-rotary boreholes drilled at the site chloride values also appear somewhat low. This difference may be due to laboratory analytical practices, but these differences appear slight compared to more marked differences that exist between results for the four BH wells and results for all air-rotary boreholes analyzed by the author. Sampling results from two boreholes drilled in close proximity of each other, BH-4 and MW-1, were therefore compared.

Profiles of chloride, bromide, and Cl/Br vs. depth for MW-1 were compared with those of BH-4 and are provided in Appendix P, Figures P-1 through P-4, pages 249 to 252. Some general trends are evident. An increase in ratios to a depth of approximately 5 m and then a subsequent decrease in ratios are present in both boreholes. There are fairly good similarities in gravimetric water content, and the location of chloride and bromide bulges. However there were marked differences in Cl/Br ratios, and to a somewhat lesser extent, chloride and bromide concentrations.

The patterns of water distribution in the subsurface are remarkably similar between BH-4 and MW-1 (Figure P-1), considering they were drilled almost one year apart and different drilling methods were used to drill each one. Peak water concentrations are spatially 0.9 meters apart and vary by 2.6%. Overall, water contents in MW-1 are higher than those found in BH-4. The lower water contents in BH-4 may be a reflection of the water lost through condensation and vaporization during drilling of BH-4.

Chloride concentrations at MW-1 are overall markedly lower than those found in BH-4. The peak chloride concentration at MW-1 is 3.6 times lower than the almost 14,100 mg/l chloride peak found at BH-4 (Figure P-2). Both peaks are found at relatively the same depth. At MW-1, the sample was collected over an interval from 3.4 to 4.6 m bgs; at BH-4, the sample was collected over an interval of 4 to 5.5 m bgs. Given the chloride concentrations found above and below the interval in question at MW-1, it does not seem likely that mixing with soils of a lower concentration could have diluted the 14,100 mg/l concentration to 3900 mg/l. Bromide concentrations at MW-1 are also lower than those found at BH-4, but by a smaller magnitude (Figure P-3). Cl/Br ratios at BH-4 are much higher than those at MW-1 (Figure P-4). Ratios at MW-1 decrease to an almost constant ratio of 55, while Cl/Br ratios at BH-4 never approach a constant value.

There are several possible explanations for the solute concentration differences seen between the two boreholes. One is that the location of BH-4 only is within a region influenced by a source of high chloride and bromide concentrations. A second is a laboratory analytical or processing error in which anion concentrations for either MW-1 or BH-4 were affected. A third explanation is that "packing" of clays, which occurred due to moisture condensation on the augers, somehow concentrated chloride and bromide unevenly within the clays. Of these, the second seems to be the more plausible explanation. These two boreholes were drilled more than a year apart, with two different drilling methods, but are located very close to one another, at least within a one meter radius. Analyses were completed by the same individual at the NMBMMR, but also a year apart. This may indicate the difference is due to the drilling method. However chloride and bromide concentrations between the two boreholes do not vary by the same magnitude, and no explanation has been found to indicate how chloride could be enriched relative to bromide via the drilling process. It is therefore more likely that some analytical error may be involved. It has been proposed that a faulty water purification system would produce water, used in the creation of the eluent, standards, etc., contaminated with high chloride concentrations to bromide. This system would have been repaired during the year between analyses and thus the effects of the impure water would be absent in the MW-1 results.

It should also be noted that gravimetric water content, and chloride and bromide concentration peaks at MW-1 are consistently stratigraphically higher than those at BH-4. It seems improbable that the difference in peak depth could be due to geologic controls or differences in solute travel times. These differences may indicate that apparent sampling depth at the surface and actual sampling depth in the borehole are asynchronous in either MW-1 or BH-4. If so, it is more likely the error would lie in the hollow-stem auger method used at BH-4. Samples are not recovered instantaneously at the surface with this method as they are with the air-rotary method. Packing of clays on the augers may also hinder the rise of samples along the flights of the auger. At this point, the actual reason is unknown.

4.4.3.2 Air-Rotary Boreholes TP-B-71, -72, -103, -106, -107, -118, and -123

Tables of results for theTP-B boreholes are provided in Appendix L, Tables L-2 through L-8. Solute profiles are found in Appendix O, Figures O-1 through O-8. Specific figures and tables will be referred to when discussing a particular borehole. Analyses on these samples were conducted using HPLC.

4.4.3.2.1 Gravimetric Water Content

Gravimetric water contents were fairly uniform in all seven boreholes. Water contents ranged from about 4% to slightly less than 20%. As with most of the previous borings at Fernandez Pueblo, low water contents are found at the surface. Water content then increases with depth. These changes in water content may be a reflection of evapotranspiration and lithology. Sands at the surface tend to lose their moisture more readily than clays with a higher matric potential at a depth less likely to be influenced by evapotranspiration. Variations in water contents below a depth of approximately 5 m, where the chloride and bromide bulges are found, are perhaps a reflection of paleoclimate influences, according to Phillips (1994), or lithologic influences. It is interesting to note that gravimetric water content decreases in the sampling interval prior to the aquifer location. This drop in water content may indicate the relative impermeability of clays or lenses of sandstone and/or limestone overlying the aquifer. The impermeability of the overlying beds may prevent any upward flux, leaching or deposition by ground water.

4.4.3.2.2 Nitrate-N

Low nitrate-N concentrations are generally found in near subsurface samples in all boreholes. This appears to be the only unifying nitrate-N characteristic among the seven boreholes. Beyond this, two items are striking about nitrate-N concentrations in these boreholes. The first is the relatively low nitrate-N concentrations in five of the boreholes, and the spikiness or sawtooth-ness of graphs associated with this low concentration. Boreholes TP-B-103, TP-B-106, TP-B-107, TP-B-118 and TP-B-123 exhibit this spikiness and low nitrate-N concentration to some extent. Nitrate-N profiles for these boreholes are shown in

Figures O-4B, -5B, -6B, -7B and -8B, pages 239 to 247 and results of laboratory analyses for each borehole are found in Tables L-4, -5, -6, -7, and -8, pages 205 to 209, respectively. Nitrate-N concentrations in these five boreholes range from 0.03 to 15 mg/l with a majority of the concentrations below 8 mg/l. Relatively high nitrate-N concentrations in the near surface at TP-B-107 (Figure O-6B) are perhaps due to cattle activity at the site. The variation in nitrate-N concentration over depth can be attributed to de-nitrification and many other processes, and subsequent transport through the subsurface.

The second item is the lack of spikiness and very high nitrate-N concentrations found at TP-B-71 and TP-B-72 (Figures O-2B and -3B, pages 229 and 231, Tables L-2 and L-3, pages 203 and 204). While drill foam contamination occurred in these boreholes (previously discussed in Sections 3.1.3.2 and 3.2.3, and Appendix H), the contribution of nitrate-N to the sample was generally less than 3%, and in most cases less than 1%. Reported values here are those that have been adjusted to pre-contaminated concentrations. Nitrate-N concentrations range from 2.9 mg/l to a high of 1657 mg/l at TP-B-71. The peak nitrate-N concentration at TP-B-71 is found at a depth of 3.0 m with a concentration of 1657 mg/l. The basal width of the peak is approximately 5 m. At TP-B-72 the basal width of the peak is also about 5 m. Peak concentration is 521 mg/l at a depth of 3.8 meters. There is no spikiness nor a sawtooth effect associated with these nitrate-N concentrations, i.e., no apparent depletion as seen in the previous five TP-B boreholes. Could nitrate-N deposition have occurred below the depth of plant uptake or microbial degradation? Or were concentrations so large to begin with that there was more than enough present for organic activity to not significantly affect the total concentrations?

The nitrate-N spikes at TP-B-72 and TP-B-71 could be associated with activity at the pueblo. In Section 4-2 travel distances were calculated as ranging from 0.8 to 0.6 m below the surface of deposition, assuming deposition during the time of occupation at the pueblo. If the surface of deposition is estimated to lie 1.1 to 1.3 m bgs then these peaks lie well beyond the outer edge of the estimated travel distance. However, as such high nitrate-N concentrations are seen only at TP-B-71 and TP-B-72, locations of relatively dense midden deposits, it seems entirely likely the influence of human activity at Fernandez Pueblo is seen in these boreholes.

4.4.3.2.3 Chloride

Chloride concentrations range from a low of 26 mg/l at TP-B-106 (Figure O-5A, page 234, Table L-5, page 206) to a high of 5960 TP-B-103 (Figure O-4A, page 232, Table L-4, page 205). The majority of chloride concentrations lie within a range of 100 to 500 mg/l. As previously noted, both TP-B-71 and TP-B-72 were contaminated with drill foam chloride. Reported concentrations here are those adjusted to pre-contaminated values. Chloride bulges are present in the seven TP-B boreholes just as they were in the previous boreholes, and are found at a depth of approximately 5 m. In the seven TP-A boreholes, the basal width of the peak varies from 5 to 7.5 meters, as was seen in the four BH boreholes. Three of the borehole chloride bulges have "shoulders" or separate peaks associated with them, which were not found in other boreholes. Shoulders are found in TP-B-103, TP-B-106, and a very subtle shoulder could be argued for TP-B-71 (Figure O-2A, page 228, Table L-2, page 203). At TP-B-106, an 845 mg/l shoulder is found at a depth of 3.0 m bgs. TP-B-103 has a higher concentration - 3231 mg/l at a depth of 3.0 m bgs, and at TP-B-71, this subtle shoulder has a concentration of 1040 mg/l at a depth of 2.4 mg/l. At TP-B- 72 (Figure O-3A, page 230, Table L-3, page 204), a separate peak above the larger peak is found at a depth of 3.0 m bgs, and has a concentration of 1295 mg/l. Below the large chloride bulge smaller chloride peaks occur in some boreholes which could be due to lithologic influences.

Chloride ages were calculated for the seven TP-B boreholes as well, shown in Tables L-2 through L-8. Generally speaking, chloride ages at the bases of chloride bulges in TP-103, -118, -107 and -123 are comparable to each other, ranging from 18,400 to 29,100 yrs bp. In TP-B-71 and TP-B-72, these ages are lower. As discussed in Appendix H, the method used to adjust chloride concentrations may have overcompensated somewhat, thus removing more chloride than necessary, and resulting in lower ages. Why chloride ages in TP-106 are anomalously low is unknown at the present time. Chloride ages calculated for the range of depths in which a tracer peak may be expected to occur (approximately 1 m below the surface of deposition, or 2.1 to 2.4 bgs) vary depending upon the cumulative chloride content in the borehole. In TP-B-71 and TP-B-72, the ages at these depths are 417 and 579 yrs, ages which initially appear to correlate reasonably well with the established age of the midden. However, if the true soil-water chloride content is actually higher than the adjusted content as discussed in Appendix H, these ages may be somewhat higher.

In Section 4.4.1.3, it was stated that chloride ages should be higher in those samples with a higher Cl/Br ratio, assuming the higher ratios are due to additional sources of chloride. This effect would be subtle in the boreholes, given the probable low additions of salt to the midden. Mixing of soils with a high chloride content with soils of a lower chloride content would also further decrease the Cl/Br ratio. This effect is seen in the TP-B boreholes, where samples are collected over larger depth intervals relative to those of the TP-A samples. Thus, ages in TP-B-71 and TP-B-72 are lower than those seen in TP-A-71 and TP-A-72.

4.4.3.2.4 Bromide

Perhaps even more so in the air-rotary boreholes, the pattern of bromide distribution in the subsurface closely tracked the pattern of chloride distribution in the subsurface. Bromide concentrations range from a low of 0.345 mg/l to a high of 61.1 mg/l. The majority of concentrations lie within a range of 1 to 5 mg/l. As with the chloride "shoulder", TP-B-72 exhibits a smaller, earlier bromide peak as do TP-B-106 and TP-B-103. A bromide bulge is present at a depth of approximately 5 meters with the same basal width as the chloride bulge. With the exception of TP-B-123 (Figure O-8A, page 246, Table L-8, page 209) and TP-B-107 (Figure O-6A, page 242, Table L-6, page 207), bromide (and chloride) concentrations approach a constant concentration with depth. Those two boreholes show slight increases in chloride concentration near the bottom of the borehole. It is possible gravel and clay found at the bottom of these boreholes may be impeding flow and causing an increase in bromide content. Or, the impermeability of the clays in these two locations may not be as effective, perhaps allowing for some deposition from rising ground water or associated upward fingering.

4.4.3.2.5 Chloride/Bromide

Given the high Cl/Br ratios found in the previous four boreholes at the site, high Cl/Br ratios in boreholes associated with the midden were expected to be found as well. Surprisingly normal, i.e. within rainwater range albeit slightly higher, consistent Cl/Br ratios were instead seen. The average rainfall ratio in these seven boreholes is 86.1 ± 19.9. This average excludes a Cl/Br ratio of 410 at the surface in TP-B-103. This high ratio is not repeated in any other borehole at this shallow depth, and is perhaps due to some anomalous influence.

Cl/Br ratios at the surface are lower in some boreholes, such as in TP-B-106 and TP-B-118, and higher in others, such as TP-B-107 and TP-B-123. Low ratios may occur for those reasons discussed previously for the TP-A holes in Section 4.4.1.5. Lithologic contribution of chloride and/or bromide does not appear to influence Cl/Br ratios. While lithologies vary from borehole to borehole, the Cl/Br ratios in each borehole appear to either remain fairly constant with depth, as in TP-B-103 (Figure O-4A), or in some cases exhibit a decrease in the ratio with depth, as in TP-B-118. Cl/Br ratios do appear to be somewhat higher than rainfall, but certainly not out of the calculated range of 63 ± 14.7. The clay minerals found in the boreholes do not contain chloride or bromide in their crystal structure, so it is unlikely they are contributing either anion to the soil water. It may be that high Cl/Br ratios in the subsurface are reflections of high Cl/Br ratios in "older", pre-historic rainwater.

There are some relatively high Cl/Br ratios found in several of the boreholes. In TP-B-118 (Figure O-7A, page 244, Table L-7, page 208), TP-B-106, TP-B-107, peaks ranging from 101 to 113 are found at various depths. These peaks are not very prominent, and are perhaps due to variations in the Cl/Br ratio in rainwater. In two of the deeper boreholes, TP-B-118 and TP-B-103, no significant changes in the ratio are noted at depths associated with the estimated travel distance. It would seem reasonable that these boreholes could serve as background. The two boreholes are fairly deep, and are drilled within 25 m of each other. They also demonstrate spatial variability of ion concentration in the subsurface.

At TP-B-71 and TP-B-72 the highest Cl/Br peaks are found. Peak ratios here are 134 and 141, found at depths of 2.4 and 3.0 m bgs. Depths of these peaks are misleading. It is the depth where half of the Cl/Br mass occurs which indicates the depth of travel. In this case, this depth occurs at 2.3 m bgs, or 1 to 1.2 m below the surface of deposition, which is almost double the estimated depth obtained from calculated percolation rates and distances discussed in Section 4.2

It could be argued that the high Cl/Br ratios are remnants of the drill foam Cl/Br ratio of 400. The author believes Cl/Br ratios due to drill foam contributions have been more than adequately removed. As will be discussed in Section 4.4.5, Cl/Br results for TP-A-71 and TP-A-72 support the Cl/Br peaks in TP-B-71 and TP-B-72 as actual results.

4.4.4 Comparisons between TP-B boreholes and BH boreholes

Cl/Br data for the seven TP-B boreholes were compared to those for the pre-existing four BH boreholes. A distinct Cl/Br peak is present in all four of BH holes, with relatively high values that in some cases exceed 200. These high ratios were disturbingly absent in the air-rotary holes. The seven TP-B boreholes were drilled through what the archaeologists defined as abundant midden material locations. Assuming vertical one-dimensional flow, if there are high Cl/Br peaks associated with the midden anywhere in the subsurface, they should exist underneath the highest concentration of midden deposits. Such high peaks are absent or depressed in the TP-B boreholes. In TP-B-71 and TP-B-72, the only boreholes with peaks assumed to be due to midden influence, peak values are markedly lower than those found in the four hollow-stem auger holes. It should be re-emphasized that the four BH boreholes and MW-1 were analyzed by NMBMMR personnel using ion chromatography, and the seven TP-B boreholes were analyzed by the author using HPLC. The fact that the eight air-rotary boreholes drilled at the site are all very similar to each other, yet markedly different from the four hollow-stem auger boreholes initially led the author to conclude that the differences were due to the different drilling methods, especially when it is noted that NMBMMR analyzed both BH-4 and MW-1, as discussed previously. As discussed above in Section 4.4.3.1, the differences are more likely due to laboratory/analytical procedures at the NMBMMR laboratory. The differences between the two sets of data are summarized in the form of arithmetic mean and standard deviations of chloride, bromide and Cl/Br, shown in Table 4-4.

Chloride ages were also compared between the two sets of boreholes. If chloride had been added to the BH samples during the laboratory process, larger chloride ages should be seen in these boreholes which are suspected of being contaminated. This is generally not the case. With the exception of BH-4 (Table K-4), chloride ages in the BH boreholes (Tables K-1 through K-4) are generally less than those found in the TP-B boreholes (Tables L-4 through L-8) for a given depth (TP-B-71 and TP-B-72 are not included in the comparison as it appears that reported chloride concentrations are lower than actual concentrations). This may be due to estimates of volumetric water contents used in the chloride age calculation. These estimates are subject to the interpretation of the lithologic log as based on the cuttings retrieved during the drilling process. It is likely that for the hollow stem auger method, the condensation created during the drilling process may have altered the appearance and texture of the samples moreso than the air-rotary process.

Table 4-4

Arithmetic Mean and Standard Deviation of TP-A Hand Auger Holes, TP-B Air-Rotary Boreholes, and Site Hollow Stem Auger Boreholes

	Depth Interval, m	Chloride mg/l	Bromide mg/l	Nitrate-N mg/l	Cl/Br
Rainwater (Table 4-1)	----	5.44 (6.46)	0.09 (0.12)	NA	63 (14.7)
Test Pit Hand Auger Holes	0 - 2.97	657 (1031)	5.75 (8.01)	184 (481)	60.0 (52.9)[1]
Test Pit Boreholes	1.5 - 20.3	933 (1267)	10.6 (13.9)	60.7 (217)	86.1 (19.6)[2]
BH-1, -2, -3, and -4	0 - 12	1371 (2616)	11.5 (14.9)	NA	106 (69.9)

Notes: NA = Not Analyzed

1) TP-A-123 not included (Section 4.4.1.5)

2) TP-B-103 not included (Section 4.4.3.2.5)

4.4.5 Comparison between TP-A and TP-B results

Solute profiles of combined TP-A and TP-B results are provided in Appendix Q. What follows is a brief discussion regarding similarities or differences between sampling locations. As each location is discussed, the appropriate tables and figures are referenced for the reader's convenience. The reader is reminded that TP-A holes were drilled outside the cleared test pit area, as the test pit had been backfilled following archaeologic investigations. Thus, approximately 1 m separates the TP-A location and the TP-B location.

TP-A-71 and TP-B-71 are shown in Figures Q-1A, -1B, -1C, and -1D, pages 254 to 257. Nitrate-N, chloride, bromide and Cl/Br ratios for the two holes exhibit very similar distribution patterns in the subsurface. Concentrations are generally higher in TP-A-71 than in TP-B-71. With the exception of Cl/Br ratios, peaks are never seen in TP-A-71, most likely because sampling depth was not deep enough. A Cl/Br peak (Figure Q-1D) is seen at approximately the same depth for both holes. In TP-A-71 it occurs at 2.36 m. In TP-B-71 it appears to be bracketed between depths of 1.8 m and 2.3 m bgs. These depths correlate very well considering they are located a meter apart. The fact that TP-A-71 bears high Cl/Br ratios makes it seem all the more likely that high Cl/Br ratios seen in TP-B-71 are not the result of drill foam contamination.

Solute profiles for TP-A-72 and TP-B-72 are shown in Figures Q-2A, -2B, -2C and -2D, pages 258 to 261. As with the TP-71 holes, nitrate-N, chloride, bromide and Cl/Br distributions appear to mimic each other well. Though nitrate-N (Figure Q-2A) concentrations are somewhat lower in TP-A-72 than in TP-B-72, both TP-A-72 and TP-B-72 exhibit an increase in nitrate-N concentration with depth. The opposite is true for chloride and bromide (Figures Q-2B and Q-2C). TP-A-72 exhibits higher chloride and bromide concentrations for a given depth than does TP-B-72. As with TP-71, the method of correction used to determine drill foam chloride and bromide concentrations appears to have somewhat overcompensated. A Cl/Br peak is found in TP-B-72 (Figure Q-2D) at a depth of 2.3 m bgs, where it was seen in the TP-71 holes. A slight peak is seen at 2.36 m in TP-A-72. Ratios are slightly lower after this depth. The peak concentration in TP-B-72 has been calculated as 141, in TP-A-72, the peak ratio is 160. Again, the high ratios found in TP-A-72 validate the calculated high Cl/Br ratios in TP-B-72.

The TP-71 and TP-72 holes exhibited high nitrate-N concentrations and also displayed nitrate-N peaks, or increasing concentrations with depth. The remainder of the TP- holes bear varying nitrate-N concentrations.

Solute profiles for the combined TP-103 holes are found in Figures Q-3A, -3B, -3C, and -3D, pages 262 to 265. Nitrate-N concentrations are relatively higher in TP-B-103 than in TP-A-103 (Figure Q-3A), but both holes exhibit low concentrations at a depth of approximately 1 to 1.7 m bgs. Here the similarity ends as from 1.6 to 2.97 m bgs nitrate-N was non-detectable in TP-A-103. Aside from chloride peaks at depths of 0.80 and 1.91 m bgs in TP-A-103, chloride and bromide deposition patterns mimic each other reasonably well between the two holes (Figures Q-3B and -3C). Chloride and bromide concentrations appear slightly lower in TP-A-103 after a depth of 2.06 m. Yet, as shown in Figure Q-3D, Cl/Br ratios follow each other amazingly well in the two holes. As discussed previously, the ratio of 410 is most likely an outlier, specific to the area in which TP-B-103 was drilled.

At TP-106, two hand auger holes TP-A-106A and TP-A-106B were drilled. For comparisons with TP-B-106 it was decided to use TP-A-106B as it was the deeper of the two hand auger holes and would provide a better means of comparisons. Solute profiles for TP-106 are found in Figures Q-4A, -4B, -4C, and -4D, pages 266 to 269. As with TP-103, nitrate-N exhibits some variability in the distribution between the two boreholes. Concentrations in both holes generally appear low at the surface with approximately the same concentrations (Figure Q-4A). However TP-B-106 exhibits an increase in nitrate-N with depth whereas TP-A-106B does not. Chloride and bromide distributions in the subsurface compare reasonably well between the two holes (Figures Q-4B and -4C). Both chloride and bromide are low in the near subsurface and then gradually increase with depth. Cl/Br exhibit more variability in the subsurface (Figure Q-4D). Ratios are generally low in the near subsurface and increase with depth in both TP-A-106B and TP-B-106. Ratios are larger in TP-A-106B than they are in TP-B-106.

Solute profiles for the TP-107 holes are found in Figures Q-5A, -5B, -5C, and 5D, pages 270 to 273. Nitrate-N concentrations are lower in TP-A-107 than in TP-B-107, yet both exhibit the same trend of decreasing concentrations with depth (Figure Q-5A). Chloride and bromide concentrations are basically in complete agreement with one another, a striking similarity even though slight variations are noted (Figure Q-5B and -5C). These slight variations become evident in Cl/Br profiles. Ratios in TP-A-107 are lower than those found in TP-B-107, yet both appear to increase at a depth of approximately 2 m (Figure Q-5D).

Similarities between TP-A-118 and TP-B-118 are disturbingly absent. Solute profiles for TP-118 holes are found in Figures Q-6A, -6B, -6C, and -6D, pages 274 to 277. Nitrate-

N, chloride, bromide and Cl/Br are consistently higher in TP-B-118. TP-A-118 exhibits wide variability in nitrate-N concentrations a depth interval of 0 to 2.51 m bgs, with concentrations generally appearing to decrease with depth (Figure Q-6A). This decrease is also present in TP-B-118 for the same interval. TP-A-118 chloride and bromide are remarkably different than TP-B-118 distributions. Except for chloride and bromide peaks at 1.75 m bgs (Figures Q-6B and -6C), the remainder of chloride and bromide concentrations are all very low. It is possible that chloride and bromide concentrations over a depth of 1.5 to 2.6 m bgs in TP-B-118 are averages of chloride and bromide concentrations at the same depth in TP-A-118. Cl/Br ratios between the two holes are also widely dissimilar. Ratios in TP-A-118 are generally lower than TP-B-118, and there appears to be no similarity in distribution patterns with depth (Figure Q-6D).

Sampling depths at TP-A-123 barely coincide with those from TP-B-123. Solute profiles are found in Figures Q-7A, -7B, -7C, and -7D, pages 278 to 281. Only one sampling point is comparable, however several things are striking. Nitrate-N concentrations in TP-A-123 are large compared to those in TP-B-123, for this reason the two solute profiles were not overlaid (Figure Q-7A). If the nitrate-N concentration were areally distributed over both drilling locations, then sampling over an interval of .91 to 1.30 m in TP-B-123 should yield an average higher than the observed 2.33 mg/l. This strengthens the opinion that the cause of high nitrate-N concentrations at TP-A-123 are most likely local, as discussed previously. No comparisons for chloride and bromide distributions can be made, other than it appears that chloride and bromide concentrations in TP-A-123 are lower than those found in TP-B-123 (Figures Q-7B and -7C). The same is true for Cl/Br ratios. In TP-A-123, ratios increase with depth to the last sampling point at 1.3 m bgs (Figure Q-7D). As the first data point for TP-B-123 is located at 1.2 m bgs, any attempts at making comparisons would not be valid.

Cl:Br peak
TP-71
~2.

4.4.6 The Recharge Rate

Peaks in the Cl/Br ratio at TP-A-71, TP-A-72, TP-B-71 and TP-B-72, indicate midden influence. Using an estimate of one-half of the mass of the Cl/Br peak, it appears that the tracer has traveled 1 to 1.2 m below the surface of deposition. On the basis of pottery sherds, the age of occupation has been established at 1300 to 1450 AD. Therefore, using ages of 695 and 545 yrs bp, the new percolation rate is conservatively estimated as 1.7 x 10^{-3} to 2.2 x 10^{-3} m/yr. Using an estimated 30% porosity, the estimated recharge rate is 5.8 x 10^{-4} to 7.3 x 10^{-4} m/yr. The observed recharge rate is 1.7 to 2.4 times as much as those calculated using the chloride mass balance method, which were and 3.0 to 3.4 x 10^{-4} m/yr, respectively (see Table 4-3).

should use ~0.15

To more fully validate the differences in recharge rates would require accurate measurements of porosity and volumetric water content, precipitation and chloride concentration in rainfall. The calculations presented here indicate that potentially large differences exist between the actual and estimated recharge rates. Had chloride mass balance recharge rate estimates alone been used at this site, estimated travel rates would have been less than actual rates. Landfills which are designed using recharge estimates based upon the chloride mass balance method may be underestimating the speed with which a contaminant could reach the ground-water table.

The nitrate-N peaks found only in TP-B-71 and TP-B-72, together with the high nitrate-N concentrations found only in TP-A-71 and TP-A-72 indicate a source of nitrate-N

NO_3 [illegible] 3.5-4m

in the thickest midden deposits only. As these peaks occur at depths below the Cl/Br peaks, their origin is under question. The mean calculated percolation (seepage) rate of 1.95×10^{-3} m/yr was applied to the middle of the nitrate-N curve in TP-B-71, an estimated depth of 3.3 m bgs or 2 to 2.2 m below the surface of deposition. The estimated time of deposition is 1026 to 1128 yrs bp, correlable with the age of the pithouse structures found at the site. To verify this estimate of age and the source of nitrate-N would require further archaeologic work, but could also further serve in the use of the site as a natural analogue, and strengthen the validation of vadose-zone solute transport models.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are presented on the basis of work completed at Fernandez Pueblo:

1) Chloride/bromide is a suitable tracer to determine recharge rates at Fernandez Pueblo. The recharge rate has been established as ranging from 5.8×10^{-4} to 7.3×10^{-4} m/yr;
2) The observed recharge rate is approximately 1.7 to 2.4 times greater than that of the original calculated recharge rate of 3.0 to 3.4×10^{-3} m/yr (although further work to quantify parameters such as porosity, volumetric water content, precipitation rates and chloride concentration in precipitation may alter this original calculated recharge rate determined by using the chloride mass balance method);
3) Calculated recharge rates using chloride mass balance are a valid means of determining solute transport distances. The conservative use of such recharge rates may not be sufficient, however. As indicated by the results of this study, they may be off by approximately 50%;
4) Determination of the recharge rates at Fernandez Pueblo could not have been completed without drilling in locations of the thickest midden deposits. Drilling in locations where midden deposits were not as abundant revealed no Cl/Br peaks; and

5) The combination of shallow hand auger and deep boreholes were invaluable in validating observed Cl/Br ratios in each borehole, especially in the case of drill foam contaminated boreholes TP-B-71 and TP-B-72.

Recommendations for future work at Fernandez Pueblo or other locations include

1) The processing of all permits necessary to conduct field work in an archaeologic site be conducted in a timely manner;
2) Archaeologic investigations be conducted as soon as possible to determine locations of highest midden content;
3) All laboratory analyses to be conducted by the same individual using the same method;
4) Parameters such as volumetric water content and porosity be established for each lithology encountered;
5) Weather stations be established at the study area to determine precipitation rates and chloride and bromide concentrations;
6) No drilling additives of any kind to be added to boreholes. If they are necessary, experiments should be conducted to determine the actual sorption of the drillfoam agent on lithologies encountered in the borehole, and to what concentration;
7) Determination of chloride and bromide concentrations due to extraneous influences such as cattle; and
8) Follow-up and investigate the source of the nitrate-N peaks found in the subsurface at TP-B-71 and TP-B-72.

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APPENDIX A

Tracer Selection and Sulfate Work

Tracer Selection and Sulfate Work

A.1 Introduction

Selecting a tracer which could be used at the midden was somewhat more difficult than initially believed. Ideally, a tracer should be a substance which experiences neither a decrease nor increase in mass once it is deposited and as it passes through the soil. An ideal tracer also does not experience a decrease or increase in velocity due to interaction with soil particles and soil particle surfaces. Currently, there are few usable natural tracers to determine recharge rates in arid environments. Some examples are bomb-^{36}Cl, bomb-^{3}H isotopes, and meteoric chloride. Chloride-36 and tritium are useful on the decadal time scale, as they were created during nuclear testing in the during the 1950's and 1960's (Phillips, 1994)[1]. However, they may not provide an accurate picture of ground-water movement over time periods dealing with hundreds of years. Meteoric chloride can be used for longer-term tracer studies. However, in the Southwest a chloride bulge occurs, the origin of which is not exactly clear. This chloride bulge varies in concentration depending on location, and may interfere when tracking chloride movement (Phillips, 1994)[1].

The dilemma we were facing was trying to determine what tracer may have been created by humans who lived over 500 years ago. Chloride, for the above-mentioned reason, was out. Given the length of time involved since pueblo occupation, any nitrate initially deposited may have undergone some changes in concentration due to the nitrogen cycle. Fluoride was not chosen as it reacts almost as readily as the hydroxyl ion. At the time we were trying to determine a potential tracer, we were also looking for a suitable site. With no other midden material to work with, we analyzed samples of midden material provided to us by OCA Archaeologists for potential tracers. (When I speak of "midden material", I am using the term loosely. These samples consisted of soil removed from middens. All the artifacts are removed). The midden material was obtained from several sites throughout New Mexico. These were analyzed by the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) for major cations, anions, and extractable cations. The results are shown in Tables A-1A, A-1B and A-1C. Large quantities of sulfate were present in each sample, thus we considered sulfate as a potential tracer. We conducted several laboratory analyses based on these results, which are discussed below.

A.2 Sulfate

A.2.1 Sample Preparation

The investigation of sulfate as a tracer consisted primarily of studying several fuel wood species and determining the concentration of sulfate in their ash. Types of brush burned for their ash were chosen on the basis of what was present during the period of pueblo occupation. The OCA archaeologists indicated cottonwood, juniper, mesquite, piñon, and four-wing salt bush were most likely used by the pre-historic occupants as a source of wood for their fires. The wood samples were not collected in the study area, as it was not yet known, but rather were collected from several locations in the surrounding Socorro area. Samples of each type of wood were burned and the ash sent to the NMBMMR lab for analysis of major cations and anions in the ash leachate. Again, results indicated high concentrations of sulfate.

A.2.2 Laboratory Analyses and Results

Analyzing the wood ash consisted of first burning the wood, then leaching the resulting ash. Fires were started by lighting a match and applying the burning end to kindling chopped from the wood to be burned. Once the wood was burned, the ash was collected in a 1-gallon plastic bag and taken to the Hydrology lab. There, a 100-g sample was placed in a 500 ml polypropylene bottle to which 100 ml of Type I, (de-ionized, de-aerated) water was added. The sample was shaken for 24 hours, then centrifuged. The resulting supernatent was collected and sent to the NMBMMR Laboratory for soluble cation and anion analyses. The results are shown in Table A-2. Again, high levels of sulfate were reported. Based upon these results, we decided to send those samples with the highest sulfate content to Geochron Laboratories (a division of Krueger Enterprises, Inc., Cambridge, MA) for sulfate isotope analyses. Sulfur isotope ^{34}S is preferentially taken up by plants (Trust and Fry, 1992)[2], and it was believed that the difference in the isotopic ratio could prove to be the tracer for which we were looking.

The samples sent to Geochron were prepared in the following manner. One hundred grams of ash was leached with approximately 100 ml of Type I water, shaken, and centrifuged for at least 1 hour. The resulting supernatent was filtered and placed in a beaker. The pH of the solution was adjusted to 4.5 using 1N HCl. Once the desired pH was met, an extra 10 ml of 1N HCl were added. This solution was heated to boiling. Warm 0.4 M $BaCl_2$ was added while stirring the original solution. Barium chloride solution was added until a precipitate formed. At this point, an extra 2 ml $BaCl_2$ were added. The precipitate was filtered using an ashless filter paper, washed with Type I water and dried overnight. The next day, the filter paper and precipitate were placed in a crucible and slowly heated as the filter paper oxidized. Once all the filter paper was oxidized, a lid was placed on the crucible and the sample was heated for 1 hour over a blue flame (approximately 800°C). The sample was cooled, weighed, and placed in a pre-cleaned glass vial for transport to Geochron Laboratories.

Results of the Geochron analyses are shown in Table A-3. The results indicated there were differences in the isotopic ratio, and for the time being sulfate was the tracer of choice. However, initial results from major cation and anion analyses conducted on soil samples collected at Fernandez Pueblo would also show very high levels of sulfate. Given such large background concentrations and the presence of crystalline calcite ($CaCO_3$), selenite and gypsum ($CaSO_4 \cdot 2H_2O$), we decided sulfate as a tracer would prove unreliable. Subsequent discussions with Dr. Fred Phillips and Dr. Andy Campbell of the NMT Geoscience Department would lead us to investigate the use of the Cl/Br ratio as a soil-water tracer

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Table A-1A. Results of Analyses on Various OCA Midden Samples*

Soluble Cations - mg/kg

Lab #	Identification	Na	K	Mg	Ca
1869	#1) LA953,FS#800,S.V.38 531N,115E,Strat 20, Bot.level 12	420	360	3.9	30
1870	#2) KA953,FS#295,S.V.7 567N,101E,Strat C4,level 15	300	50	7.2	37
1871	#3) MNM 41.3489,FS#273,LA7 89N,76E,Strat 4, level 1	11	43	7.4	83
1871 dup.		8.4			
1955	Trench 24,Site 50240 Alameda #6	44	52	16	120
1956	FS #226, LA24 Feature 5 #7	110	28	63	320
1957	Feature 3,5100 #4, Strat 5	17	22	9.4	40
1958	5055 #5, Strat 6	25	91	6.2	45

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* Analyses conducted by the New Mexico Bureau of Mines and Mineral Resources unless otherwise indicated.

Table A-1B. Results of Analyses on Various OCA Midden Samples*

Soluble Anions - mg/kg

Lab #	Identification	Cl	SO4	F	NO3
1869	#1) LA953,FS#800,S.V.38 531N,115E,Strat 20, Bot.level 12	160	940	9.8	19
1870	#2) KA953,FS#295,S.V.7 567N,101E,Strat C4,level 15	54	490	13	17
1871	#3) MNM 41.3489,FS#273,LA7 89N,76E,Strat 4, level 1	9	30	.85	4.7
1871 dup.		4	6.5	.9	.94
1955	Trench 24,Site 50240 Alameda #6	120	350	1.6	1.7
1956	FS #226, LA24 Feature 5 #7	200	850	1.3	1.2
1957	Feature 3,5100 #4, Strat 5	5.5	7.5	2.2	3
1958	5055 #5, Strat 6	8.8	57	.85	.55

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* Analyses conducted by the New Mexico Bureau of Mines and Mineral Resources unless otherwise indicated.

Table A-1C. Results of Analyses on Various OCA Midden Samples*

Extractable Cations meq/100g soil (NH4-O-Ac)

Lab #	Identification	Na	K	Ca	Mg
1869	#1) LA953,FS#800,S.V.38 531N,115E,Strat 20,Bot.level 12	3.8	5.8	31.8	2.1
1870	#2) KA953,FS#295,S.V.7 567N,101E,Strat C4,level 15	3.0	2.3	35.4	2.1
1871	#3) MNM 41.3489,FS#273, LA7 89N.76E,Strat4, level 1	0.27	0.54	36.4	1.2
1871 dup.		0.22	0.59	38.0	1.3
1955	Trench 24, Site 50240 Alameda #6	0.68	0.42	34.6	2.0
1956	FS#226, LA 24 Feature 5 #7	0.94	0.94	31.8	3.7
1956 dup.		0.98	1.0	42.4	4.0
1957	Feature 3, 5100 #4 Strat 5	0.34	0.92	18.2	5.5
1958	5055 #5 Strat 6	0.33	1.06	17.0	5.1

* Analyses conducted by New Mexico Bureau of Mining and Mineral Resources unless otherwise indicated.

* Analyses conducted by the New Mexico Bureau of Mines and Mineral Resources unless otherwise indicated.

Table A-2. Results of Analyses for Wood Ash Leachate*

Soluble Cations - mg/kg

Identification	Na	K	Mg	Ca
Salt Bush	120	5600	10	120
Mesquite	50	3800	0.5	2.5
Pinon	44	180	54	87
Juniper	410	2100	6.4	660
Cottonwood	3300	1.6%	.10	.69

Soluble Anions - mg/kg

Identification	Cl	SO4	F	NO3
Salt Bush	110	8600	5.0	74
Mesquite	530	4100	<5.0	6.7
Pinon	40	180	2.5	<5.0
Juniper	260	1600	<5.0	5.2
Cottonwood	170	11000	<5.0	12

Table A-3. Sulfate Isotope Analyses (Geochron Labs, Cambridge, MA)

Type of Wood	$\delta^{34}S$
Cotton Wood	- 3.1 - 3.1
Mesquite	+4.8
Four-wing Salt Bush	-0.4

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* Analyses conducted by the New Mexico Bureau of Mines and Mineral Resources unless otherwise indicated.

APPENDIX B

Fernandez Pueblo and Inhabitants

Fernandez Pueblo and Inhabitants

Fernandez Pueblo is located approximately 45 air kilometers east of the City of Socorro, in the Chupadero Arroyo drainage area of the northern Jornada del Muerto. In the region surrounding the present-day Fernandez pueblo, 257 sites have been identified as being pre-historic Native American occupations (Doleman, 1995)[1]. Human groups have lived in or near Chupadera Mesa for the last 12,000 years (Montgomery et. al, 1989)[2]. Cultures at these sites vary from Mogollon to Anasazi to a hybrid of the two. The Pueblo IV period is represented by the construction of large masonry pueblos and glaze decorated pottery (Doleman, 1989)[1]. On the basis of pottery sherds, OCA archaeologists determined that the Fernandez Pueblo locale was occupied during an age of transition from the Pueblo I pithouses to the Pueblo IV village agricultural settlements. The inhabitants of the pueblo belonged to a culture known as the Piro. The Piro/Tompiro designation is a type of linguistic affiliation. The historic occupants of the region are seen as being related to the historic occupants of Senecu, Socorro, and Isleta Pueblos of the Rio Abajo Area (Montgomery et al., 1989)[2].

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[1] Doleman, W.H., Second Progress Report: Phase 1 Archaeological Testing at Fernandez Pueblo (LA 781). Office of Contract Archaeology, University of New Mexico, 1995.

[2] Montgomery, J., Martin, J., Shelley, P., Chupadera Mesa Cultural Sequence. p. 26-54. *In* J. Montgomery and K. Bowman (ed.) Archaeological Reconnaissance of the Chupadera Arroyo Drainage, Central New Mexico. ACA Report CD89.1. Llano Estacado Center for Advanced Professional Studies and Research, Eastern New Mexico University, Portales, 1989.

APPENDIX C

Salt Collecting Locations and Results of Analyses

Salt Collecting Locations and Results of Analyses

C.1 Introduction

The location of Fernandez Pueblo suggests the inhabitants of the pueblo obtained salt from one of three sources: the Estancia Basin, the Zuni salt lake, or the Carlsbad region in southeastern New Mexico. These naturally-occurring salts contain a specific Cl/Br ratio. It was possible this ratio could be preserved and traced in the subsurface. Therefore it was necessary to determine what these ratios were at the salt source locations.

C.2 Salt Collection

The OCA archaeologists determined that salt the pre-historic occupants of Fernandez Pueblo may have used was collected from two different areas in New Mexico: Zuni Salt Lake, and the Estancia Basin. Charlie Carroll with the Bureau of Land Management collected salt samples from the Zuni Salt Lake. Dan Dolmar and myself collected salt from the second area located in the Estancia Basin, known as Laguna del Perro. Salt could only be collected from one area of the Laguna del Perro dry lake beds. It was necessary to contact Mrs. Maxine Moser of Albuquerque, NM, to determine exactly where the salt could be collected. Dan and I managed to collect several samples from what was once Mrs. Moser's family salt mine on the edge of one of the lake beds.

To determine what, if any, effect cattle excrement had at the site, a sample of cowlick salt was collected from a block of salt at the location known as South Windmill (see text). The origin of the cowlick salt is the Carlsbad region (J. McCord, personal communication, 1994). Salt collecting locations are shown in Figure C-1.

C.3 Results

Results of the laboratory analyses conducted for major components of the salt are shown in Table C-1. The calculated Cl/Br ratio of the salts varied from a high of 32,345 for salt collected from the Zuni Salt Lake, to a low of 12,200 for salt collected from Laguna del Perro. The ratio of chloride to bromide in the cowlick sample was 14,545. Cl/Br ratios in rainwater have been determined as 63 ± 14.7, much, much lower than ratios in the salts. If sufficient salt or human excrement was deposited in the midden, it seems reasonable to assume that ratios higher than rainfall would be present in the subsurface and could be traced.

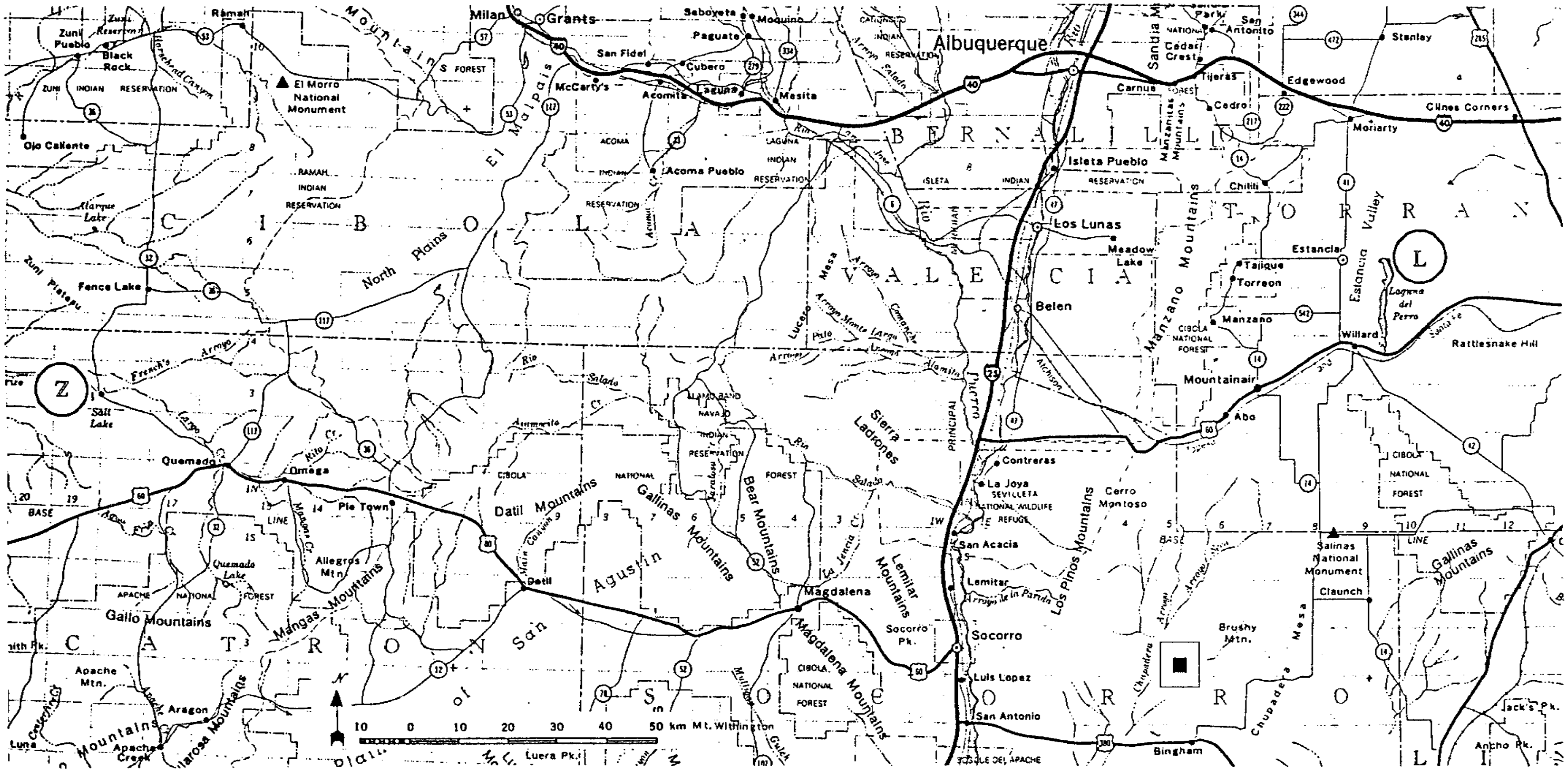

Figure C-1. Salt Collecting Locations

(L) **Laguna del Perro/Estancia Basin**

(Z) **Zuni Salt Lake**

NMBMMR Resource Map 11

Table C-1. Results of Salt Source Analyses

Source	Na%	K%	Mg%	Ca%	SO4%	NO3%	F%	Cl%	Br, ppm[1]	Cl/Br
Salt from Estancia Basin	21.3	0.14	0.35	0.24	5.1	NA	NA	42.7	35	12200
Salt from Zuni	20.9	0.06	0.05	0.06	0.52	NA	NA	46.9	15	32345
Salt Lick, field sample	33	0.32	0.019	0.12	0.27	MI	MI	48	33	14545

Notes: NA = Not Analyzed
MI = Matrix Interference
1) Sample Size=20 grams

APPENDIX D

Lithologic Logs
TP-A Hand-auger holes, Hollow-stem Auger and Air-rotary Boreholes

TP-A-71
Lithologic Log

Date Drilled 2/4/95

Depth Interval, cm	Lithologic Description	Comments
0 - 15	**Sand**: 90% sand, 10% silt; orangish brown; medium to very fine grained sand; poorly sorted, low sphericity; subangular to subround	Charcoal, ash and rootlets
15 - 31	**Sand and Clay and Silt**: 40% sand, 40% clay, 30% silt; orangish brown; sand is moderately well sorted, high sphericity; well rounded; clay is plastic and elastic, non-sticky; fizzes well	Moist; charcoal and rootlets present
31 - 46	As above; reddish brown color	Roots
46 - 61	**Sand with Silt and Clay**: 60% sand; 35% silt, 15% clay; dark brown color; sand as above with some gravel size clasts; some whitish crystalline material, calcite/gypsum; clay as above	Plant material
61 - 91	As above; clay forms good ribbons	Ash present (~3 to 5%)
91 - 107	**Clay and Sand**: 75% clay, 25% sand; dark brown; rare gravel size clasts; clay is plastic and elastic, non-sticky; fizzes readily	
107 - 122	**Sand and Clay and Silt**: 45% sand, 35% clay, 20% silt; dark brown color with orangish (feldspar) sand grains; fizzes well	Moist; ash present (~2 to 3%)
122 - 137	**Clay with Sand**: 85% clay, 15% sand; light reddish brown, caliche and kaolinite present; clay is plastic, elastic and non-sticky; fizzes well	Some ash and charcoal present
137 - 152	**Clay**: 90% clay, 10% very fine sand and rare gravel size sandstone clasts; grayish purple; clay is slightly sticky, elastic and plastic	
152 - 168	As above; fizzes very well; some kaolinite	

TP-A-71
Lithologic Log

Date Drilled 2/4/95

Depth Interval, cm	Lithologic Description	Comments
168 - 183	As above; purple gray clay with whitish grains of calcium, gypsum, and kaolinite; clay is slightly sticky	Moderately moist
183 - 198	**Clay**: purplish brown, some whitish grains may be calcite and gypsum; fizzes well; clay is sticky, plastic and elastic	
198 - 213	As above; ~5% sand clasts	Moist
213 - 229	As above; 100% clay, slightly sticky, plastic, rare coarse grained sand or fine grained gravel sandstone clasts	
229 - 244	As above: fizzes well; clay is almost spongy in texture, very plastic and elastic, non-sticky	Slightly dry
244 - 259	As above	
259 - 274	As above; red-purple brown color; some kaolinite; rare calcite crystals; slightly stiff clays, somewhat plastic; fizzes well	
274 - 290	As above; purple brown color; fizzes well; clay is slightly stiff, somewhat plastic	
290 - 305	As above; purple brown color; rare calcite crystals; clay is slightly elastic, plastic and non-sticky, fizzes well	Pottery sherd, slightly moist sample
	TD @ 305 cm bgs	

TP-A-72
Lithologic Log

Date Drilled: 2/4/95

Depth Interval, cm	Lithologic Description	Comments
0 - 15	**Sand**: 100% sand; reddish orange-brown; medium to very fine grained sand; poorly sorted, low sphericity; subangular to subround; some gravel clasts of sandstone; fizzes well	Moist; plant material
15 - 31	As above; sand has yellow-amber colored grains (selenite?)	Pottery sherds, charcoal and rootlets
31 - 46	**Sand with Silt and Clay**: 85% sand, 15% silt and clay; dark brown; as above; fizzes well	As above
46 - 61	**Sand and Clay**: 65% sand, 35% clay; as above; some gravel sandstone clasts	Moist
61 - 76	**Sand and Clay**: 50% sand, 50% clay; sand as above; dark red brown with some light colored clays; clays are plastic, elastic, non-sticky	Rootlets and charcoal
76 - 91	As above: decrease in clay to 40%, silt to 10%; reddish orange brown color; fizzes well	rare charcoal, very moist
91 - 107	**Sand with Silt and Clay**: 70% sand, 25% silt, 5% clay; light orange brown	Rootlets, moist
107 - 122	**Clay with Sand**: 85% clay, 15% sand, rare silt; first appearance of evaporite material; sand as above, fizzes well	Slightly drier than above
122 - 137	As above; dull red brown with whitish grains; clay is slightly sticky, plastic and elastic; fizzes well	Moist
137 - 152	As above; some crystalline gypsum	slightly drier than above

TP-A-72
Lithologic Log

Date Drilled: 2/4/95

Depth Interval, cm	Lithologic Description	Comments
152 - 168	**Clay with Evaporites**: 70% clay, 25% evaporites, 5% sand; light brown to purple brown; some clay in hard clumps	As above
168 - 183	As above; clay is slightly sticky and stiff; evaporites are similar to caliche	As above
183 - 198	**Clay with Sand**: 75% clay, 25% sand; greenish kaolinite present, some very fine grained pebble gravel sandstone; sand as above; fizzes moderately	As above
198 - 213	As above; reddish brown color; less evaporite material; few hard clay pebbles; calcite and gypsum present; fizzes well	Moist
213 - 229	**Clay**: 90% clay, 10% sand; dark reddish brown; some sandstone pebbles which appear to fizz with acid	As above
229 - 244	As above; dark reddish brown; calcite and selenite crystals present; clay is sticky; fizzes moderately	
244 - 259	As above; color change to grayish brown; clay is plastic and elastic, slightly sticky	
259 - 264	**Clay and Sand**: 60% clay, 40% sand; sand grains are a dull tan color, some selenite and calcite present, all else as above; some whitish material may be kaolinite; fizzes moderately; clays as above	Some plant material possibly sloughing from above
	TD @ 264 cm bgs	

TP-A-103
Lithologic Log

Date Drilled: 2/5/95

Depth Interval, cm	Lithologic Description	Comments
0 - 15	**Sand**: 100%; dark red brown; medium to very fine grained sand, poorly sorted, moderate sphericity, subround to subangular; orange, clear, and black sandstone (?) grains	roots and grass present
15 - 31	**Sand with Clay and Silt**: 85% sand, 15% clay and silt; dark red to orange brown; fizzes slightly with acid; all else as above	slightly moist; rootlets
31 - 46	As above; rare sandstone clasts	As above
46 - 61	**Sand**: 100%; pinkish orange; medium to fine grained sand, moderately sorted; moderate sphericity, subround to angular; fizzes violently with acid	Orangish-white sand grains
61 - 76	As above	As above; some rootlets
76 - 91	**Sand**: 90% sand, 5% silt, 5% clay; all else as above	As above
91 - 107	As above	As above
107 - 122	As above; increase in amount of dark grains to 5-10%	rare rootlets
122 - 137	**Sand**: as above, color change to light orangish-pink; decrease in dark grains	drier than above sample
137 - 152	**Sand with Silt and Clay**: 80% sand; 20 % silt and clay; all else as above	slight powder texture
152 - 168	**Sand with Silt**: 80% sand, 20% silt; all else as above	
168 - 183	As above; some calcareous clasts	
183 - 198	As above; slightly more reddish in color; rare sandstone clasts with calcareous cement	No rootlets
198 - 213	**Sand**: as above; grain size change to fine to very fine; more orangish in color	

TP-A-103
Lithologic Log

Date Drilled: 2/5/95

Depth Interval, cm	Lithologic Description	Comments
213 - 229	As above; color change to bright orangish red; white calcareous clasts, gypsum, and selenite crystals	
229 - 244	As above	
244 - 259	**Sand**: 80% sand, 15% clay, 5% silt; brilliant orangish-red color; medium to very fine sand; poorly sorting, moderate sphericity, round to subround	
259 - 274	As above; no fizz; selenite present, decrease in clay, increase in silt	
274 - 290	As above; some plant material (from above?)	
290 - 305	**Sand and Clay**: 75% sand, 20% Clay, 5% Silt, all else as above; increase in dark clasts	moist
	TD @ 305 cm bgs	

TP-A-106A
Lithologic Log

Date Drilled: 2/5/95

Depth Interval, cm	Lithologic Description	Comment
0 - 15	**Sand with Silt**: 80% sand, 15% silt, 5% clay; reddish light brown; medium to very fine grained, poorly sorted, low sphericity, subangular to round; No fizzing; sand grains are amber, clear, and dark sandstone fragments	Pottery sherds, slightly moist, rootlets
15 - 30	As above; some clods of sand; fine to medium grained gravel clasts; poorly sorted, moderate to low sphericity, subangular to subround; fizzes moderately well	drier than previous sample
30 - 46	As above; some gray clasts similar in appearance to tuff, fizz very well, possibly limestone fragments? some clods of clay and rare kaolinite; sample fizzes very well with acid	some rootlets
46 - 66	**Sand and Clay**: 50% sand, 50% clay; sand as above; fizzes moderately well, clay is non-sticky, plastic and elastic	Moist
66 - 76	**Sand with Clay and Silt**: 70% sand, 15% clay, 15% silt; light brown; fizzes very well	Plant material, moist
76 - 91	**Sand and Clay**: 50% sand, 50% clay; very light brown, some evaporite material (~ 10%)	Moist
91 - 107	**Sand and Clay**: 65% sand, 35% clay; rare evaporites; pinkish orange to light brown in color; fine to very fine sand; poorly sorted; low to moderate sphericity; angular to subangular	
107 - 122	As above: increase in evaporites to ~15%; some clods of clay; light brown to yellowish orange color; drusy calcite, possibly gypsum; sand is poorly sorted, low sphericity, angular to subangular	Moist

TP-A-106A
Lithologic Log

Date Drilled: 2/5/95

Depth Interval, cm	Lithologic Description	Comment
122 - 130	Increase in sand to 75%, clay decrease to 25%; sand as above; some selenite crystals, fizzes well	
	TD @ 130 cm bgs	

TP-A-106B
Lithologic Log

Date Drilled: 2/5/95

Depth Interval, cm	Lithologic Description	Comments
0 - 15	**Sand with Silt**: 80% sand, 15% silt, 5% clay; reddish light brown; medium to very fine grained, poorly sorted, low sphericity, subround to round; No fizzing; some sand grains are strikingly clear, amber, and dark sandstone fragments	
15 - 30	As above: some large clods of clay; brown; fine to medium grained gravel clasts; poorly sorted, moderate to low sphericity, subangular to subround; fizzes well	Plant materia moist sample
30 - 46	**Clay and Sand**: 80% clay, 20% sand; dark brown to milk chocolate in color; sand as above with some degraded sandstone clasts; clay is plastic and elastic	Plant material moist sample
46 - 60	**Sand and Clay**: 50% sand, 50% clay; sand as above; some green staining/limonite(?) associated with sandstone clasts; kaolinite and evaporites present, clay is non-sticky, plastic and elastic; fizzes well	Plant material
60 - 76	**Sand with Clay**: 80% sand, 20% clay; light brown; evaporites appear to be in stringers; some selenite; fizzes very well	Moist
76 - 91	As above	As above
91 - 107	As above: very light brown in color; limonite/iron staining associated with degraded sandstone	As above
107 - 122	**Sand with Silt and Clay**: 80% sand, 10% silt, 10% clay; bright reddish orange to light brown; sand as above; evaporites and very fine dark sandstone grains, some selenite crystals and calcite; fizzes very well.	As above

TP-A-106B
Lithologic Log

Date Drilled: 2/5/95

Depth Interval, cm	Lithologic Description	Comments
122 - 137	As above: large sandstone clasts, fine grained gravel to fine to very fine sand; light brown to yellowish orange; sand as above, poorly sorted; fizzes well	Rare plant material, moist
137 - 152	**Sand and Evaporites**: 70% sand, 30% evaporites; small whitish crystals, sand is brown, selenite colored grains; stiff clays; fizzes very well	
152 - 168	**Evaporites, Sand and Clay**: 30% selenite, calcite and sand grains as above with clumps of salmon colored sand grains; fizzes violently	
168 - 175	**Clay and Sand**: 60% clay, 40% sand; sand as above with degraded sandstone clasts; kaolinite present; sample is purple ash-gray when wet	very dry sample
	TD @ 175 cm bgs	

TP-A-107
Lithologic Log

Date Drilled: 2/4/95

Depth Interval, cm	Lithologic Description	Comments
0 - 15	**Sand with Silt**: 80% sand, 20% silt; reddish brown; amber colored sand grains, rare reddish color; medium to very fine grained sand; moderate sorting; low to moderate sphericity; subround to round; weak fizzing	Moist
15 - 31	As above: some whitish/caliche-like material; fizzes well	Some plant material
31 - 46	**Sand with Silt and Clay**: 65% sand, 20% silt, 15% clay; color change to orangish pink; slight increase in evaporite material; fizzes violently; sand as above	Moist, some plant material
46 - 61	**Sand with Clay and Silt**: 65% sand, 25% clay, 10% silt(?); light brown; sand is poorly sorted, varying sphericity; angular to round, some sandstone clasts; clay is sticky; sample fizzes violently	Slightly drier; increase in rootlets
61 - 76	**Sand and Clay**: 50% sand, 50% clay; as above	As above
76 - 91	As above; ~10% evaporite material that fizz very well; light brown to yellowish orange; predominantly very fine sand, poorly sorted, low sphericity, angular to subangular	As above
91 - 107	Increase in evaporite material; all else as above	As above
107 - 122	As above; light brown color	As above
122 - 137	As above; light brown to yellowish orange; sand grains are subangular to subround; clay is plastic but non-elastic; fizzes well	Moist
137 - 152	**Clay and Sand**: 50% clay, 40% sand, 10% evaporites; clay is plastic and elastic, non-sticky	Slightly drier than above

TP-A-107
Lithologic Log

Date Drilled: 2/4/95

Depth Interval, cm	Lithologic Description	Comments
152 - 168	**Clay with Sand**: 60% clay, 20% sand, 20% evaporites; increase in evaporites and clods of clay, some kaolinite; less sand; sample fizzes well; becomes reddish brown when wet	
168 - 183	**Clay and Sand and Evaporites**: 40% clay, 30% sand, 30% evaporites; light gray to red; sample fizzes well	
183 - 198	As above; decrease in sand, increase in clay content; color change to light grayish purple; sample fizzes very well; clay is elastic, plastic and slightly sticky	
198 - 213	**Clay with Evaporites**: 85% clay, 15% evaporites; as above	
213 - 221	**Clay with Sandstone and Evaporites**: 75% clay, 20% sandstone, 5% evaporites; color change to reddish purple; rare sandstone grains, coarse sand to very fine gravel may be due to boulder at base of auger hole; sample fizzes well	Hit somethin hard at 221 cm
	TD @ 221 cm bgs	

TP-A-118
Lithologic Log

Date Drilled: 2/5/95

Depth Interval, cm	Lithologic Description	Comments
0 - 15	**Sand with Silt and Clay**: 80% sand, 10% silt, 10% clay; dark brown; medium to very fine grained sand; poorly sorted; moderate to high sphericity; subround; grains are translucent orange (feldspar) and slightly amber (selenite?) in color; no fizzing	Plant materi
15 - 31	As above; sample fizzes more strongly than before; slight increase in clay content	Very moist
31 - 46	**Sand and Silt**: decrease in clay content, 80% sand, 20% silt; reddish brown color	Charcoal an rootlets
46 - 61	As above	As above
61 - 76	**Sand with Silt and Clay**: 80% sand, 10% silt, 10% clay; color change to light brown to yellowish orange; sand as above; sample fizzes very well	Some rare plant materia
76 - 91	**Sand** as above; beginning of evaporite layer; slight color change to orangish-pink; fizzes very well	Downward lightening of color
91 - 107	**Sand and Evaporites**: 85% sand, 15% evaporites; color change to pinkish orange/salmon color; medium to very fine sand, as above; rare silt; fizzes well	Rare charcoal, moist sample
107 - 122	**Sand with Silt and Clay**: 80% sand, 20% silt and clay; predominantly orangish pink color, some clumps of darker grains; fizzes very well; some selenite(?)	Pleasant texture, almost foam
122 - 137	As above with 10% evaporites, some sandstone clasts; increase in fine-grained material; rare crystalline and dark clasts as above	Slightly mois
137 - 152	**Sand** as above, increase in dark clasts; fizzes well	Pleasant texture

TP-A-118
Lithologic Log

Date Drilled: 2/5/95

Depth Interval, cm	Lithologic Description	Comments
152 - 168	**Sand with Silt**: 80% sand, 20% silt; light yellowish orange, increase in fine material; rare evaporite clumps and dark material (sandstone); some angular to subangular, translucent grains may be calcite and selenite/gypsum; sample fizzes very well	Dry
168 - 183	As above; limonite - iron staining present, most likely associated with sandstone clasts; clasts fizz when ground; poorly sorted sand with orangish grains that do not fizz	Dry
183 - 198	**Sand with Silt and Clay**: 80% sand, 10% silt, 10% clay; increase in fine to very fine grained sand; sample fizzes well	Dry
198 - 213	As above, increase in clay to 15%, sand decrease; slightly more reddish in color with clumps of whitish material, however sample is still yellowish pink; fizzes moderately well	Dry; rare twigs may be sloughing from above
213 - 229	As above; very fine sand predominates;	As above
229 - 244	As above, color change to light reddish orange to light brown	
244 - 259	**Sand with Silt**: 85% sand, 15% silt; light brown to yellowish orange; fine to very fine sand with rare medium grains, moderately sorted, low sphericity; angular to subangular; some whitish evaporite grains, fizzes well	Slightly moist, some plant materia as above
259 - 264	As above; sharp increase in dry, hard material; fizzes very well; increase in medium sand grains, round to angular, low to high sphericity	Not enough sample collected for analysis
	TD @ 269 cm bgs	

TP-A-123
Lithologic Log

Date Drilled: 2/4/95

Depth Interval, cm	Lithologic Description	Comments
0 - 15	**Sand**: 100% sand; reddish brown; medium to fine grained sand; well sorted; moderate to low sphericity, subangular to subround; no fizz	Cattle excrement; plant materia
15 - 30	As above; rare sandstone grains; no fizz	
30 - 46	**Sand**: 95% sand; 5% clay and silt; very well sorted sand; fizzes well	Very moist, rootlets
46 - 66	**Sand and Clay**: 50% sand, 50% clay; sand as above with rare gravel (pebble sandstone); some kaolinite and dark gray to purple gray clays; clay is slightly plastic and non-sticky; sample fizzes very well	
66 - 91	**Clay with Sand**: 75% clay, 25% sand; sand is reddish brown as above, some gravel size clasts of sandstone; clays are purple and grayish white kaolinite, elastic, plastic and non-sticky; fizzes well	
91 - 107	As above; increase in clay to 90%, sand to 10%; color change to grayish (ash) purple; clay as above; sample fizzes violently	Root materia
107 - 122	**Clay with Gravel**: 75% clay, 25% gravel; fine grained gravel clasts of sandstone, fizz well, but do not appear to be limestone; some kaolinite present	
122 - 137	**Gravel with Clay**: increase in gravel clasts to 75%. Encountered sandstone at base of auger hole	
	TD @ 137 cm bgs	

BH-1
Lithologic Log

Date Drilled: 8/17-18/93

Depth interval, m	Lithologic Description	Comments
0 - 0.9	**Sand:** 80% med. to v. fine sand; rich brown red; sand is subangular to round; mod. to low sphericity; poorly sorted; >5% angular sandstone clasts, similar to those on surface	Compacts well; Pottery and ash
0.9 - 2.4	**Silt and Sand with Clay:** 45% silt, 30% sand as above, 20% clay as above, purple brown; some v. hard clods of clay; >5% white-yellow grains; poorly sorted	Some of sample fizzes with acid
2.4 - 4.0	**Clay with Silt and Sand:** 60% clay, 20% silt, 20% coarse to v. fine sand and subangular rock fragments of purple sandstone; clay and silt appear in clods of 2-30 mm; some whitish-yellow sand size grains, about 2-3% of sample (fizz with HCl)	Very hard drilling, Augers are smoking
4.0 - 5.5	**Silt and Clay:** 50% silt, 30% clay, 20% sand and sst. rock fragments as above; purple brown	Looks like cake mix
5.5 - 7.0	**Clay:** 100% moist clay clods; red brown; some angular sst. frags, subround; yellowish white clay material	
7.0 - 8.5	Same as above: dark red brown; few rock frags., subround, mod sphericity; some whitish green clays	Ground is vibrating
8.5 - 10.1	Same as above: clods larger in size than previous sample, up to 30 mm; some black cs. grd. sand-size clasts within clods	Augers are h and steaming
10.1 - 11.6	Same as above: brown red; some whitish-gray clay (?) fizzes with HCl; some sst. clasts (about 5%)	Tripped out t check bit
11.6 - 13.1	Same as above: purple brown; clods of clay range from 6mm downward; some whitish-yellow and yellow gray clasts <5% of sample	
13.1 - 14.6	Same as above: color of clay clods varies from purple brown to red brown; size of clods is larger than previous sample; less colored clasts	

BH-1
Lithologic Log

Date Drilled: 8/17-18/93

Depth interval, m	Lithologic Description	Comment
14.6 - 15.2	**No Sample**: Unable to collect sample due to balling of clays around augers	
@ 15.2	**Clay:** Wet watery clay, bright vermilion red color	Very slow drilling
	TD @ 15.2 m bgs, water @ 15.2 m bgs No water level due to sloughing of borehole	

BH-2
Lithologic Log

Date Drilled: 8/19-20, 23/93

Depth Interval, m	Lithologic Description	Comments
0 - 0.6	**Sand:** 100% med. to v. fine sand; brown red; sand is subang. to round; mod. to low sphericity; poorly sorted; >5% angular sst. clasts, similar to those on surface, 2-4 mm diameter	Compacts well, moist from recent rains
0.6 - 1.2	**Sand:** 100% sand as above; brown; increase in fine sands; fragments of purple sst.; some calcareous material fizzes with HCl	Pottery sherd Compacts we
1.2 - 2.1	**Silt and Sand:** 50% silt, 45% v. fine sand, 5% sst. clasts; tan red brown; clasts are subang. to subround; low sphericity, pebble to granule gvl.	Hit boulder a 4'; cake mix
2.1 - 3.7	**Silt with Sand:** 80% silt, 15% f. to v. f. sand, 5% subangular rock fragments of purple sandstone, up to 40 mm long, low sphericity; rock fragments increase with depth	Very hard drilling; interbedded with softer material
@ 3.7	Cs. grained sst. rock fragments, v. angular to subang.; low to mod. sphericity; very hard material	Split spoon sample.
3.7 - 4.6	**Silt and Clay:** 65% silt, 25% clay, 10% sand, 5% sst. rock fragments as above; light tan brown; sand grains consistent with rock fragments	Very slow, hard drilling
4.6 - 5.2	**Clay with Silt:** 80% clay, 15% silt, 5% sst frags. and sand as above; clay in v. hard clods w/moist interior increase with depth; broke through hard material at 15 ft	Melted bit
5.2 - 5.3	Same as above: approx. 5 1/2 in. of sample collected; v. hard formation; dusty red brown color	Split spoon sample
5.2 - 6.7	**Clay:** 100% clay clods; dusty red brown; some subang. rock frags., 2 to 25 mm; 2 different types of fragments: on is sst, the other whitish, crumbly, fizzes with HCl	Limestone pebbles present (per B Colpitts)

BH-2
Lithologic Log

Date Drilled: 8/19-20, 23/93

Depth Interval, m	Lithologic Description	Comments
6.7 - 8.2	**Same as above:** 90% clay clods, 10% rock frags; red brown; some small clasts of sand within clods; some rock frags fizz with HCl	Augers steaming
8.2 - 9.8	**Same as above:** clods larger in size than previous sample, some fizz; clay and rock frags also appear as loose material; loose material increases with depth, rock frags decrease	Augers are h and steaming
9.8 - 11.3	**Same as above:** 100% watery red clay	Water @ 37' bgs
11.3 - 11.6	**Clay:** Drier clay compacted by sampler; sst. frags. present; color generally purple brown with some white-green clay or v. f. grained sst present	Split spoon samples
11.6 - 11.9	Very moist clay, no rock fragments, rare whitish fragments < 1mm diameter	
	TD @ 11.9 m bgs, water @ 11.2 m bgs Water level 6.2 m bgs recorded 8/24/93	

BH-3
Lithologic Log

Date Drilled: 8/24, 26/93

Depth Interval, m	Lithologic Description	Comments
0 - 0.3	**Sand:** 95% med. to v. fine sand, 5% silt; dull brown red; sand is angular to subround, mod. to low sphericity; poorly sorted; some clods of sand and whitish carbonate grains	Compacts loosely Pottery and ash
0.3 - 0.6	**Sand with Silt**: 85% sand as above, 15% silt; dark brown (coffee colored); flecks of evaporites	
0.6 - 0.9	**Sand with Silt:** 80% sand, 20% silt; some v. fine pebble gravel-sized sst clasts; some 2 - 4mm v. hard clay clods	Color change to dark red brown
0.9 - 2.1	**Sand with Silt:** 85% sand as above, 10% silt, 5% hard red clay clods; red brown; some calcareous material and sst. clasts as above; rare v. fine clods of sand	Drilled through a boulder
2.1 - 3.7	**Clay and Silt:** 50% silt, 45% clay, 5% sand; Some gravel pebble-sized clasts as above, subround, low sphericity; v. hard clods of clay	Augers are steaming
3.7 - 5.2	**Clay:** 90% clay, 10% silt; hard clods of clay, some whitish green clay and yellowish calcareous clasts; some white hard clay(?) with dendritic patterns	
5.2 - 5.3	**Clay:** As above but increase in green clay content; sample not very well compacted in tube, loose, moist sample; some blackish pebbles of ?	Shelby Tube Sample
5.3 - 6.7	**Clay:** 100% clay clods; red; relatively little loose sample; some v. hard clods that inside contain v. cs. grained clasts of ?; some whitish gray material	
6.7 - 8.2	Same as above: moist; clay clods are larger in size, up to 50 mm long and 40 mm wide; some black grains of ?	Hard drilling
8.2 - 8.8	Same as above: dark red brown, showing some gradational color changes to green; all else same as above	Shelby Tube Sample

BH-3
Lithologic Log

Date Drilled: 8/24, 26/93

Depth Interval, m	Lithologic Description	Comments
	TD @ 8.8 m bgs Water @ 8.8 m bgs 8/26/93	

BH-4
Lithologic Log

Date Drilled: 8/26-27/93

Depth Interval, m	Lithologic Description	Comments
0 -0.9	**Sand with Clay and Silt:** 80% med. to v. fine sand, 20% silt and clay; reddish brown grey; sand is subang. to round; mod. to low sphericity; poorly sorted; some organic matter	
0.9 - 2.4	**Sand and Clay with Silt:** 50% sand as above, 50% clay and silt; some whitish-yellow sand size grains, about 2-3% of sample (fizz with HCl)	Soil compact when squeezed
2.4 - 4.0	**Silt and Clay with Sand:** 65% clay and silt, 35% sand as above; reddish brown; some pebble gravel sized clasts of sandstone; some clods of tan brown sand	"
4.0 - 5.5	Same as above: 70% Clay and Silt, 30% fine to v. fine sand as above; clay and silt appear in clods of 2-30 mm; some black sand grains	
5.5 - 7.0	**Clay:** 100% clay clods; dark red brown; trace sand; some whitish clays; some clasts of sandstone	Sample is moist
7.0 - 8.5	Same as above: Increase in whitish -green clays, about 10%; in brown clays there are some sand cs. to fine sands	
8.5 - 10.1	**Clay:** 100% clay clods, grey clay in discrete clods of 3 mm dia.; some clays show gradation in color from red to grey; absence of yellow-white grains	
10.1 - 11.6	Same as above: Appearance of sandstone clasts (about 5%)	
11.6 - 11.9	**Clay and Silt with Sand:** Calcareous clay with greenish white clay, some clear to black sand grains, about 5% as above	Shelby Tube Sample
11.9 - 12.2	Sample is better consolidated than above, more clayey; clay appears in "balls" cemented by tube, brown red and white-green	

BH-4
Lithologic Log

Date Drilled: 8/26-27/93

Depth Interval, m	Lithologic Description	Comments
	TD @ 12.2 m bgs Water encountered at 11.6 m bgs	

South Windmill
Lithologic Log

Date Drilled: 6/9/94

Depth Interval, m	Lithologic Description	Comments
0 - 0.9	**Silt:** 75% silt, 20% sand and 5% clay; red-brown; white grains in sample may be gypsum; sand is v. fine; clay clods up to 7 mm dia., some have streaks of white through them.	Red top soil; root zone
0.9 - 1.4	**Silt with Sand:** 75% silt, 25% v. fine sand; rare fine gravel, up to 13 mm length; whitish red in color, some whitish grains (gypsum?).	
1.4 - 1.8	**Silt with Clay:** 45% silt, 40% clay, 15% sand; light brown orange; sand is v. fine to cs. sand pebbles; clay is plastic, not sticky.	Color change
1.8 - 2.4	**Clay and Silt:** 65% clay, 20% silt, 15% sand; pale brown yellow; sand is fine to v. fine black flecks to silicates; clay is v. plastic, not sticky. Overall appearance of sample is like cake flour.	Color change looks like cak mix
2.4 - 3.0	**Clay with Gravel:** 60% clay, 20% gravel, 15% sand and 5% silt; pale brown yellow to pale brown red; v. poorly sorted; gravel ranges in size from 5 to 25 mm (fine gravel); sand is v. fine to cs.; angular-subangular; low sphericity; v. poorly sorted. Some clay clods; clods of greenish-white clay.	Gravel fizzes with addition of HCl; most likely limestone
3.0 - 4.0	Same as above: slight increase in smaller size gravels and sands; color change to pale brown yellow; compacts when squeezed with hand.	
4.0 - 4.9	**Clay and Gravel:** 50% clay, 30% gravel 10% sand and 10% silt; pale brown yellow; cohesive when squeezed; gravel predominantly a larger size fraction.	
4.9 - 5.5	**Clay with Gravel:** 80% clay, 15% gravel, 5% silt and red and black sand; pale yellow-brown (yellow when wet); sand is subangular to subround; low sphericity; clay is sticky and plastic when wet.	

South Windmill
Lithologic Log

Date Drilled: 6/9/94

Depth Interval, m	Lithologic Description	Comments
5.5 - 7.9	**Clay and Gravel:** 65% clay, 30% gravel, 5% silt and sand; pale brown yellow; poorly sorted; gravels up to 15 mm size, angular to subangular; moderate to low sphericity, gravels appear to be a grey aphanitic sst(?); rare orange-red sand; some loose clay clod grains.	Slow drilling bit is chewing up boulders.
7.9 - 8.5	**Clay:** 80% clay, 10% gravel, 10% silt and sand; Clay is now appearing in balls w/dust coating and moist, hard interior. All else as above.	
8.5 - 10.1	**Clay and Gravel:** 60% clay, 30% gravel, 10% silt and sand, as above.	
10.1 - 11.0	**Clay with Gravel:** 85% clay, 10% gravel and sand, 5% silt; v. fine gravel to fine sand; multicolored sample but overall a dusty light brown color. All else as above.	
11.0 - 11.6	**Clay:** 95% clay, 5% gravel; stiff clay in balls and clods with dark red brown interiors; gravel is black to grey and red, angular, as above, may be "disguised" as clay balls; some pale brown clays.	Moist
11.6 - 13.1	**Clay with Gravel:** 80% clay, 20% gravel and sand; light brown yellow; clay is somewhat sticky and plastic; all else as above.	
@ 14.6	**Clay with Gravel:** v. moist, dark brown orange yellow; stiff; some gravel 10-15% as above. Unable to collect sample 13.1 - 14.6 m bgs, sample not coming to surface.	
	TD @ 14.6 m bgs	

North Windmill
Lithologic Log

Date Drilled: 6/10/94

Depth Interval, m	Lithologic Description	Comments
0 - 0.9	**Sand:** 75% sand, 25% silt; 1/2 mm - 1/256 mm (silt); red brown, grains are subround, windblown?; some 5mm clasts of grey sst(?); poorly sorted. Moist- compacts well when squeezed with hand.	Top soil; aeolian deposits
0.9 - 1.5	**Sand and Clay or Silt:** 60% sand, 40% clay &/or silt; 1/2 mm - silt size; sand is angular to subround, v. poorly sorted; sample is moist w/some clods of clay: white (gypsum?) clasts and some whitish clays & grayish sst(?).	Compacts loosely when squeezed
1.5 - 2.4	**Clay or Silt:** 90% clay and or silt; 10% sand, in clasts; brown-red; poorly sorted; clay in chips, some white (gyp?) clay clumps with reddish coating, others are red clumps.	Color change hard clay; smoking augers
2.4 - 4.0	**Clay:** 100%, (rare sand); some whitish clays (<3%). Clay predominantly in red clay clumps.	Moist clay, in chips
4.0 - 8.5	**Clay:** 100%; dark red brown; in lumps: chips to grain size. Moisture content increasing with depth. Very slow drilling, some gypsum (?) crystals 7.0 - 8.5 m bgs.	Large clay clumps
8.5 - 8.7	**Clay:** As above; v. moist, sample is in clumps.	Aquifer material?
8.7 - 8.8	**Clay:** As above; v. moist, sticky and plastic.	Aquifer?
8.8 - 10.1	**Clay and Silt w/Gravel:** light red-brown; drier than above; gravel is dark, aphanitic, up to 3 cm in diameter. Also, some well indurated clay clumps. Rest of clay in sample is unconsolidated. This lithology underlies the aquifer material.	Drilled through aquifer.
	TD @ 10.1 m bgs	

MW-1
Lithologic Log

Date Drilled: 9/8-9/94

Depth Interval, m	Lithologic Description	Comments
0 -1.5	**Sand with Gravel**: 90% sand, 10% gravel; reddish brown; medium to very fine sand and very fine to fine gravel; poorly sorted, moderate to low sphericity, angular to subround; few evaporitic materials and quartz, feldspar	
1.5 - 3.0	**Sand**: 95% sand, 5% silt; sand is very fine to fine, moderately sorted, moderate sphericity, subround to angular; selenite, calcite and gypsum present	Moist
3.0 - 3.4	**Sand**: 100% sand; as above; color change from reddish brown to yellow brown; clods of sand up to 20 mm long, subround and low sphericity; some evaporites, rare quartz and plagioclase	Transition - color change
3.4 - 4.6	**Sand** as above, more light brown in color; gypsum crystals present	Moist
4.6 - 6.1	**Clay**: 90% clay, 10% sand; sand as above; clay is reddish brown with purple cast; rare kaolinite, selenite, and evaporites	Moist
6.1- 7.6	**Clay** as above; twigs in sample indicate sloughing of surface sands	
7.6 - 9.1	**Clay**; kaolinite present	
9.1 - 9.8	**Clay**: grey and purple clay, light reddish gray in overall color; clay in small clods/platelets; rare kaolinite and caliche	Approximatel 30-40% surface sands
9.8 - 9.9	**Clay** as above, slight increase in greenish clays	
9.9 - 10.2	**Clay** as above; increase in kaolinite(?) and whitish coating	
10.2 - 12.5	**Clay** as above; decrease in white clays with depth	
12.5 - 13.1	**Clay**; some sandstone gravels and siliceous material	

MW-1
Lithologic Log

Date Drilled: 9/8-9/94

Depth Interval, m	Lithologic Description	Comments
	TD @ 13.1 m bgs	

TP-B-71
Lithologic Log

Date Drilled: 3/20/95

Depth Interval, m	Lithologic Description	Comments
0.9 - 1.5	**Sand with Clay**: 75% sand, 25% clay; 5YR 5/4, reddish brown; medium to very fine grained sand, poorly sorted, low sphericity; angular to round, fizzes very well	Pottery sherd plant material
1.5 - 2.1	As above	
2.1 - 2.4	As above; possible caving from above	Addition of drill foam at 2.4 m
2.4 - 3.0	**Sand and Clay**: 50% sand, 50% clay; 5YR 4/3, reddish brown; sand as above; clay is plastic and elastic; fizzes very well	Addition of drill foam at 3.0 m
3.0 - 4.6	As above; 2.5 to 5YR 5/3, reddish brown; stiff clays, slightly plastic	
4.6 - 6.1	**Clay**: 100% clay, 10R 5/2, rare amber sand grains; clay is slightly stiff, not elastic or plastic with hard clumps of clay	Addition of drill foam at 5.2 m
6.1 - 7.6	As above; 2.5 YR 5/3 to 10R 5/3, reddish brown, few gypsum crystals, weak fizz	
7.6 - 8.2	**Clay and Sand**: 50% clay, 25% sand, 25% gravel; gypsum and/or selenite present; very fine gravel size clasts of sandstone, angular, low sphericity, poorly sorted sample; weak fizz	Boulders, har drilling
8.2 - 9.1	**Clay and Gravel and Sand**: increase in sandstone gravels and sands to 30 to 40%, sand grains to 25%, and clay to 40%, weak fizz	Lithologic change at 8.2 m
9.1 - 9.8	As above; some whitish evaporite clasts; moderate to strong fizz	Lens of Boulders?
9.8 - 10.4	**Clay**: 90% clay, 10% surface sands; 10R 5/3 to 5/2, weak red; clumps/clods of stiff clays	Out of boulde layer

TP-B-71
Lithologic Log

Date Drilled: 3/20/95

Depth Interval, m	Lithologic Description	Comment
10.4 - 11.6	**Clay with Evaporites**: 80% clay, 20% calcite/evaporite material; some sandstone clasts embedded in clay; fizzes very well	
11.6 - 13.1	As above; increase in evaporites to 25%; rare "sticks" (<1%) indicate sloughing from above; some kaolinite present, stiff clays and clay clods; sample fizzes well	
13.1 - 14.6	**Clay**: 90% clay, 10% surface sands; 2.5 YR to 10R 6/3, light reddish brown to pale red; clay clods as above; some sandstone rare calcite/gypsum clasts; moderate fizz	Moist
14.6 - 15.5	As above, rare sandstone and evaporites, less clay clods; 10R 5/3 to 4/3, weak red	
15.5 - 16.2	**Clay with Sandstone and Evaporites**: 70% clay, 30% sandstone and evaporites, as above; 10R 5/2, weak red; clay as above	Clay has a progressively finer texture
16.2 - 17.1	**Clay**: as above; color change to 2.5YR 5/2; clay is slightly plastic, slightly elastic	
17.1 - 18.6	As above; 2.5YR 4/3; weak fizz	
18.6 - 20.1	As above; rare evaporites and sandstone; clay as above	
20.1 - 20.4	**Clay with Sand**: 85% clay, 15% sand; 2.5YR 5/3, reddish brown; very weak fizz; clay is plastic, elastic and slightly sticky	
	TD @ 20.4 m bgs	

TP-B-72
Lithologic Log

Date Drilled: 3/22-23/95

Depth Interval, m	Lithologic Description	Comment
0.9 - 1.5	**Sand with Clay**: 70% sand, 30% clay; 5YR 5/3, reddish brown w/some purple clay fragments; medium to very fine sand, poorly sorted, low sphericity, subangular to round; fizzes well; reddish feldspar and calcite, selenite, gypsum; clay is plastic, slightly elastic, non-sticky; wet color: 5YR 4/3 to 3/3, reddish brown and dark reddish brown	Very dry and very loose sample, some plant material
1.5 - 3.1	As above; 5YR 5/3 to 4/3, reddish brown	Washout, dril foam added
3.1 - 3.8	As above	Washout, drill foam added
3.8 - 4.6	No sample collected; addition of drill foam and installation of surface/conductor casing	see p. 29
4.6 - 5.5	**Clay** with surface sands: 60% clay with 40% surface sands as above; 10R 5/2 to 10R 4/2, weak red; fizzes well; clay is stiff, slightly plastic; non-elastic, slightly sticky	Washout, drill foam added
5.5 - 7.0	**Clay with sandstone gravels**: 70% clay, 20% gravels; some surface sands; some kaolinite; wet color 2.5 YR 4/3, weak red; clay is slightly stiff, non-sticky, plastic and sl. elastic; sandstone gravels fizz - $CaCO_3$ cement? they appear dark and aphanitic, but limestone is not found anywhere else	drill foam add
7.0 - 7.6	**Clay**: gravels as above, <5%; 2.5YR 5/3; to 10R 5/3; reddish brown to weak red; wet 10R 5/3 to 4/3, weak red, all else as above; gravels fizz well	
7.6 - 8.8	**Clay**: some surface sands and gravel clasts ~20%; fizzes fairly well; wet 10R 4/3 to 2.5YR 4/3, weak red to reddish brown; clay is plastic, elastic and slightly sticky	

TP-B-72
Lithologic Log

Date Drilled: 3/22-23/95

Depth Interval, m	Lithologic Description	Comments
8.8 - 9.9	**Clay** as above: 2.5YR 5/2 to 4/3, weak red	
9.9 - 11.4	**Sandstone gravel with clay**: 20% clay, 80% sandstone; 10R 5/1 to 5/2, reddish gray to weak red; medium sand to fine gravel, poorly sorted, low sphericity, angular; fizzes well; wet 10R 3/2 to 2.5YR 3/2 dusky red; clay as above	
11.4 - 11.6	**Clay and sandstone gravel**: 50% clay, 50% sandstone; some whitish, caliche-like material and surface sands < 5%; when wet 10R 4/2; very plastic, elastic and non-sticky clay	
11.6 - 12.8	**Clay**: 10R 4/3 weak red, few evaporite sediments as above; fizzes well; wet 2.5YR 4/3 reddish brown; wet clay is stiff, non-plastic, non-elastic and non-sticky	
12.8 - 13.7	**Clay**: 10R 5/3 when dry, wet 10R 5/3 to 2.5YR 5/3, weak red to reddish brown, all else as above	slightly moist
13.7 - 15.2	**Clay**: 10R 4/3, weak red when dry and wet; wet clay is slightly sticky with some slightly stiff clods of clay, but is plastic and elastic	fairly moist sample
15.2 - 16.8	**Clay**: slight increase in surface sands and evaporites 10-20%; 10R 5/3 to 2.5YR 4/3 weak red to reddish brown; wet color 2.5YR 5/3	
16.8 - 17.5	**Clay**: 2.5YR 5/3 reddish brown; fizzes well; wet color is 2.5YR 4/2 to 10R 4/2, weak red; wet clay is plastic, elastic and slightly sticky	
17.5 - 18.3	**Clay**: 2.5YR 6/2, pale red; wet 2.5YR 5/3 reddish brown; wet clay as above	Dry sample, texture almost like cake flour
18.3 - 19.2	**Clay**: few sandstone gravels (~5%); 10R 6/3; rare kaolinite and caliche; wet clay as above	As above

TP-B-72
Lithologic Log

Date Drilled: 3/22-23/95

Depth Interval, m	Lithologic Description	Comments
	TD @ 19.2 m bgs	

TP-B-103
Lithologic Log

Date Drilled: 3/14/95

Depth Interval, m	Lithologic Description	Comments
0.9 - 1.5	**Sand with Silt and Clay**: 70% sand, 25% silt, 10% clay; 5YR 6/4, light reddish brown; sand is coarse to very fine sand, poorly sorted, moderate to low sphericity; wet color 5YR 8/4, pink (pinkish orange)	
1.5 - 1.8	**Sand**: 90% sand, 10% silt and clay; 7.5YR 7/4, pink; all else as above; predominantly sand colored grains; rare reddish orange and translucent amber grains; wet color 5YR 7/4 to 7.5YR 7/4, pink	Pleasant texture, slightl moist
1.8 - 2.7	**Sand with Clay and Silt**: 80% sand, 20% clay and silt; 7.5YR 7/4 to 6/4, pink to light brown; sand as above, more orangish brown (selenite) grains; fizzes well; clay forms ribbons	Rare plant material
2.7 - 3.0	**Sand and Clay**: 60% sand, 40% clay; 7.5YR 7/3; fizzes well; clay in hard clods; wet color 7.5 YR 8/4, pink; wet clay is slightly sticky, plastic and semi-elastic	
3.0 - 3.7	**Sand with Silt**: 80% sand, 20% silt; 10YR 7/4 very pale brown; coarse to medium sand; moderately well sorted, low sphericity; angular to subround; mostly translucent grains; fizzes well; evaporites clods	
3.7 - 4.3	**Sand and Clay**: 7.5YR 6/4, light brown sand with some 5YR 5/3 reddish brown clay clods; fizzes well; selenite crystals with rare, 2 mm crystals; sand as above; clay is plastic; non-elastic, non-sticky	
4.3 - 4.9	**Clay with Gravel and Sand**: 80% clay, 20% gravel and sand; sand as above, gravel is angular sandstone chips; fizzes well; clay is sticky, plastic and elastic	
4.9 - 6.4	**Clay**: some surface sands as above; clay in clods; 10R 4/3, weak red; weak fizz; wet color 10R 5/3 to 4/3, weak red; clays are stiff, non-sticky and very slightly plastic	

TP-B-103
Lithologic Log

Date Drilled: 3/14/95

Depth Interval, m	Lithologic Description	Comments
6.4 - 7.6	**Clay** with surface sands: 10R 4/3, weak red; clay in stiff clods; wet color 2.5YR 5/3 to 10R 5/2, reddish brown to weak red; clays are stiff, slightly sticky and slightly plastic, non-elastic	
7.6 - 8.4	As above; purplish clay but color is 10R 4/2, weak red; fizzes moderately well; wet color 10R 5/3 to 2.5YR 5/3, weak red to reddish brown; wet clays are stiff, non-sticky, plastic or elastic	
8.4 - 9.5	**Clay**: decrease in surface sands; clay as above except wet color is 2.5YR 5/3 to 6/3, reddish brown to light reddish brown	
9.5 - 9.8	**Clay**: 5YR 7/1 light gray, light gray coating washes off clay to reveal 10R 4/2 clays; lots of kaolinite and evaporites, fizzes well; wet color 5YR 7/2, pinkish gray; non-sticky, stiff clays	Big color change
9.8 - 10.4	**Clay**: 2.5YR 6/2 pale red; evaporite stringers in clays fizz well, all else really doesn't; stiff, slightly plastic and non-elastic wet clays, slightly sticky	
10.4 - 10.7	**Clay**: As above; wet color 5YR 7/2 to 2.5YR 6/2 to 7/2; pinkish gray to pale red	
10.7 - 12.2	**Clay**: rare nodules of Baca(?) sands; 10R 5/2 to 4/2, weak red; caliche present with surface sands and rare kaolinite; wet color 10R 4/2 to 2.5YR 4/2, weak red; wet clays are semi-stiff and slightly plastic, non-elastic	
12.2 - 13.7	**Clay**: some sandstone clasts, few surface sands, and some caliche; fizzes moderately well; wet color 2.5YR 4/3 reddish brown, wet clays are plastic and non-elastic, somewhat stiff	

TP-B-103
Lithologic Log

Date Drilled: 3/14/95

Depth Interval, m	Lithologic Description	Comments
13.7 - 14.9	**Clay**: 90% clay, 10% sandstone clasts; 10R 4/3 weak red; fizzes moderately well; wet color 2.5YR 4/3, reddish brown, wet clays are slightly sticky, plastic and non-elastic	
14.9 - 16.5	**Clay**: 10R 5/3, weak red to 10R 6/3, pale red; clays have interbedded caliche-like material, surface coatings fizz well; wet color 10R 5/2 to 4/2, weak red; wet clays as above, slightly stiff	Color change
16.5 - 18.0	**Clay**: 10R 5/3, weak red; fizzes well; some greenish semi-crystalline material; rare sandstone clasts; wet color 10R 4/2, weak red; wet clays are stiff, slightly plastic, non-elastic and non-sticky	Disseminated clays not in clods
18.0 - 19.2	**Clay**: 10R 5/2, weak red; moderate fizzing of surface sands, some greenish and brick red grains; wet color 10R 4/2 to 2.5 YR 4/2, weak red; wet clay is soft, plastic and elastic, sticky	
19.2 - 19.8	**Clay**, some sandstone grains and rare caliche, moderate fizz; all else as above	
	TD @ 20.7 m bgs; sample is too wet to accurately describe	

TP-B-106
Lithologic Log

Date Drilled: 3/13/95

Depth Interval, m	Lithologic Description	Comment
0.9 - 1.5	**Clay with Sand**: 80% clay, 20% sand; color varies from 5YR 5/3 (sands and loose clays) to 2.5YR 6/2 (clay clods); fizzes well; wet color 5YR 5/3, clay is stiff, slightly plastic, non-elastic and non-sticky	
1.5 - 2.4	As above: some sandstone gravel clasts; 2.5YR 4/3, reddish brown to 10R 5/2, weak red; some caliche, fizzes well; wet color 2.5YR 4/3 to 3/3, reddish brown to dusky red; wet clays are stiff, slightly plastic, non-elastic	
2.4 - 3.0	**Sandstone/Gravel**: 90% sandstone gravels, 10% clay, sand and silt (undifferentiated); 10R 6/1, reddish gray to 2.5YR N5/, reddish gray; gravels are coarse to fine grained, poorly sorted, low sphericity, and angular, selenite present; weak fizz; wet color 5YR 3/2 dark reddish brown to 10R 3/2 dusky red	Lens (?) of Sandstone
3.0 - 3.5	**Gravel with Clay**: 60% gravel, 40% clay; 10R 5/2, weak red; moderate fizz, wet color 10R 3/2; clay is plastic and slightly elastic	
3.5 - 4.6	**Gravel and Sand w/Silt and Clay**: 80-90% gravel and sand, 10-20% silt and clay; 10R 5/1, reddish gray; wet color is 10R 3/1 to 5YR 3/2, dark reddish gray to dark reddish brown	Lens of Sandstone(?)
4.6 - 6.1	As above: fizzes well; 2.5YR N6/ reddish gray, red clay clods about 5-10% of sample, wet color 5YR 4/2, dark reddish gray	
6.1 - 7.6	**Clay**: 10R 5/3, weak red; some gravel chips; wet color 2.5 YR 4/3 to 10R 4/3 to 3/3, reddish brown to weak red to dusky red; wet clays are stiff, slightly plastic, non-elastic and non-sticky	

TP-B-106
Lithologic Log

Date Drilled: 3/13/95

Depth Interval, m	Lithologic Description	Comment
7.6 - 9.1	**Clay** as above, rare kaolinite; 2.5 YR 5/3 to 10R 5/3, reddish brown to weak red; fizzes well; wet color 2.5 YR 4/3, reddish brown; wet clays are stiff, low to no plasticity, non-elastic and non-sticky	Moist sampl
9.1 - 10.7	**Clay**: As above, wet color 10R 5/3 to 4/3, weak red; wet clay is plastic with some stiff clods, slightly sticky, non-elastic	
10.7 - 12.2	**Clay**: 10R 5/2, weak fizz; rare kaolinite, wet color as above, wet clay is plastic, elastic, only slightly sticky	
12.2 - 12.5	**Clay** as above; rare evaporite and greenish grains; some sandstone and surface sands; wet color 2.5YR 4/2 reddish brown, wet clay is plastic and elastic	
12.5 - 12.6	**Aquifer Sands**: fizz well, wet color 5YR 5/3 to 4/3, reddish brown; medium to fine grained sand, moderately sorted, moderate sphericity, subround; clear rounded quartz, reddish grains somewhat similar to surface sands	
	TD @ 13.1 m bgs, not able to describe all samples from 12.6 to 13.1 m bgs, too watery	

TP-B-107
Lithologic Log

Date Drilled: 3/13/95

Depth Interval, m	Lithologic Description	Comment
0.9 - 1.5	**Clay**: 90% clay, 10% sand; 7.5YR 6/4 to 5/4, brown to light brown, to 5YR 7/6, reddish yellow; evaporite clasts, selenite and gypsum; sand is medium to very fine, moderately well sorted; moderate sphericity, subround; wet color 7.5 YR 5/3, brown, wet clay is plastic and elastic	
1.5 - 2.7	**Clay and Sand**: 60% clay, 20% sand; sand color as above, clay is 10R 5/3 to 6/3, weak to pale red; fizzes violently; clay is loose and in clods; wet color 2.5YR 6/3 to 6/4, light reddish brown to reddish brown	
2.7 - 4.3	**Clay**: 10R 4/2, weak red (clay appears two-toned); some gypsum crystals, calcite, and rare sandstone clasts; wet 10R 6/3, pale red; wet clay is plastic and elastic	Moist
4.3 - 5.8	**Clay**: 5-10% sandstone gravels and sands; 10R 5/3 to 4/3 weak red, to 2.5YR 5/3 to 4/3 reddish brown; moderate to weak fizz, wet 10R 4/2, wet clay is soft, plastic with some hard clods, moderately elastic	Texture is almost like cake flour; very moist
5.8 - 7.3	**Clay** as above; color is 2.5YR 6/3 to 5/3, light reddish brown to reddish brown; moderate to weak fizz; wet clay is 2.5YR 4/2, weak red; wet clay as above	As above
7.3 - 8.5	As above; wet color 2.5YR 6/3, light reddish brown	As above
8.5 - 10.1	**Clay**: 10R 5/3 to 5/2, weak red; some sandstone clasts; weak fizz; wet 2.5YR 5/3, reddish brown, not as plastic or elastic as above	Transition, hard clay clods, not as moist
10.1 - 11.3	**Clay** as above; wet color 10R 5/2 to 4/2; wet clay is slightly sticky, very plastic and very elastic	Texture almo like cake flou
11.3 - 11.6	**Gravel and Clay**: 75% sandstone gravel, 25% clay; 10R 4/2, weak red; gravel is angular, low sphericity; moderate to weak fizz, wet 2.5YR 5/2, wet clay as above	

TP-B-107
Lithologic Log

Date Drilled: 3/13/95

Depth Interval, m	Lithologic Description	Comment
	TD @ 12.5 m bgs, samples too wet to describe	

TP-B-118
Lithologic Log

Date Drilled: 3/14/95

Depth Interval, m	Lithologic Description	Comment
0.9 -1.5	**Sand**: 75% sand, 25% silt and/or clay; 7.5YR 7/3 to 6/3, pink to light brown; medium to very fine sand, poorly sorted, low to high sphericity, angular to round; wet 7.5YR 6/4, light brown	Moist
1.5 - 2.7	**Sand** as above: 7.5YR 7/4 to 6/4, light brown to brown; increase in white, opaque evaporites; fizzes well; wet 5YR 6/4 to 5/4, light reddish brown to reddish brown	Color change
2.7 - 3.7	As above: 2.5YR 6/4, light yellowish brown; yellow and dull translucent grains, medium to very fine; clods of evaporites and reddish grains with rare clods of clay; wet 10YR 6/4, light yellowish brown	Color change moist
3.7 - 4.6	**Clay with Sand**: 80% clay, 20% sand; 7.5YR 6/4 to 6/3, light brown; sand as above but predominantly reddish k-spar grains; wet 5YR 5/4 to 5/3, reddish brown; wet clay is plastic and elastic	Color change
4.6 - 6.1	**Clay and Sand**: 50% clay, 50% sand; 2.5YR 4/3, reddish brown; weak fizz; some sand grains are jade colored; wet 2.5YR 5/4, reddish brown; wet clay is somewhat stiff, non-plastic or elastic; sands also associated with Baca Formation	Plant materia indicates sloughing surface sands
6.1 - 7.6	**Clay**: 100% clay; 10R 4/2 to 4/3, weak red; weak to no fizz, although some clay clumps appear to fizz more than others (associated with surface sand coating?); wet 2.5YR 3/3 to 4/3, reddish brown to dark reddish brown, and 10R 5/3 to 4/3, weak red	
7.6 - 8.8	**Clay** as above; some whitish kaolinite clays; 10R 5/2 to 4/2, weak red; no fizz; wet 2.5 YR 5/3 to 4/3, reddish brown	

TP-B-118
Lithologic Log

Date Drilled: 3/14/95

Depth Interval, m	Lithologic Description	Comment
8.8 - 9.5	**Clay**: kaolinite appears to make up 30% of sample; 10R 5/2; slight fizz appears to be associated with surface sands; wet color as above; wet clay is softer than previous, more plastic, but non-elastic	Slightly mois
9.5 - 10.1	**Clay with Silt and Sand**: Not sure if sands and silts are due to sloughing, sand appears in clods; wet 2.5YR 5/2, weak red; wet clay is soft, sticky, plastic and elastic	
10.1 - 10.7	**Clay** as above: weak fizz; some sandstone fragments; angular, coarse sand size. less kaolinite present, but clay clods more abundant but wet clay as above	
10.7 - 12.2	**Clay** as above: 10R 5/2, weak red; no kaolinite; weak fizz; some sand/limonitic nodules appear to contain Baca sands; wet 10R 5/3 to 5/2; wet clay as above	
12.2 - 13.7	**Clay** as above: sandstone clasts as above (~10%); fizzes more strongly than previous; kaolinite and clasts embedded in red clay clasts; wet as above	
13.7 - 15.2	As above; finer sandstone clasts with more apparent surface sands; fizzes well; wet as above	
15.2 - 16.5	**Clay**: 10R 5/2 to 4/3, weak red; with rich amber selenite, fizzes well; wet 10R 5/3, weak red; wet clay as above	
16.5 - 17.4	**Clay** as above, increase in surface grains; wet 2.5YR 5/2 to 4/2, weak red; wet clay is more stiff, not as plastic or elastic	
17.4 - 18.3	**Clay**: 10R 5/2, more disseminated in appearance; evaporites from above; fizzes very well; some sandstone clasts; wet is 10R 5/2 to 4/2, wet clay as above	

TP-B-118
Lithologic Log

Date Drilled: 3/14/95

Depth Interval, m	Lithologic Description	Comment
18.3 - 19.2	**Clay** as above: 5YR 4/2, dark reddish gray to reddish brown, 2.5YR 5/3; moderate to weak fizz; wet 10R 4/2, weak red; wet clay as above	Texture change, almo like cake flou
19.2 - 19.8	**Clay with Sandstone/gravel**: 85% clay, 15% gravels; sandstone chips are varying sizes, poorly sorted, low sphericity, angular; fizzes moderately well; wet 2.5YR 5/2 to 4/2, weak red; clay is non-sticky, plastic and elastic	
	TD @ 19.8 m bgs	

TP-B-123
Lithologic Log

Date Drilled: 3/13/95

Depth Interval, m	Lithologic Description	Comments
0.9 - 1.5	**Clay with surface Sands**: 85% clay, 15% sand: 2.5YR 5/3 to 4/3, reddish brown; rare sandstone pebbles; sand is coarse to very fine, poorly sorted, low sphericity, subangular to subround; rare whitish kaolinite; fizzes moderately well; wet 2.5YR 4/3, wet clay is stiff, non-plastic and non-elastic	
1.5 - 3.0	**Clay**: in clods and loose; 2.5YR 4/3 to 4/2, weak red to reddish brown; fizzes well; wet 2.5YR 5/3 to 4/3; reddish brown; wet clay is soft, moderately plastic with low elasticity	Slightly moist
3.0 - 4.6	**Clay**: 2.5YR 5/3 to 4/3, reddish brown; some evaporitic/caliche-like material embedded in clay; ~10% kaolinite; fizzes well; wet 2.5YR 5/3; wet clay is plastic, semi-elastic with some stiff clods of clay	Moist
4.6 - 6.1	**Clay**: 10R 4/2 to 5/3, dusky to weak red; clay is loose, disseminated and in clods; fizzes well; some sandstone clasts; rare evaporitic clasts; wet 10R 5/3 to 4/3, weak red; wet clay is plastic and elastic	
6.1 - 7.6	**Clay** as above with caliche/kaolinite(?) - whitish material; dry and wet color 10R 6/2 to 5/2, pale to weak red; fizzes well; wet clay is slightly sticky, plastic and elastic	
7.6 - 8.2	**Clay**: mainly disseminated; some kaolinite and evaporitic(?) balls; no fizz; wet 10R 4/2; wet clay is slightly sticky, soft, very plastic and elastic	
8.2 - 8.5	**Clay** as above: ~10% sandstone chips; 10R 5/2, weak red; weak fizz with some clays fizzing more than others; rare sandstone and selenite clasts; wet 10R 5/2 to 5/3, weak red; wet clay as above	

TP-B-123
Lithologic Log

Date Drilled: 3/13/95

Depth Interval, m	Lithologic Description	Comment
8.5 - 9.1	**Sandstone gravel and Clay**: 50% gravel; 50% clay; gravels are angular, poorly sorted (various sizes), low sphericity; weak fizz; wet 2.5YR 4/3; reddish brown; wet clay as above	
9.1 - 9.8	**Aquifer Sand with minor Clay**: overall color 5YR 3/3; weak fizz; predominantly dark mafic(?) or sandstone grains, some quartzose material, yellowish , purple and reddish grains	
	TD @ 9.8 m bgs	

APPENDIX E

Monitoring Well Data

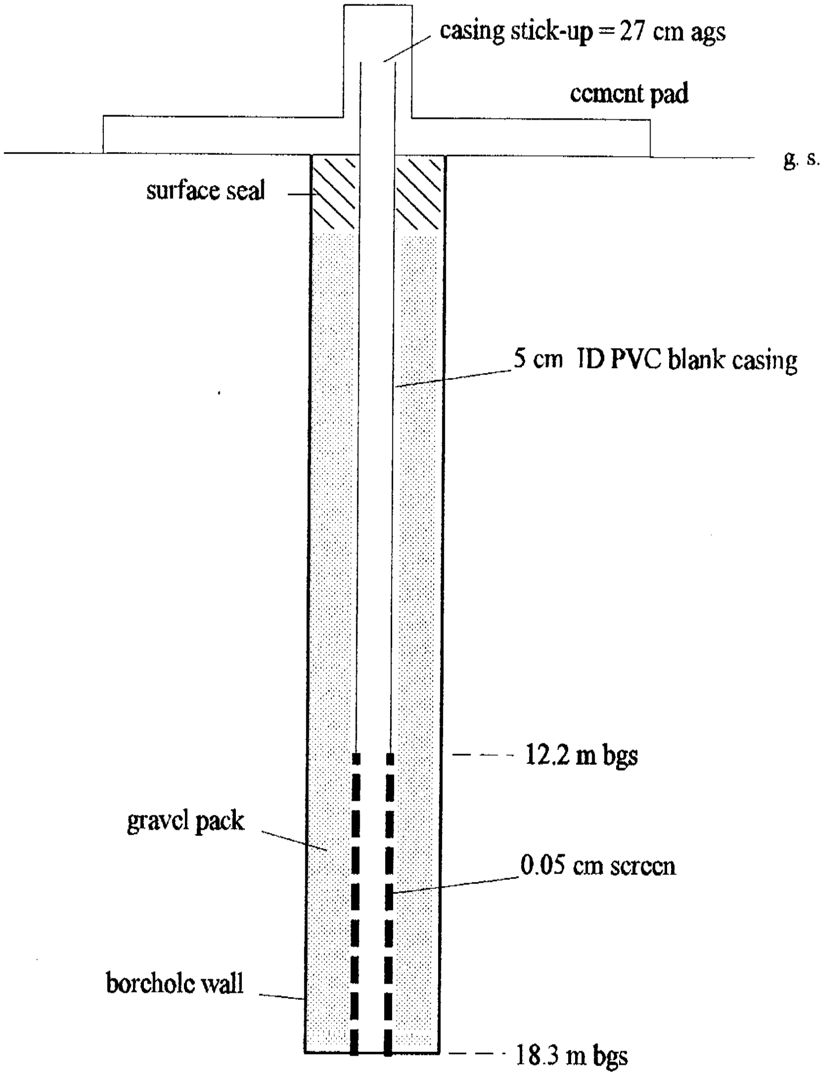

Figure E-1. Schematic Diagram of Monitoring Well MW-1

APPENDIX F

TP-B Water Level Elevations

Table F-1. TP-B Water Level Elevations[1]

Borehole Name	Ground Surface Elevation, m	Elevation at which ground-water was encountered, m	Piezometric level elevation, m
TP 106	1642.29	1629.19	1636.59
TP 123	1643[2]	1633.25	----
TP 107	1643.07	1630.57	1634.67
TP 103	1643.45	1622.75	1634.75
TP 118	1644.24	1623.44[3]	----
TP 71	1644.74	1623.74	1636.84
TP 72	1644.52	1625.32[3]	----
MW-1	1643.17	1624.87	1634.67

Notes:

[1] Elevations are surveyed and referenced to mean sea level

[2] Estimated elevation based upon surrounding contours

[3] Stopped drilling before ground water was encountered

NA-Not available, either due to sloughing of borehole or because stopped drilling prior to reaching ground water

APPENDIX G

Electromagnetic Survey at Fernandez Pueblo and Hand Auger Hole EM-1

Electromagnetic Surveys at Fernandez Pueblo and Hand Auger Hole EM-1

Electromagnetic inductance (EM) surveys were conducted at Fernandez Pueblo. The purpose of the surveys was to determine the extent of the pueblo and midden, and any potential "hot spots" of midden material leachate. Dan Dolmar, a fellow graduate student at NMTech used Geonics, Ltd. (Ontario, Canada) EM-31 and EM-38 electromagnetic inductors to measure ground conductance. Both instruments were used to create a grid survey over approximately a 500 by 450 m area. Ground conductance readings were taken at 0.5 m intervals. The results of the EM-31 survey were used to produce a map of ground conductance at the site, shown in Figure G-1. Dan's surveys revealed a generally low conductance over the extent of the pueblo and anomalously high readings at several locations over the gridded area.

At one of these locations, roughly 540N:575E as shown in Figure G-1, Dan completed an exploratory hand auger hole. The hand auger hole, known as EM-1, was drilled in September 1994 to a depth of 305 cm. A 10-cm diameter bucket auger was used to collect soil samples every 15 cm. Subsurface lithologies encountered during drilling included relatively large thicknesses of evaporite layers at a depth less than 1.5 m from the surface. Samples were processed in the manner described in Section 3.2, and were analyzed for major cations and anions by NMBMMR personnel using IC. As the samples were analyzed by the NMBMMR, the Cl/Br ratios are suspect. However there is no reason to suspect the reported concentrations of sulfate and calcium. The results for soil-water concentrations are shown in Tables G-1 and G-2. Note the high concentrations of sulfate and calcium. The results of the IC analysis and hand auger holes drilled by the archaeologists indicate there is a strong correlation between the depth and thickness of a calcic/evaporate soil horizon to the high conductance readings of the EM surveys.

FERNANDEZ PUEBLO — LA 781

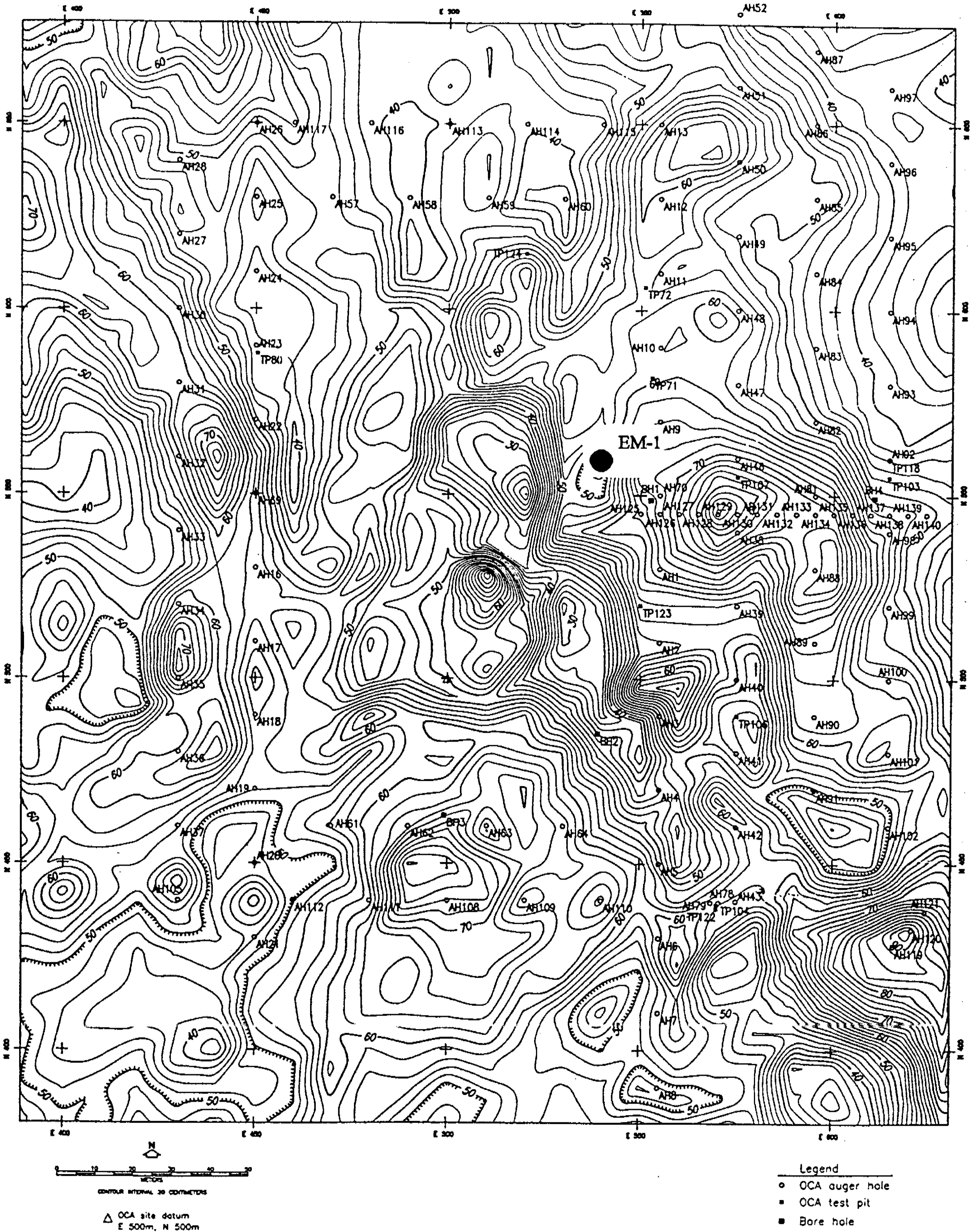

Figure G-1. EM-31 Conductance Survey and Location of EM-1

contour interval = 2 mSiemens/m

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Table G-1. EM-1 major cation concentrations

Depth, cm	Na, mg/l	K, mg/l	Ca, mg/l	Mg, mg/l
15	45.44	881.17	1776.88	331.74
30	38.44	657.67	1608.69	198.13
46	27.62	145.85	807.78	119.10
61	43.09	99.41	526.29	101.56
76	76.46	478.26	9540.70	691.36
91	359.43	932.66	9061.71	1866.88
107	1199.93	1398.64	8667.00	3946.77
122	2112.86	1183.20	6363.43	4213.29
137	3454.04	959.06	6015.50	4559.10
152	4520.87	721.15	6876.92	5351.29
168	5142.22	193.53	4744.69	4183.00
183	5364.62	79.63	4184.58	3681.85
198	5443.91	25.01	3939.02	3409.86
213	5444.61	12.55	4264.81	3161.41
229	5087.42	12.62	4012.08	2863.08
244	4837.22	11.65	4009.76	2686.85
259	4566.38	9.77	3892.84	2584.29
274	3782.56	7.34	3635.06	2243.97
290	4310.68	9.49	4421.72	2644.24
305	4005.26	10.54	4251.10	2501.79

Table G-2. EM-1 major anion concentrations

Depth, cm	Br, mg/l	Cl, mg/l	F, mg/l	NO_3, mg/l	SO_4, mg/l	Cl:Br
15	0.95	30.45	------	272.67	231.77	31.90
30	0.33	38.44	------	94.63	189.26	118.18
46	0.29	22.44	------	46.60	155.34	76.47
61	0.54	27.70	------	43.09	340.09	51.43
76	0.29	14.97	------	7.81	34811.76	51.11
91	2.45	97.60	------	17.04	28878.49	39.87
107	4.66	218.59	------	16.81	36624.57	46.89
122	5.03	269.70	------	10.69	37584.00	53.58
137	7.19	1792.30	------	7.36	41128.04	249.17
152	13.66	3794.26	------	4.92	46997.96	277.80
168	31.73	1216.33	------	5.24	39338.00	38.33
183	25.33	1695.42	------	15.18	34895.36	66.93
198	33.67	2252.93	------	6.90	32928.05	66.90
213	37.12	2517.23	------	------	30592.73	67.81
229	36.67	2585.04	------	------	27661.46	70.49
244	36.94	2667.80	------	------	25563.95	72.22
259	41.62	3253.55	------	------	23324.21	78.18
274	39.92	3343.33	------	------	19883.00	83.76
290	47.26	3909.68	------	------	22926.02	82.72
305	34.93	3893.17	------	3.21	21759.90	111.47

APPENDIX H

Chloride, Bromide and Nitrate-N adjustment of Drill Foam-contaminated TP-B-71and TP-B-72

Chloride, Bromide and Nitrate-N adjustment of Drill Foam-contaminated TP-B-71 and TP-B-72

H.O Introduction

When drill foam was added to the boreholes at TP 71 and TP 72, addition of chloride, bromide and nitrate-N via the drill foam were also added to the samples. Drill foam and drill foam-contaminated samples were prepared and analyzed by HPLC as discussed in Section 3.2.3. A chromatogram of the HPLC analysis for drill foam is shown in Figures H-1. The results of the HPLC analyses indicated 72.2 mg/l chloride, 0.18 mg/l bromide, and 0.257 mg/l nitrate-N were in the drill foam which was added to the borehole. The drill foam Cl/Br ratio is 401. Therefore, it became necessary to "remove" these concentrations from the soil-water concentrations. Tables of calculations outlining the method of removal of added chloride, bromide and nitrate-N for TP-B-71 and TP-B-72 are provided in Tables H-1 and H-2. As shown in Figure H-1, a chromatogram of drill foam, a large distinct peak is present at 51.40 minutes, as well as smaller peaks of chloride, bromide and nitrate at 5.28, 7.71, and 9.50 minutes. The peak at 51.4 min. is present in all samples known to be contaminated with drill foam, and is unique to these samples. Drill foam was added at the base of TP-B-118, where a sample was unable to be collected, and in TP-B-71 and TP-B-72. Representative chromatograms from TP-B-71 and TP-B-72 are shown in Figures H-2 and H-3. The distinct peak present in Figure H-1 is found in Figure H-2, a chromatogram of a sample from TP-B-71 at 47.85 min. and in Figure H-2, TP-B-72, at 47.90 min. (the retention time of the peak decreased with column use. These samples were run a first time but it was necessary to run them again, four days later, as nitrate-N concentrations were initially above the detection limit).

H.1 Method of Adjustment

Adjustments to the original soil-water chloride, bromide, and nitrate-N concentrations were made in the following manner. The ratio of the area of the distinctive peak in the drill foam to that of the area of the reduced distinct peak in the sample was obtained (Eq. 1). Assuming chloride, bromide, and nitrate-N concentrations were reduced by the same amount as the distinct peak, the amount of the ion originally present in the drill foam was divided by this ratio to determine how much of the ion the drill foam contributed (Eq. 2):

$$1)\quad \frac{XD_p}{XS_p} = \frac{XD_{Cl}}{XS_{Cl}} \qquad\qquad 2)\quad \frac{XD_{Cl}}{\left(\frac{XD_p}{XS_p}\right)} = XS_{Cl}$$

where XD_p = Drill foam peak height
XS_p = Sample peak height due to drill foam
XD_{Cl} = Original drill foam anion (Cl, Br, or NO_3-N) concentration
XS_{Cl} = Drill foam anion concentration contributed to the sample

This ratio and subsequent drill foam contribution are labelled as "percent of Drill Foam" and "Diluted Drill Foam Contribution", shown in columns two through five in Tables H-1A and H-2A. The word "diluted" is used to describe the drill foam because once the drill foam is applied to the borehole, it mixes with soil water already present and is thus diluted. The original, reported values of the HPLC, i.e., non-adjusted, contaminated sample results, and the HPLC ratio are also provide in the tables and are shown in columns six through nine. The adjusted value of the ion is then obtained by subtracting the diluted drill foam contribution from the reported HPLC value. These adjusted values are shown in Tables H-1B and H-2B, columns two through four. For comparison purposes, the percentages of the original HPLC value contributed by the drill foam ions are shown in columns five through seven under the heading "% DF Contribution". Soil-water concentrations are determined using gravimetric water contents, and the now-adjusted concentrations of chloride, bromide, and nitrate-N are shown in columns eight through 10 in Tables H-1B and H-2B. The adjusted Cl/Br ratio is shown in column 11. Note how Cl/Br ratios have decreased when compared to the original HPLC ratios in Tables H-1A and H-2A. Samples obtained from depths in which contamination was greatest, such as 8.7 m in TP-B-71 and 3.4 m in TP-B-72 exhibit the largest decreases in ratios. Samples in which contamination was the least, such as at 2.3 m depth in TP-B-71 and 5.0 m depth in TP-B-72, show the least decreases in the Cl/Br ratio.

H.3 Uncertainty of Method

Chloride and bromide concentrations from these boreholes were then compared with other TP-B boreholes. As concentrations are lower in TP-B-71 and TP-B-72 throughout the boreholes relative to other TP-B boreholes, it appears that the method of adjustment has removed more chloride and bromide than was originally contributed by the drill foam. Chloride and bromide concentrations were then compared with those in the corresponding hand auger holes (TP-A-71 and TP-A-72). Chloride concentrations are 14% lower in TP-B-72 (based on comparisons with the last two data points in TP-A-72) and 60% lower in TP-B-71 (based on comparisons with the last seven data points in TP-A-71). Bromide concentrations are 40% to 47% lower in TP-B-71 and TP-B-72, respectively (generally speaking, when all TP-A chloride and bromide concentrations are compared to all TP-B concentrations, TP-A concentrations are found to be either higher or lower than concentrations in the TP-B boreholes, so the comparisons in the case of TP-B-72 and TP-B-71 may not be truly valid).

As we are interested in the Cl/Br ratio, hand calculations were made to increase soil-water chloride concentrations to 60% of their original value and increase bromide concentrations to 40% of their original value at TP-B-71. The resulting Cl/Br ratios were found to be 14% to 15% higher than the previously adjusted values, which appears to correlate well with the high ratios found in TP-A-71. When the same adjustments were made for TP-B-72 (14% increase for chloride, 40% increase for bromide) Cl/Br ratios decreased by 20%. The chloride adjustment of 14% may not be valid for TP-B-72, as comparisons with the hand auger hole data were made on the basis of two points. Therefore, on the basis of results for TP-B-71, it would appear there is an approximate 14% to 15% error associated with this method of drill foam adjustment, which tends to decrease Cl/Br ratios more than necessary.

```
P\DATA1\7172.41R Date printed=06-14-1995 Time= 17:41:47
ame=Drill Foam
.0 min. Low Y=8.963 High Y=485.849 mv Span=476.886
```

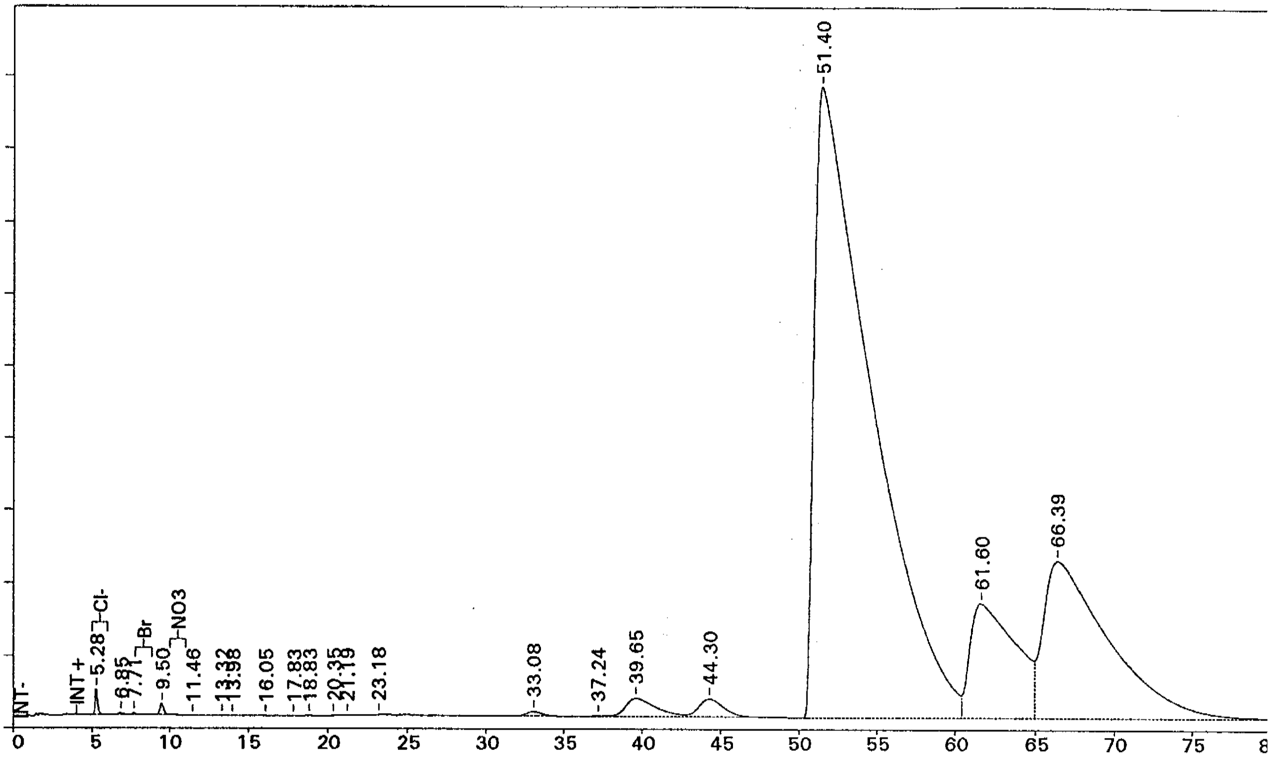


Figure H-1
Drill Foam Chromatogram

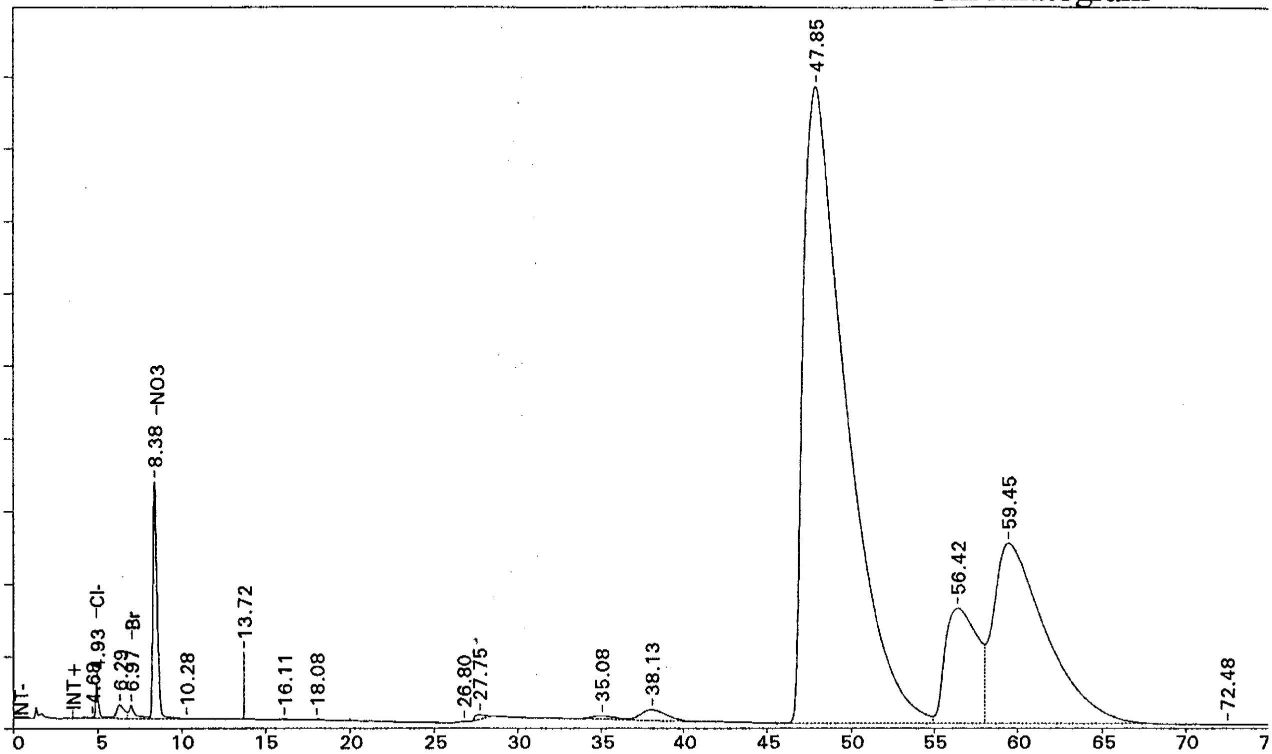
```
, all samples have drill foam, run time=85 min.
KH2PO4,pH=3.8, 2.0 ml/min, lambda=195nm, 6/14/95
file = C:\CP\DATA1\7172.41R
ate stamp = 06/14/95 Time = 17:40:30
e name = Drill Foam
cted on JUN 14, 1995  16:14:50   from port # 1
tor =    Laura Quemada
ence file name = Q0DE607Bb#37
ument = WATERS 481
d name = C:\CP\DATA1\LAURA.MET  version # 3
ate method last modified = 06/13/95 Time = 09:28:14
ration file = C:\CP\DATA1\LQ.CAL version # 97
ate cal file last modified = 06/14/95 Time = 16:54:44
ime =   85.02 minutes   Area reject = 0
t injected = 25    Dilution Factor = 1
e Weight = 1    Internal Standard Amount = 1
ing rate = 1  per second
detect threshold = 1.59   Starting peak width = .1  minutes
-Perfect Software Serial # 15483 Version = 6.07 For New Mexico Tech
's date = 06-14-1995   Time = 17:42:41

ime     Name                 Amount  Amount %       Area    Area % Type   Width       Height  Height %
280 Cl-                      2.8859 100.0000%  194,353.6    0.126%  BV    0.190    17,032.80   2.6261%
848                          0.0000   0.0000%   28,554.7    0.019%  VV    0.407     1,169.14   0.1803%
708                          0.0000   0.0000%   16,964.0    0.011%  VB    0.241     1,172.85   0.1808%
502                          0.0000   0.0000%  138,968.6    0.090%  BB    0.312     7,430.91   1.1457%
459                          0.0000   0.0000%    3,670.0    0.002%  BB    0.419       146.09   0.0225%
323                          0.0000   0.0000%      331.6    0.000%  BV    0.118        46.65   0.0072%
980                          0.0000   0.0000%    3,228.9    0.002%  VB    0.536       100.43   0.0155%
054                          0.0000   0.0000%      194.0    0.000%  BB    0.080        40.66   0.0063%
```

```
832                    0.0000  0.0000%        827.1   0.001% BB   0.236        58.33   0.0090%
834                    0.0000  0.0000%      6,177.2   0.004% BB   0.517       199.14   0.0307%
350                    0.0000  0.0000%      1,200.1   0.001% BB   0.572        34.97   0.0054%
190                    0.0000  0.0000%        921.5   0.001% BB   0.229        66.92   0.0103%
185                    0.0000  0.0000%        367.7   0.000% BB   0.120        50.87   0.0078%
085                    0.0000  0.0000%    198,117.6   0.129% BB   1.127     2,929.31   0.4516%
239                    0.0000  0.0000%      3,029.6   0.002% BV   0.626        80.70   0.0124%
652                    0.0000  0.0000%  1,576,315.9   1.025% VV   2.195    11,966.30   1.8450%
297                    0.0000  0.0000%  1,278,495.3   0.831% VB   1.813    11,755.25   1.8124%
404                    0.0000  0.0000%105,576,752.0  68.641% BV   4.227   416,247.81  64.1766%
605                    0.0000  0.0000% 14,837,770.0   9.647% VV   3.284    75,297.66  11.6093%
389                    0.0000  0.0000% 29,944,584.0  19.468% VB   4.856   102,770.35  15.8450%
a =  1.538108E+08   Total amount =  2.885882   Sample units = mg/L       Total height =  648597.2
```

```
:P\DATA1\FOAM.11R Date printed=06-22-1995 Time= 02:05:14
ıme=TP 71, 27-30 ft
ı.0 min. Low Y=-3.07 High Y=144.847 mv Span=147.917
```

Figure H-2. TP-B-71 Representativ
Chromatogram



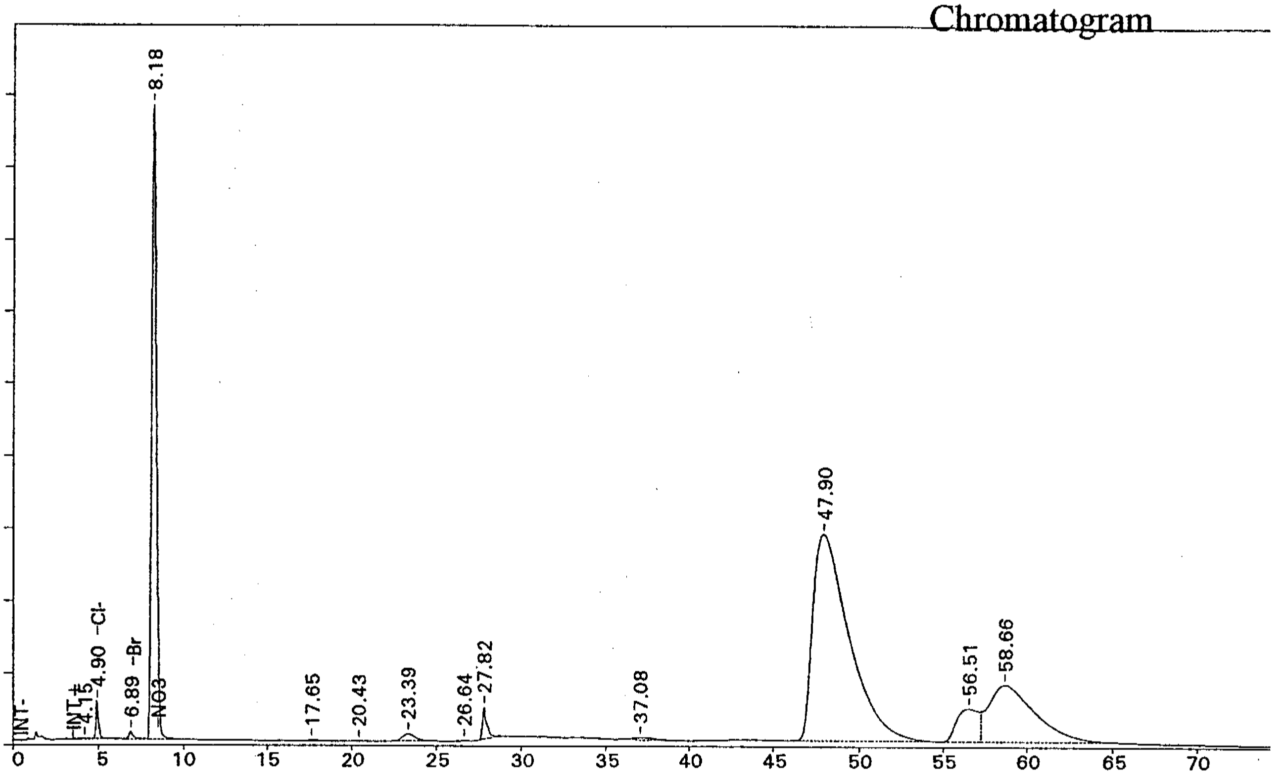
```
ting Samples, Drill Foam
KH2PO4,pH=3.8, 2.0 ml/min, lambda=195nm, 6/21/95
file = C:\CP\DATA1\FOAM.11R
ate stamp = 06/22/95 Time = 02:03:50
e name = TP 71, 27-30 ft
cted on JUN 22, 1995  00:42:49   from port # 1
tor =    Laura Quemada
ence file name = Q0E8120Ab#11
ument = WATERS 481
d name = C:\CP\DATA1\LAURA.MET  version # 16
ate method last modified = 06/21/95 Time = 15:05:22
ration file = C:\CP\DATA1\LQ.CAL version # 120
ate cal file last modified = 06/21/95 Time = 00:00:00
ime =   80.02 minutes   Area reject = 0
t injected = 25    Dilution Factor = 1
e Weight = 1    Internal Standard Amount = 0
ing rate = 1  per second
detect threshold = 1.59   Starting peak width = .1  minutes
-Perfect Software Serial # 15483 Version = 6.07 For New Mexico Tech
's date = 06-22-1995   Time = 02:06:05
```

```
'ime     Name                     Amount  Amount %        Area  Area % Type  Width        Height  Height %
.683                              0.0000   0.0000%     5,215.5  0.015% BV    0.474        183.51   0.0678%
.925 Cl-                          1.1058  92.7521%    79,805.4  0.223% VV    0.188      7,080.59   2.6150%
.295                              0.0000   0.0000%    88,922.7  0.248% VV    0.541      2,738.26   1.0113%
.967 Br                           0.0141   1.1827%    71,255.4  0.199% VV    0.442      2,689.68   0.9933%
.379 NO3                          0.0723   6.0652%   817,875.0  2.282% VV    0.281     48,528.61  17.9223%
.281                              0.0000   0.0000%     3,152.9  0.009% VB    0.451        116.51   0.0430%
.717                              0.0000   0.0000%    14,117.1  0.039% BB    0.017     13,791.29   5.0933%
.113                              0.0000   0.0000%     5,423.8  0.015% BB    0.573        157.82   0.0583%
.076                              0.0000   0.0000%     6,951.1  0.019% BB    0.699        165.85   0.0613%
```

```
800                        0.0000   0.0000%       5,616.6   0.016% BB    0.613          152.64   0.0564%
750                        0.0000   0.0000%      43,782.7   0.122% BB    0.751          971.37   0.3587%
081                        0.0000   0.0000%      66,182.3   0.185% BV    1.631          676.50   0.2498%
129                        0.0000   0.0000%     242,304.7   0.676% VB    1.796        2,248.79   0.8305%
847                        0.0000   0.0000% 23,092,456.0  64.432% BV    2.949      130,497.09  48.1945%
420                        0.0000   0.0000%  3,210,009.0   8.956% VV    2.252       23,753.10   8.7724%
451                        0.0000   0.0000%  8,086,841.5  22.564% VB    3.645       36,981.64  13.6579%
483                        0.0000   0.0000%         389.6   0.001% BB    0.167           38.79   0.0143%
a =  3.58403E+07    Total amount =  1.19216   Sample units = mg/L        Total height =  270772
```

```
:P\DATA1\FOAM.27R Date printed=06-22-1995 Time= 18:19:27
ıme=TP 72, 5-10 ft
).0 min. Low Y=8.423 High Y=207.309 mv Span=198.886
```

Figure H-3. TP-B-72 Representativ
Chromatogram



```
ting Samples, Drill Foam
KH2PO4,pH=3.8, 2.0 ml/min, lambda=195nm, 6/22/95
File = C:\CP\DATA1\FOAM.27R
ate stamp = 06/22/95 Time = 18:18:08
e name = TP 72, 5-10 ft
cted on JUN 22, 1995  16:57:27   from port # 1
tor =    Laura Quemada
ence file name = Q0E8F678b#27
ument = WATERS 481
d name = C:\CP\DATA1\LAURA.MET  version # 16
ate method last modified = 06/21/95 Time = 15:05:22
ration file = C:\CP\DATA1\LQ.CAL version # 120
ate cal file last modified = 06/21/95 Time = 00:00:00
ime =   80.02 minutes   Area reject = 0
: injected = 25   Dilution Factor = 1
e Weight = 1   Internal Standard Amount = 0
ing rate = 1  per second
detect threshold = 1.59   Starting peak width = .1  minutes
-Perfect Software Serial # 15483 Version = 6.07 For New Mexico Tech
's date = 06-22-1995   Time = 18:20:14

ime    Name              Amount  Amount %       Area  Area % Type  Width      Height  Height %
150                      0.0000   0.0000%    2,359.9  0.015%  BV   0.307      128.12   0.0455%
900 Cl-                  1.6276  85.7225%  114,647.9  0.711%  VV   0.184   10,373.04   3.6848%
886 Br                   0.0108   0.5697%   36,161.3  0.224%  VV   0.288    2,092.57   0.7433%
185 NO3                  0.2603  13.7078% 3,367,117.8 20.889% VB   0.320  175,264.50  62.2586%
650                      0.0000   0.0000%   15,061.4  0.093%  BB   0.706      355.57   0.1263%
433                      0.0000   0.0000%      692.3  0.004%  BB   0.187       61.62   0.0219%
387                      0.0000   0.0000%  101,450.0  0.629%  BB   0.873    1,935.81   0.6877%
638                      0.0000   0.0000%    2,934.8  0.018%  BB   0.576       84.91   0.0302%
817                      0.0000   0.0000%  152,545.0  0.946%  BB   0.289    8,787.67   3.1216%
```

```
.080                              0.0000   0.0000%     65,484.8   0.406%  BB    1.699        642.31   0.2282%
.898                              0.0000   0.0000%  8,451,715.0  52.432%  BB    2.475     56,916.29  20.2182%
.515                              0.0000   0.0000%    826,919.8   5.130%  BV    1.520      9,064.92   3.2201%
.660                              0.0000   0.0000%  2,982,299.5  18.501%  VB    3.145     15,803.11   5.6137%
ea =   1.611939E+07    Total amount =   1.898698   Sample units = mg/L         Total height =  281510.5
```

Table H-1A. TP-B-71 Drill Foam Calculations

Depth midpoint, m	% of Drill Foam	Diluted Drill Foam Contribution			Original/Reported HPLC Values			HPLC
		Cl, mg/l	Br, mg/l	NO_3-N, mg/l	Cl, mg/l	Br, mg/l	NO_3-N, mg/l	Cl/Br
1.2	0.278	0.201	0.001	0.001	5.87	0.060	2.46	97.8
1.8	0.338	0.244	0.001	0.001	18.7	0.138	8.52	136
2.3	0.131	0.095	0.000	0.000	29.9	0.225	15.7	133
2.7	80.0	57.8	0.144	0.206	118	0.858	68.5	138
3.8	33.7	24.3	0.061	0.087	330	3.58	126	92.2
5.3	15.8	11.4	0.028	0.041	168	1.98	40.7	84.8
6.9	8.20	5.92	0.015	0.021	39.8	0.422	2.26	94.3
7.9	8.20	5.92	0.015	0.021	26.3	0.243	0.919	108
8.7	21.9	15.8	0.039	0.056	24.1	0.226	1.60	107
9.4	12.7	9.15	0.023	0.033	26.2	0.246	1.37	107
10.1	4.59	3.31	0.008	0.012	21.2	0.234	3.23	90.6
11.0	2.16	1.56	0.004	0.006	15.4	0.169	1.51	91.1
12.3	4.13	2.98	0.007	0.011	11.6	0.142	1.70	81.7
13.9	1.89	1.36	0.003	0.005	11.0	0.122	1.13	90.2
15.1	1.59	1.15	0.003	0.004	12.0	0.140	1.31	85.7
15.9	1.68	1.21	0.003	0.004	13.4	0.142	1.38	94.4
16.6	1.09	0.785	0.002	0.003	11.7	0.132	1.00	88.6
17.8	1.24	0.892	0.002	0.003	13.6	0.140	0.958	97.1
19.4	1.77	1.28	0.003	0.005	11.9	0.129	0.954	92.2
20.3	7.35	5.31	0.013	0.019	17.3	0.184	2.32	94.0

Note: Bold typeface indicates addition of drill foam to the borehole at this depth.

Table H-1B. TP-B-71 Drill Foam Calculations (cont'd)

Depth midpoint, m	Adjusted Values Cl, mg/l	Adjusted Values Br, mg/l	Adjusted Values NO3-N, mg/l	% Drill Foam Contribution Cl, mg/l	% Drill Foam Contribution Br, mg/l	% Drill Foam Contribution NO_3-N, mg/l	Soil Water Concentrations Cl, mg/l	Soil Water Concentrations Br, mg/l	Soil Water Concentrations NO_3-N, mg/l	Cl:Br
1.2	5.67	0.060	2.46	3.42	0.833	0.029	201	2.11	87.3	95.3
1.8	18.5	0.137	8.52	1.30	0.441	0.010	634	4.72	292	134
2.3	29.8	0.225	15.7	0.317	0.105	0.002	1040	7.84	548	133
2.7	60.2	0.714	68.3	48.9	16.8	0.300	1461	17.3	1657	84.4
3.8	306	3.52	126	7.37	1.69	0.069	2771	31.9	1141	86.9
5.3	157	1.95	40.7	6.78	1.43	0.100	1390	17.3	361	80.2
6.9	33.9	0.407	2.24	14.9	3.50	0.932	383	4.61	25.3	83.2
7.9	20.4	0.228	0.898	22.5	6.07	2.29	228	2.56	10.1	89.3
8.7	8.30	0.187	1.54	65.6	17.4	3.51	252	5.68	46.9	44.5
9.4	17.0	0.223	1.34	34.9	9.27	2.38	414	5.41	32.4	76.4
10.1	17.9	0.226	3.22	15.6	3.53	0.365	176	2.22	31.7	79.2
11.0	13.8	0.165	1.50	10.1	2.31	0.368	117	1.40	12.8	83.8
12.3	8.62	0.135	1.69	25.7	5.24	0.625	87.3	1.36	17.1	64.0
13.9	9.64	0.119	1.13	12.4	2.78	0.429	91.0	1.12	10.6	81.3
15.1	10.8	0.137	1.31	9.60	2.05	0.313	124	1.57	15.0	79.1
15.9	12.2	0.139	1.38	9.06	2.13	0.313	144	1.64	16.2	87.7
16.6	10.9	0.130	0.997	6.71	1.48	0.279	128	1.53	11.7	83.9
17.8	12.7	0.138	0.955	6.56	1.59	0.332	138	1.50	10.4	92.2
19.4	10.6	0.126	0.949	10.7	2.47	0.477	163	1.94	14.6	84.4
20.3	12.0	0.171	2.30	30.7	7.19	0.815	192	2.74	36.9	70.2

Note: Bold typeface indicates addition of drill foam to the borehole at this depth

Table H-2A. TP-B-72 Drill Foam Calculations

Depth, midpoint, m	% Drill Foam Solutes	Diluted Drill Foam Contribution			Original/Reported HPLC Values			
		Cl, mg/l	Br, mg/l	NO3-N, mg/l	Cl, mg/l	Br, mg/l	NO3-n, mg/l	Cl/Br
1.2	1.64	1.18	0.003	0.004	5.17	0.040	1.83	129
2.3	8.00	5.78	0.014	0.021	38.6	0.248	6.87	156
3.4	9.35	6.75	0.017	0.024	29.9	0.225	15.7	133
4.2	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
5.0	2.94	2.12	0.005	0.008	344	3.82	43.5	90.1
6.2	1.69	1.22	0.003	0.004	131	1.60	4.73	81.9
7.3	2.13	1.54	0.004	0.005	75.5	0.931	3.28	81.1
8.2	2.88	2.08	0.005	0.007	30.5	0.300	2.02	102
9.4	1.67	1.21	0.003	0.004	20.8	0.205	1.34	101
10.7	5.65	4.08	0.010	0.015	30.1	0.251	3.05	120
11.5	2.49	1.80	0.004	0.006	25.5	0.255	2.34	100
12.2	0.303	0.219	0.001	0.001	15.6	0.155	0.491	101
13.3	0.433	0.313	0.001	0.001	13.9	0.127	0.271	109
14.5	0.621	0.448	0.001	0.002	10.7	0.108	0.325	99.1
16.0	0.448	0.324	0.001	0.001	17.7	0.171	0.490	104
17.1	1.93	1.40	0.003	0.005	16.5	0.172	0.904	95.9
17.9	0.787	0.569	0.001	0.002	16.8	0.151	0.614	111
18.7	0.377	0.272	0.001	0.001	16.5	0.136	0.543	121

Note: Bold typeface indicates addition of drill foam to the borehole at this depth. N/S = not sampled at this depth

Table H-2B. TP-B-72 Drill Foam Calculations

Depth midpoint, m	Adjusted Values			% Drill Foam Contribution			Soil Water Concentrations			
	Cl, mg/l	Br, mg/l	NO3-N, mg/l	Cl, mg/l	Br, mg/l	NO_3-N, mg/l	Cl, mg/l	Br, mg/l	NO_3-N, mg/l	Cl:Br
1.2	3.99	0.037	1.83	22.9	7.38	0.230	149	1.38	68.2	108
2.3	32.8	0.234	6.85	15.0	5.81	0.299	1295	9.22	270	141
3.4	23.2	0.208	15.7	22.6	7.48	0.153	770	6.92	521	111
4.2	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
5.0	342	3.81	43.5	0.617	0.139	0.017	3507	39.1	446	89.6
6.2	130	1.60	4.73	0.929	0.190	0.092	1172	14.4	42.7	81.3
7.3	74.0	0.927	3.27	2.03	0.411	0.167	717	8.99	31.7	79.8
8.2	28.4	0.295	2.01	6.82	1.73	0.367	434	4.51	30.8	96.4
9.4	19.6	0.202	1.34	5.79	1.47	0.320	298	3.07	20.3	97.0
10.7	26.0	0.241	3.04	13.6	4.05	0.476	624	5.78	72.8	108
11.5	23.7	0.251	2.33	7.06	1.76	0.274	268	2.83	26.4	94.6
12.2	15.4	0.154	0.490	1.40	0.352	0.159	149	1.49	4.73	99.6
13.3	13.6	0.126	0.270	2.25	0.614	0.411	145	1.35	2.88	108
14.5	10.3	0.107	0.323	4.19	1.04	0.491	101	1.05	3.19	95.9
16.0	17.4	0.170	0.489	1.83	0.472	0.235	172	1.68	4.83	102
17.1	15.1	0.169	0.899	8.46	2.02	0.550	181	2.02	10.8	89.6
17.9	16.2	0.150	0.612	3.38	0.939	0.330	206	1.90	7.77	109
18.7	16.2	0.135	0.542	1.65	0.499	0.179	212	1.77	7.07	120

Note: Bold typeface indicates addition of drill foam to the borehole at this depth. N/S = not sampled at this depth

APPENDIX I

Clay Mineralogy Analyses at BH-4

Analysis of Clay Mineralogy at BH-4

At the onset of the site investigation at Fernandez Pueblo, lithologic samples from BH-4 were sent to the NMBMMR Clay Laboratory for clay mineral analyses. On the basis of lithologic descriptions for BH-4 (Appendix D, page 124) and the results of the analyses, the contact between geologic formations could be determined. Kaolinite and illite compose 80 to 90% of the clays found in the Quaternary colluvium and are predominant from 0 to 2.4 m bgs. Clays in the Eocene Baca Formation are predominantly illite and smectite with minor kaolinite. The mineralogy changes at a depth of 5.5 m, where mixed-layer illite/smectite and smectite predominate. Just a trace of kaolinite is present below 5.5 m. These changes in clay mineralogy correlate very well with the observed lithologic changes in BH-4.

Table I-1. Mineralogy of Clay-size Fraction at BH-4

Sample Depth, m	KAO	ILL	CHL	SME	I/S	Others & Comments
0 - 0.9	2	4	?	1	3	QTZ, (CAL) (very poorly crystalline)
0.9 - 2.4	3	6	?	1	-	CAL, QTZ (poorly crystalline)
2.4 - 4.0	1	3	?	2	4	CAL, QTZ, FEL
4.0 - 5.5	1	2	?	3	4	CAL, QTZ, FEL
5.5 - 7.0	Tr	-	?	4	6	(QTZ), (FEL), (CAL
7.0 - 8.5	Tr	-	?	3	7	QTZ, (FEL), (CAL)
8.5 - 10	Tr	-	?	3	7	QTZ, (FEL), (CAL)
10 - 11.6	Tr	1	-	4	5	QTZ, (FEL?)

* Analyses conducted by the NMBMMR Clay Mineralogy laboratory

NOTES:

1) KAO = kaolinite, ILL = illite, CHL = chlorite, SME = smectite, and I/S = mixed-layer illite and smectite
2) Clay minerals reported as parts in ten
3) Non-clay minerals: CAL = calcite, FEL= feldspar, QTZ = quartz
4) (?) = mineral may be present in small amounts, __ = major component, and ( ) = minor component
5) Smectite present is Na-rich, not Ca-rich

APPENDIX J

Archaeologic and Hand Auger Sampling Results

Table J-1. Archaeologic Test Pit/Midden Samples*

Location	Chloride, mg/l	Bromide, mg/l	Cl:Br
SU 72, FS 79, Lvl 4, Strat 6E	180	6.43	28.0
SU 80, FS 82, Lvl 4, Strat 6	202	9.27	21.7
SU 71, FS 76, Lvl 5, Strat 13	53.2	20.1	2.65
SU 71, FS 75, Lvl 4, Strat 7	805	6.33	127
SU 71, FS 74, Lvl 3, Strat 2	275	8.77	31.4

* Analyses by NMBMMR

Table J-2. SU 72 NE

Depth, cm	Chloride, mg/l	Bromide, mg/l	Cl:Br
14	57.7	ND	ND
24	74.3	ND	ND
36	49.6	0.60	83.3
46	65.2	ND	ND
55	16.2	0.24	67.5

* Analyses by NMBMMR
No sample collected 0-10 cm bgs

Table J-3. SU 72 SE

Depth, cm	Chloride, mg/l	Bromide, mg/l	Cl:Br
8	25.8	ND	ND
19	64.5	7.74	8.33
27	45.6	0.40	115
36	53.3	0.84	63.3
44	109	0.82	133

* Analyses by NMBMMR

Table J-4. SU 72 Pit*

Depth, cm	Chloride, mg/l	Bromide, mg/l	Cl:Br
145	ND	0.31	ND
175	535	94.9	78.1
189	847	8.47	100
198	1578	10.8	147
206	1813	12.3	147
217	2113	13.4	158
226	1376	14.5	95.2
235	1416	10.6	133
241	3855	16.8	230

*Analyses by NMBMMR
No sample collected from 152-168 cm bgs

Table J-5. Cl-1*

Depth, midpoint, cm	Chloride, mg/l	Bromide, mg/l	Cl/Br	%Gravimetri Water Conte
7.5	55.1	----	----	1.59
22.5	32.4	----	----	2.63
37.5	22.6	1.46	15.4	1.69
53.0	21.4	----	----	2.04
68.5	18.8	0.982	19.1	2.46
83.5	14.9	1.10	13.5	3.59
98.5	11.8	0.515	23.0	5.86
114.0	11.0	0.441	25.0	6.69
129.5	4.24	0.279	15.2	9.89
144.5	10.0	----	----	5.71
159.5	25.9	----	----	5.11
175.0	33.2	----	----	4.60

*Analyses by NMBMMR

Table J-6. Cl-2*

Depth, midpoint, cm	Chloride, mg/l	Bromide, mg/l	Cl/Br	% Gravimetri Water Conte
7.5	65.9	----	----	2.72
22.5	53.2	----	----	3.41
37.5	25.3	----	----	2.41
53.0	11.2	0.520	21.6	5.32
68.5	7.24	0.232	31.2	8.58
83.5	4.00	----	----	12.5
98.5	5.48	----	----	12.5
114.0	------	----	----	13.8
129.5	------	----	----	8.10
144.5	------	----	----	12.4
159.5	------	----	----	10.9
175.0	------	----	----	14.0
190.5	------	----	----	17.5
205.5	------	0.163	----	16.3
220.5	------	----	----	14.7

*Analyses by NMBMMR

Table J-7. Cl-3*

Depth, midpoint, cm	Chloride, mg/l	Bromide, mg/l	Cl/Br	% Gravimetric Water Conten
7.5	36.1	----	----	2.65
22.5	28.4	----	----	1.94
37.5	14.0	----	----	1.78
53.0	32.5	----	----	1.88
68.5	45.8	0.982	46.7	3.25
83.5	4.52	----	----	7.07
98.5	ND	----	----	8.02
114.0	9.20	0.468	19.7	7.35
129.5	8.01	0.408	19.6	7.30
144.5	13.1	0.630	20.8	8.99
159.5	29.9	----	----	8.64
171.0	34.1	0.630	54.2	8.99

*Analyses by NMBMMR

Table J-8. AH-1*

Depth, midpoint, cm	Chloride, mg/l	Bromide, mg/l	Cl/Br	%Gravimetric Water Conten
7.6	53.0	ND	----------	1.32
22.9	19.8	ND	----------	1.78
38.1	29.5	0.950	31.0	2.20
53.3	4.32	ND	----------	5.10
68.6	6.11	ND	----------	7.53
83.8	16.2	0.646	25.0	7.07
99.1	16.7	0.397	42.0	5.60
114.3	10.1	ND	----------	5.49
129.5	5.62	ND	----------	5.32
144.8	ND	0.432	----------	5.10
160.0	ND	0.405	----------	5.49
175.3	ND	ND	----------	5.04
190.5	ND	ND	----------	5.21

*Analyses by NMBMMR

Table J-9. AH-2*

Depth, midpoint, cm	Chloride, mg/l	Bromide, mg/l	Cl/Br	%Gravimetri Water Conten
7.6	72.1	ND	----------	1.57
22.9	43.5	ND	----------	1.42
38.1	108	ND	----------	2.93
53.3	85.3	0.186	457	4.06
68.6	21.6	0.675	32.0	4.88
83.8	23.1	0.251	92.0	4.33
99.1	23.9	0.576	41.5	3.73
114.3	55.1	ND	----------	4.77
129.5	186	2.23	83.6	5.49
144.8	909	10.9	83.7	10.2
160.0	1199	19.1	62.9	11.5
175.3	1719	24.1	71.3	12.4
190.5	53.2	28.0	1.90	14.5

*Analyses by NMBMMR

Table J-10. AH-3*

Depth, midpoint, cm	Chloride, mg/l	Bromide, mg/l	Cl/Br	%Gravimetri Water Conter
7.6	96.8	ND	----------	1.16
22.9	58.2	ND	----------	1.21
38.1	30.4	ND	----------	2.20
53.3	21.1	ND	----------	4.77
68.6	17.7	ND	----------	5.93
83.8	418	0.190	2200.00	5.88
99.1	42.7	ND	----------	4.60
114.3	42.1	ND	----------	4.11
129.5	36.5	ND	----------	3.52
144.8	119	ND	----------	3.31
160.0	302	6.22	48.48	5.93
175.3	940	13.8	68.04	8.17
190.5	1062	24.4	43.48	8.87

*Analyses by NMBMMR

Looks like first three rows of this table have errors - use spreadsheet values

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Table J-11. TP-A-71

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Depth midpoint, cm	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl:Br	%Gravimetric Water Content	Chlori age, y
8	8.00	6.77	0.80	3.94 1.18	?8.43	6.2
23	22.9	57.4	0.77	5.91 0.40	75.0 ?	6.5
38	38.1	6.57	0.66	8.41 5.80	10.0	8.9
53	1489	ND	ND	----	12.3	364
69	70	1.27	39.8	55 55.1	9.65	377
91	543	5.43	65.6	100 100	7.99	512
114	2574	18.4	525	140 140	6.50	1042
130	1953	14.4	679	135	11.9	1512
145	1769	12.1	753	146	16.8	2047
160	1863	12.1	843	155	15.3	2591
175	2220	14.0	1135	159	19.1	3402
191	1989	12.5	995	159	21.8	4185
206	1896	12.1	938	156	21.3	4956
221	2906	18.1	1509	160	20.2	6078
236	3026	16.6	1614	182	20.0	7173
251	3250	21.1	1806	154	23.5	8635
267	3542	23.4	1984	152	21.6	1009
282	3449	23.0	1995	150	21.0	1148
19. 297	3691	25.7	2159	143	21.7	1301

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Table J-12. TP-A-72

Depth, midpoint, cm	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl:Br	%Gravimetric Water Content	Chlo age,
8	33.5	1.10	1.54	30.4	5.32	2.
23	12.0	1.52	4.29	7.9	7.41	4.
38	6.56	0.682	18.0	9.6	8.99	5.
53	5.97	0.761	7.73	7.8	9.17	6.
69	23.1	0.575	2.69	40.2	9.77	1
84	19.1	0.731	11.1	26.1	9.05	1.
99	16.4	0.702	7.25	23.3	6.61	1
114	22.1	0.763	13.0	29.0	13.1	2
130	14.2	0.598	7.08	23.7	12.3	2
145	26.4	0.511	0.458	51.7	14.7	3
160	125	1.07	ND	117.0	16.9	7
175	441	3.40	2.121	129.7	14.9	21
191	907	6.64	1.838	136.5	16.2	52
206	1323	9.6	7.4	137.9	19.0	10
221	1773	12.1	22.2	146.6	20.2	17
236	1997	12.5	46.2	160.2	18.9	24
251	2388	15.4	103.2	155.0	18.6	33
18 262	2392	15.2	148.8	157.8	14.0	38

Table J-13. TP-A-103

Depth, midpoint, cm	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl/Br	%Gravimetric Water Content	Chlorid age, yr
8	3247	ND	ND	------	6.16	-----
23	3.48	0.793	0.170	4.39	8.23	0.7
38	3.59	0.560	3.06	6.41	9.83	1.5
53	3.01	0.480	5.19	6.28	10.93	2.2
69	5.04	0.367	3.18	13.7	8.64	3.2
84	8.60	0.354	0.339	24.3	7.47	4.7
99	18.0	0.617	0.069	29.2	6.61	7.4
114	25.3	0.905	0.189	27.9	5.93	11
130	37.4	0.979	0.142	38.2	6.33	16
145	71.5	1.44	0.041	49.6	5.37	25
160	218	3.30	0.309	66.3	5.37	51
175	417	5.83	ND	71.5	5.49	102
191	3828	ND	ND	-------	5.32	556
206	1001	13.0	ND	77.1	4.00	646
221	1295	16.2	ND	79.9	4.33	771
236	1321	16.1	ND	82.1	6.67	968
251	1633	19.4	ND	84.2	6.72	1213
267	1700	19.3	ND	88.2	6.04	1442
282	1565	17.8	ND	87.8	7.41	1701
297	1727	19.3	ND	89.7	8.23	2018

Table J-14. TP-A-106A

Depth, midpoint, cm	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl:Br	%Gravimetric Water Content	Chlori age, y
8	16.2	0.594	29.0	------	5.21	0.9
23	9.39	0.573	15.5	16.4	8.34	2.7
38	5.53	0.429	4.74	12.9	13.6	4.4
53	5.29	0.464	0.189	11.4	13.4	5.9
69	2.84	0.404	1.52	7.03	12.4	6.6
84	4.97	0.513	0.051	9.68	12.1	7.9
99	12.3	0.596	0.794	20.7	12.6	12
114	9.64	0.658	0.127	14.6	11.6	14
126	10.1	0.496	0.413	20.4	10.2	16

Table J-15. TP-A-106B

Depth, midpoint, cm	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl:Br	%Gravimetric Water Content	Chlor age, y
8	9.13	1.54	60.4	5.94	4.93	0.5
23	4.70	0.348	22.8	13.5	9.17	1.5
38	3.80	0.360	6.59	10.6	14.7	2.7
53	8.79	0.451	0.616	19.5	12.1	4.7
69	7.52	0.484	0.772	15.5	10.5	6.4
84	5.57	0.576	1.21	9.67	12.6	8.1
99	6.92	0.558	0.414	12.4	13.1	10
114	21.7	0.876	1.23	24.8	9.35	15
130	21.2	0.744	0.064	28.4	9.23	20
145	52.3	1.77	0.102	29.5	13.8	37
160	171	3.53	0.030	48.4	17.8	115
171	160	4.28	0.400	37.4	12.1	147

Table J-16. TP-A-107

Depth, midpoint, cm	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl:Br	%Gravimetric Water Content	Chlor age,
8	4.70	ND	17.2	----	5.43	0.3
23	8.28	ND	5.08	----	7.64	1.8
38	9.84	0.399	3.22	24.7	8.17	3.6
53	7.32	0.374	14.4	19.6	11.1	5.6
69	4.38	0.379	7.64	11.5	14.2	6.9
84	7.62	0.482	9.74	15.8	12.4	9.0
99	35.4	1.73	7.43	20.4	11.5	18
114	165	2.69	ND	61.3	8.93	50
130	428	5.74	ND	74.6	9.35	138
145	678	8.34	ND	81.4	12.9	330
160	1083	12.6	ND	86.3	13.2	640
175	1222	16.3	1.48	75.1	13.5	101
191	1748	18.4	0.50	95.2	16.8	161
206	2174	22.4	ND	97.0	15.4	226
217	2019	20.9	ND	96.6	12.0	263

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Table J-17. TP-A-118

Depth midpoint, cm	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl:Br	%Gravimetric Water Content	Chlori age, y
8	8.06	0.050	2.39	162	6.84	0.6
23	7.28	0.380	1.80	19.2	6.89	0.9
38	8.35	0.581	1.53	14.4	7.07	1.6
53	11.1	0.438	0.803	25.4	6.16	2.4
69	11.0	0.360	4.44	30.5	7.70	3.4
84	14.7	0.547	0.954	26.8	10.38	5.3
99	14.3	0.415	0.039	34.4	9.11	6.9
114	18.8	0.846	0.674	22.2	8.11	8.7
130	17.0	0.793	0.255	21.4	8.23	10
145	33.6	ND	2.49	----	7.53	13.5
160	8.38	1.09	0.081	7.69	7.01	14.2
175	2859	40.0	2.14	71.5	6.21	232
191	13.4	0.894	0.250	15.0	5.32	233
206	13.0	0.694	0.327	18.8	5.43	234
221	13.8	0.611	0.197	22.5	5.04	234
236	14.0	0.939	0.188	14.9	4.66	235
251	23.4	0.477	0.846	49.0	7.47	237

Table J-18. TP-A-123

Depth, midpoint, cm	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl:Br	%Gravimetric Water Content	Chlo age,
8	12.1	0.753	334	16.1	3.25	0.
23	31.4	0.873	125	36.0	5.04	4.
38	11.4	0.578	45.1	19.7	6.89	5.
53	6.40	0.343	12.9	18.7	10.6	7.
76	19.9	0.419	3.90	47.6	12.5	1
99	74.8	0.914	1.98	81.8	13.8	4
114	151	1.104	5.93	137	10.1	7
130	273	0.182	42.1	1500	4.17	10

APPENDIX K

Hollow-Stem Auger Sampling Results

Table K-1. BH-1

Depth, midpoint, m	Chloride*, mg/l	Bromide, mg/l	Cl:Br	%Gravimetric Water Content	Chloride age, yrs
0.5	38.9	1.56	25.0	2.57	6.9
1.7	351	7.14	49.1	10.7	595
3.2	4360	16.0	273	8.29	8421
4.7	5542	27.5	201	3.68	12539
6.2	1154	8.69	133	7.35	14253
7.8	203	2.21	91.7	13.0	14787
9.3	102	1.44	71.0	13.7	15070
10.8	373	2.45	152	12.8	16033
12.3	295	1.98	149	12.2	16762
13.9	186	1.54	121	12.8	17192

*Analyses by NMBMMR

Table K-2. BH-2

Depth, midpoint, m	Chloride*, mg/l	Bromide, mg/l	Cl:Br	%Gravimetric Water Content	Chloride age, years
0.3	43.4	ND	----	1.94	3.9
0.9	ND	ND	----	2.20	3.9
1.7	45.2	ND	----	2.15	14
2.9	72.1	7.60	9.48	1.57	32
4.1	193	11.0	17.5	1.11	82
4.9	26.7	0.713	37.5	4.93	96
5.3	41.7	0.466	89.5	4.44	106
6.0	39.3	ND	----	7.63	136
7.5	212	1.89	112	10.3	552
9.0	471	2.32	203	11.5	1695
10.5	424	2.80	151	29.7	4355
11.4	90.3	1.92	47.1	23.8	5153
11.7	273	4.41	61.9	37.1	5401

*Analyses by NMBMMR

Table K-3. BH-3

Depth, midpoint, m	Chloride*, mg/l	Bromide, mg/l	Cl:Br	%Gravimetric Water Content	Chloride age, yrs
0.2	87.2	ND	----	1.78	3.6
0.5	50.3	1.82	27.7	2.72	10
0.8	33.8	ND	----	4.17	16
1.5	ND	2.80	----	3.79	16
2.9	2689	39.4	68.3	8.23	4009
4.4	3692	30.5	121	10.5	11772
5.3	1614	15.0	107	8.74	13479
6.1	209	4.67	44.8	19.2	13885
7.5	599	12.9	46.6	7.05	14652

*Analyses by NMBMMR

Table K-4. BH-4

Depth, midpoint, m	Chloride*, mg/l	Bromide, mg/l	Cl:Br	%Gravimetric Water Content	Chloride age, yrs
0.5	75.0	12.4	6.07	2.67	13
1.7	92.1	2.76	33.3	3.73	72
3.2	4644	19.0	245	5.76	5761
4.7	14068	64.7	218	6.78	25910
6.2	5864	54.1	108	14.8	43441
7.8	2627	16.1	164	12.9	50301
9.3	570	9.20	62.0	11.4	51616
10.8	1036	8.17	127	10.4	53785
11.7	1959	13.0	150	14.5	57221
12.0	382	2.21	173	10.4	57382

*Analyses by NMBMMR

Table K-4A. BH-4 Major Cations and Anions*

Depth, m	Cl	SO_4	Br	Na	K	Mg	Ca
0.5	7.0	1100	17	48	67	42	480
1.7	2.5	5300	6.0	80	130	140	2400
3.2	44	4300	13	420	26	215	1200
4.7	185	3900	87	430	44	240	1200
6.2	270	6800	105	500	38	400	2200
7.8	90	6500	15	310	22	110	490
9.3	50	1000	11	230	16	50	260
10.8	50	1100	13	220	22	60	290
6.2 dup	270	9600	105	460	34	380	1900
Method	IC	IC	IC	AA	AA	AA	AA

All results in mg/kg dry soil
*Analyses by NMBMMR

Table K-5. South Windmill*

Depth midpoint, m	Chloride, mg/l	Bromide, mg/l	Cl/Br	%Gravimetric Water Content	Chloride age, yrs
0.5	67.9	1.49	45.5	8.64	35
1.1	1054	2.99	352	8.17	817
1.6	2940	9.41	313	7.87	2191
2.1	2984	9.89	302	7.30	3638
2.7	2278	6.68	341	7.58	5088
3.5	5677	17.0	333	2.99	6867
4.4	5706	17.5	326	2.77	8797
5.2	4366	14.1	310	4.49	10738
6.2	4892	10.1	486	3.73	13559
7.5	5008	10.6	471	3.41	16575
8.2	3208	13.8	232	5.54	18487
9.3	3551	8.74	406	3.95	20653
10.5	1461	3.51	417	7.93	22648
11.3	536	1.55	347	12.0	23299
11.9	2074	5.66	367	5.93	24338

*Analyses by NMBMMR

Table K-6. North Windmill*

Depth, midpoint, m	Chloride, mg/l	Bromide, mg/l	Cl/Br	%Gravimetric Water Content	Chloride age, yrs
0.5	73.5	0.653	113	5.43	27
1.2	76.6	0.712	108	6.33	70
2.0	851	5.54	154	8.70	119
3.2	151	0.874	173	16.8	1313
4.7	84.1	0.657	128	17.7	1826
6.2	24.0	0.727	33.0	16.7	2127
7.8	18.0	10.3	1.75	15.2	2207
8.7	31.8	0.237	134	32.8	2239
9.4	86.3	0.677	127	8.87	2355

*Analyses by NMBMMR

APPENDIX L

Air Rotary Borehole Sampling Results

Table L-1. MW-1*

Depth, midpoint, m	Chloride, mg/l	Bromide, mg/l	Cl/Br	% Gravimetric Water Content	Chloride age, yrs
0.8	40.6	0.96	42.1	4.28	21
2.3	1084	13.7	79.3	5.43	1382
3.2	1754	20.2	86.9	5.93	2825
4.0	3893	44.8	87.0	8.40	6848
5.3	3129	41.8	74.9	20.2	17716
6.9	1160	17.6	66.1	17.4	21584
8.4	182	3.38	53.8	15.0	22106
9.4	99.1	2.50	39.6	13.8	22301
9.9	112	2.10	53.5	14.0	22396
10.2	97.5	1.85	52.7	15.6	22458
10.5	106	2.03	52.2	14.7	22520
11.0	107	1.94	55.2	15.5	22621
11.7	104	1.89	55.0	11.7	22745
12.5	104	1.66	62.8	13.9	22890
13.1	119	2.05	57.9	11.4	22999
13.6	87.7	1.59	55.3	15.7	23083
14.3	98.0	1.53	63.9	15.3	23235
15.1	97.0	1.63	59.5	17.4	23405
15.5	112	1.87	60.0	17.2	23522
16.3	113	2.28	49.6	13.3	23674
17.1	119	2.52	47.2	8.34	23774
17.4	273	3.95	69.1	51.4	24481

* Analyses by NMBMMR

Table L-2. TP-B-71

Depth, midpoint, m	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl:Br	% Gravimetric Water Content	Chloride age, yrs
1.2	201	2.11	87.3	95.3	2.99	28
1.8	634	4.72	292	134	3.09	209
2.3	1040	7.84	548	133	3.04	417
2.7	1461	17.3	1657	84.4	4.49	851
3.8	2771	31.9	1141	86.9	14.2	6583
5.3	1390	17.3	361	80.2	14.5	10665
6.9	383	4.61	25.3	83.2	10.7	11496
7.9	228	2.56	10.1	89.3	10.9	11920
8.7	252	5.68	46.9	44.5	3.52	12037
9.4	414	5.41	32.4	76.4	4.49	12282
10.1	176	2.22	31.7	79.2	12.7	12463
11.0	117	1.40	12.8	83.8	15.4	12683
12.3	87.3	1.36	17.1	64.0	12.3	12878
13.9	91.0	1.12	10.6	81.3	13.4	13125
15.1	124	1.57	15.0	79.1	10.6	13325
15.9	144	1.64	16.2	87.7	10.2	13466
16.6	128	1.53	11.7	83.9	10.3	13591
17.8	138	1.50	10.4	92.2	11.3	13830
19.4	163	1.94	14.6	84.4	7.47	14063
20.3	192	2.74	36.9	70.2	7.12	14211

Table L-3. TP-B-72

Depth midpoint, m	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl:Br	%Gravimetric Water Content	Chlorid age, yr
1.2	149	1.38	68.2	108	2.83	19
2.3	1295	9.22	270	141	2.67	579
3.4	770	6.92	521	111	3.20	1007
4.2	NA	NA	NA	----	NA	NA
5.0	3507	39.1	446	89.6	12.1	5721
6.2	1172	14.4	42.7	81.3	14.2	8271
7.3	717	8.99	31.7	79.8	13.0	9587
8.2	434	4.51	30.8	96.4	7.53	9941
9.4	298	3.07	20.3	97.0	7.58	10247
10.7	624	5.78	72.8	108	4.55	10899
11.5	268	2.83	26.4	94.6	10.7	11273
12.2	149	1.49	4.73	99.6	13.1	11449
13.3	145	1.35	2.88	107	11.5	11686
14.5	101	1.05	3.19	95.9	12.7	11882
16.0	172	1.68	4.83	102	12.7	12299
17.1	181	2.02	10.8	89.6	10.0	12544
17.9	206	1.90	7.77	109	9.35	12718
18.7	212	1.77	7.07	120	9.05	12908

Table L-4. TP-B-103

Depth midpoint, m	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl:Br	% Gravimetric Water Content	Chlor age,
1.2	141	0.345	0.115	410	4.77	31
1.7	68.9	2.24	0.178	30.7	6.33	61
2.3	2141	24.5	0.772	87.5	4.99	102
2.9	3231	37.2	14.4	86.8	8.05	330
3.4	3305	37.6	0.977	87.8	3.74	417
4.0	5585	60.0	0.659	93.1	5.37	683
4.6	5960	61.1	0.081	97.6	7.07	1032
5.6	3428	35.3	0.028	97.2	19.6	1983
7.0	1918	20.4	0.247	93.9	17.4	2590
8.0	1058	10.8	0.059	98.0	18.7	2850
8.9	274	3.42	0.030	80.1	18.0	2910
9.6	186	2.96	3.71	62.8	14.9	2935
10.1	235	2.08	3.85	113	17.8	2960
10.5	219	2.54	3.27	86.2	16.7	2983
11.4	265	3.30	5.00	80.3	16.6	3033
13.0	306	3.63	5.48	84.3	13.6	3113
14.3	221	2.75	3.37	80.6	14.8	3169
15.7	161	1.80	0.663	89.7	17.5	3218
17.2	282	3.17	4.47	88.9	16.3	3310
18.6	314	3.62	5.62	86.9	9.59	3359
19.5	423	5.18	7.24	81.6	7.35	3393

Table L-5. TP-B-106

Depth, midpoint, m	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl:Br	% Gravimetric Water Content	Chlo age,
1.2	26.0	1.22	0.965	21.2	14.4	6
2.0	81.5	2.76	3.69	29.5	12.4	17
2.7	845	24.5	0.133	34.5	3.20	55
3.3	814	19.3	2.20	42.1	6.89	10
4.0	2687	47.9	7.67	56.1	2.41	19
5.3	1590	25.4	0.097	62.6	3.31	319
6.9	131	1.91	5.65	68.9	10.6	347
8.4	94.1	1.39	4.14	67.8	13.4	373
9.9	110	1.40	3.92	78.5	12.9	400
11.4	109	1.39	3.67	78.3	12.9	427
12.3	149	1.94	4.62	76.8	9.23	442

Table L-6. TP-B-107

Depth, midpoint, m	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl:Br	% Gravimetric Water Content	Chlori age, y
1.2	264	2.66	30.4	99.1	10.6	104
2.1	2630	24.1	8.42	109	14.0	452
3.5	2971	32.0	0.383	92.7	17.2	1333
5.0	1779	20.2	0.718	88.1	14.7	1804
6.6	141	1.71	0.563	82.6	12.5	1836
7.9	110	1.33	1.31	82.7	11.3	1856
9.3	445	4.51	3.61	98.7	10.1	1933
10.7	590	6.62	4.75	89.1	7.70	2007

Table L-7. TP-B-118

Depth midpoint, m	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl:Br	% Gravimetric Water Content	Chlor age,
1.2	60.5	1.09	7.73	55.4	4.06	11
2.1	684	8.72	4.91	78.5	3.79	352
3.2	3483	36.1	1.17	96.5	2.62	182
4.1	4377	43.5	1.89	101	3.63	354
5.3	3348	33.7	14.9	99.5	14.8	1192
6.9	1759	16.9	5.24	104	16.5	1777
8.2	726	6.58	4.74	110	15.9	1987
9.1	219	2.75	3.09	79.8	15.5	2026
9.8	216	2.57	3.04	84.1	14.9	2052
10.4	202	2.65	2.99	76.2	14.7	2075
11.4	199	2.45	3.05	81.1	15.1	2115
13.0	179	2.16	2.97	82.7	14.9	2166
14.5	281	3.19	4.12	88.3	10.8	2225
15.8	362	4.15	2.24	87.2	11.0	2293
16.9	278	2.56	3.52	109	12.5	2343
17.8	325	4.10	3.76	79.4	10.4	2380
18.7	230	2.91	3.67	79.0	9.53	2403
19.5	377	4.56	5.53	82.8	6.67	2433

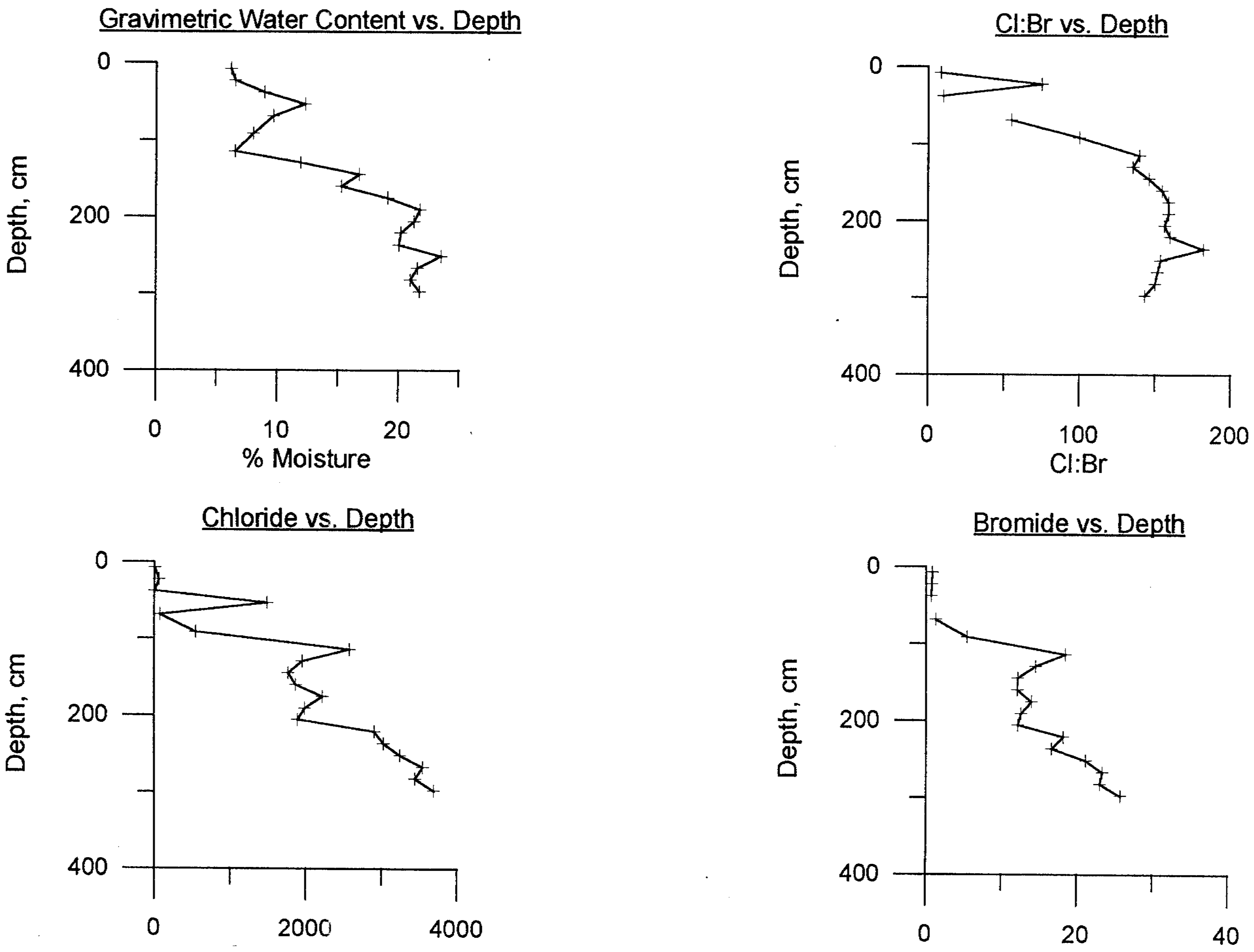
Table L-8. TP-B-123

Depth midpoint, m	Chloride, mg/l	Bromide, mg/l	Nitrate-N, mg/l	Cl:Br	% Gravimetric Water Content	Chlo Age,
1.2	1823	19.1	2.33	95.6	13.7	95
2.3	3065	32.3	0.795	94.9	16.1	739
3.8	3921	42.9	0.428	91.4	16.5	197
5.3	1203	13.3	1.77	90.6	15.9	232
6.9	102	1.40	2.94	72.7	14.9	235
7.9	127	1.72	2.82	74.1	15.7	238
8.4	901	10.1	3.47	89.4	7.87	242
8.6	1006	11.2	3.11	89.5	8.81	245

APPENDIX M

Hand Auger TP-A Profiles

Figure M-1A. TP-A-71



Gravimetric Water Content vs. Depth

Cl:Br vs. Depth

Chloride vs. Depth

Bromide vs. Depth

Figure M-1B. TP-A-71

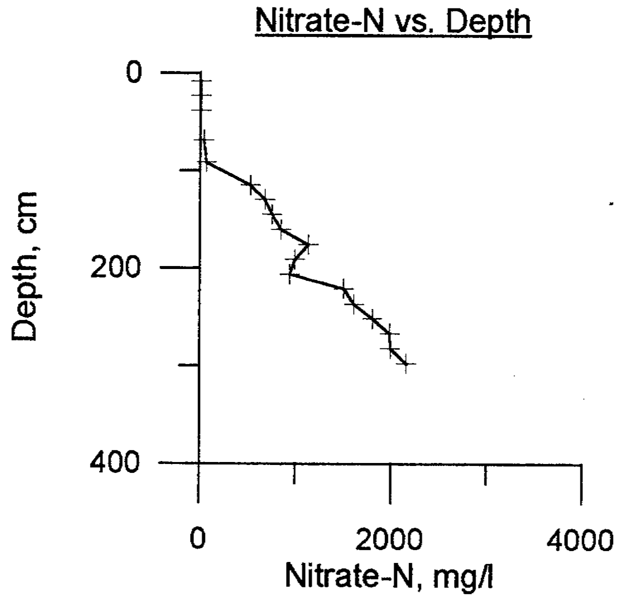
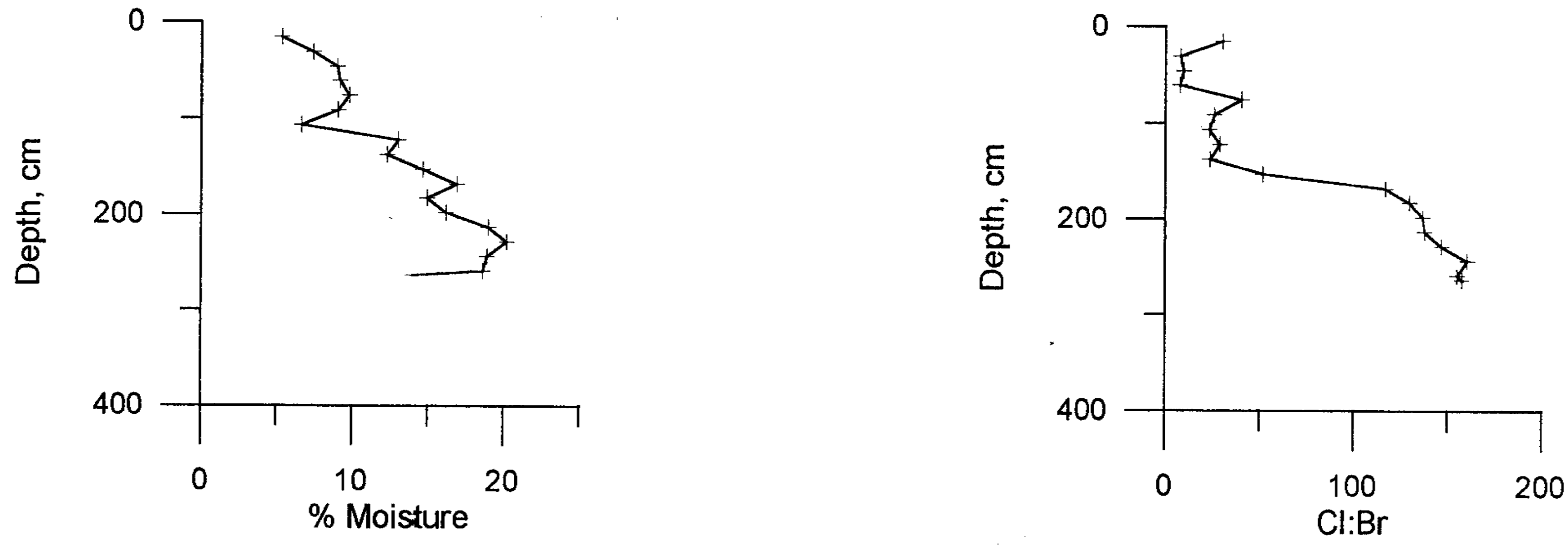
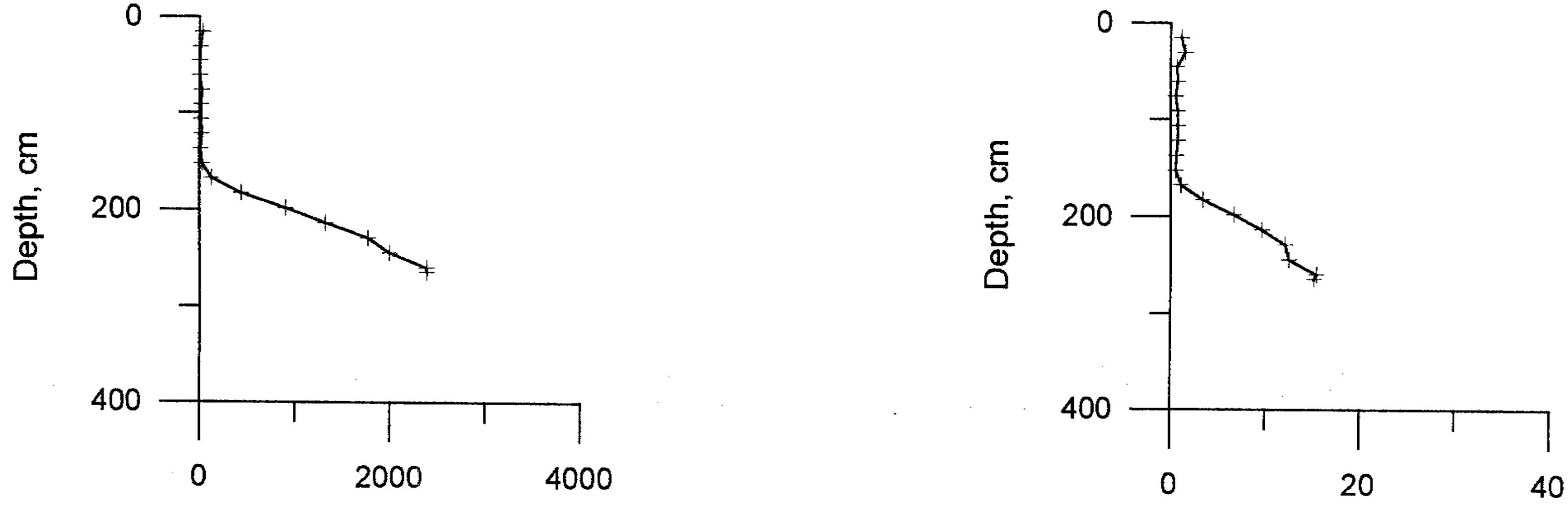


Figure M-2A. TP-A-72

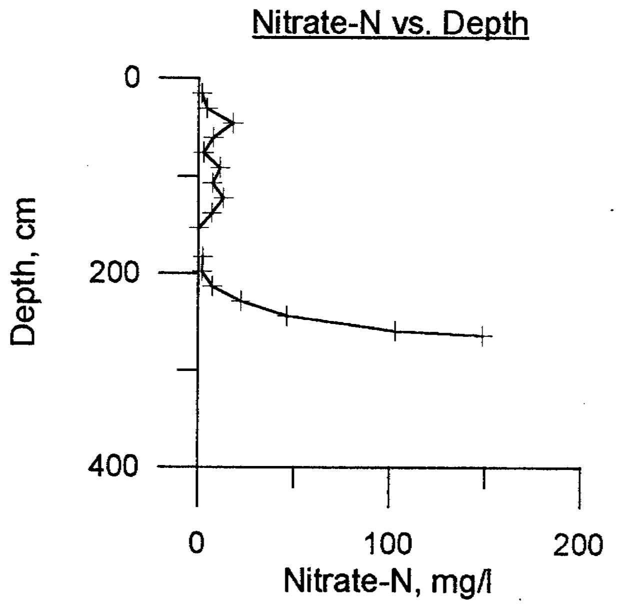

Gravimetric Water Content vs. Depth

Cl:Br vs. Depth


Chloride vs. Depth

Bromide vs. Depth

Figure M-2B. TP-A-72



Nitrate-N vs. Depth

Figure M-3A. TP-A-103

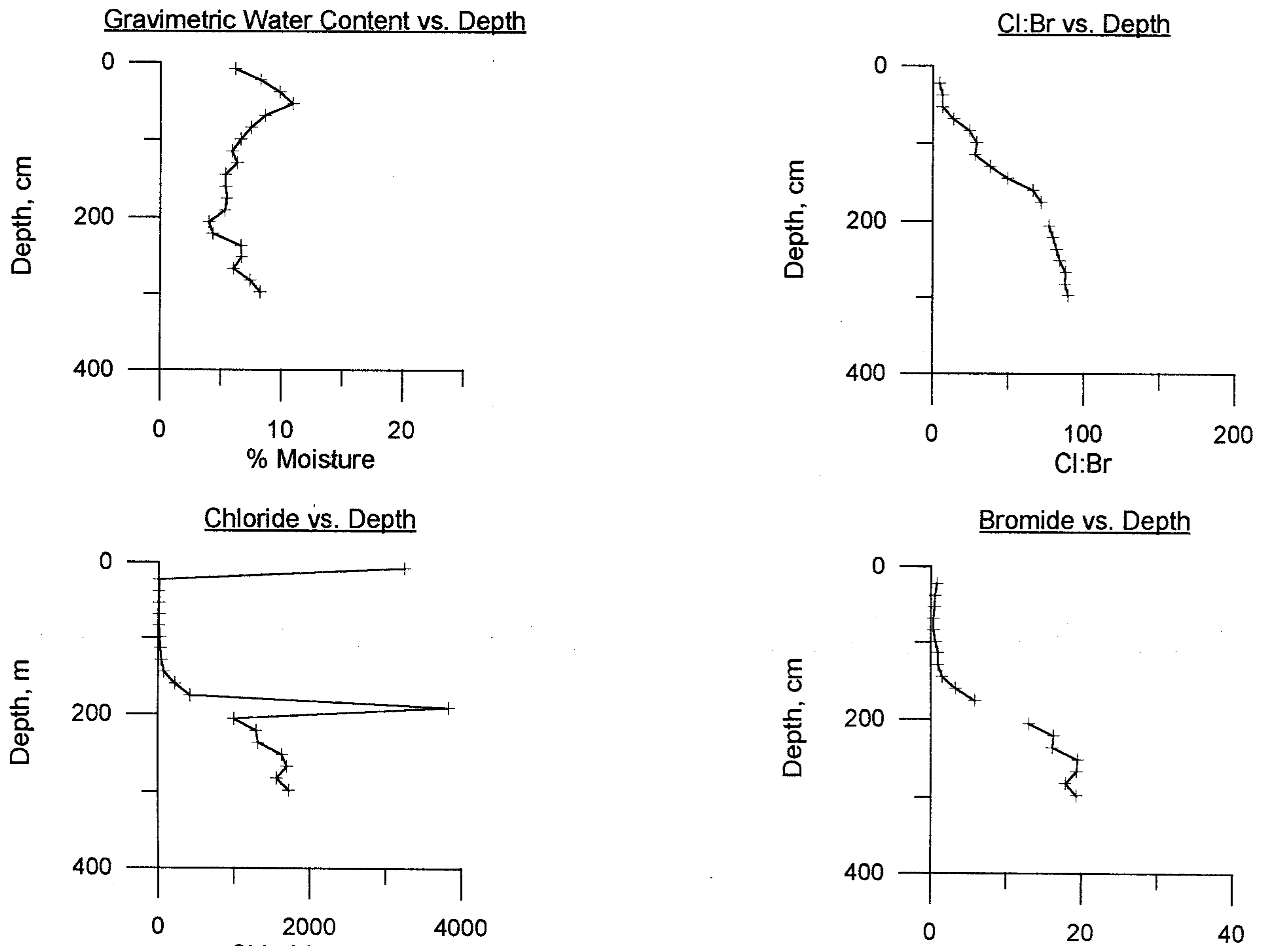
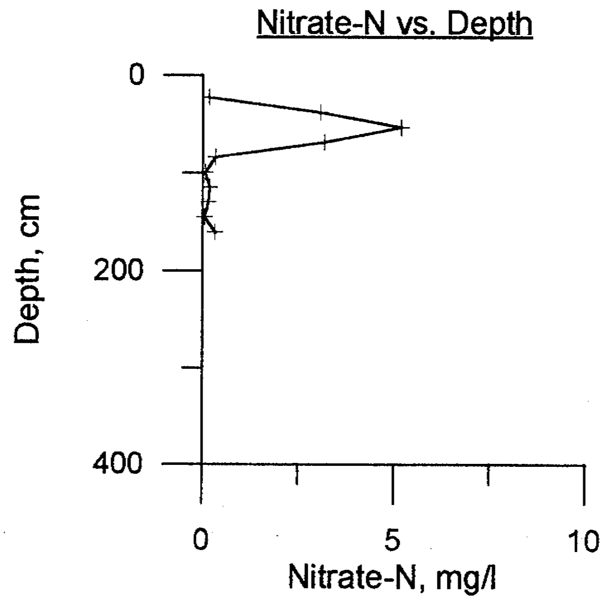


Figure M-3B. TP-A-103



Note: Nitrate-N concentrations are below detection limits
from 175 to 297 cm bgs.

Figure M-4A. TP-A-106 A&B

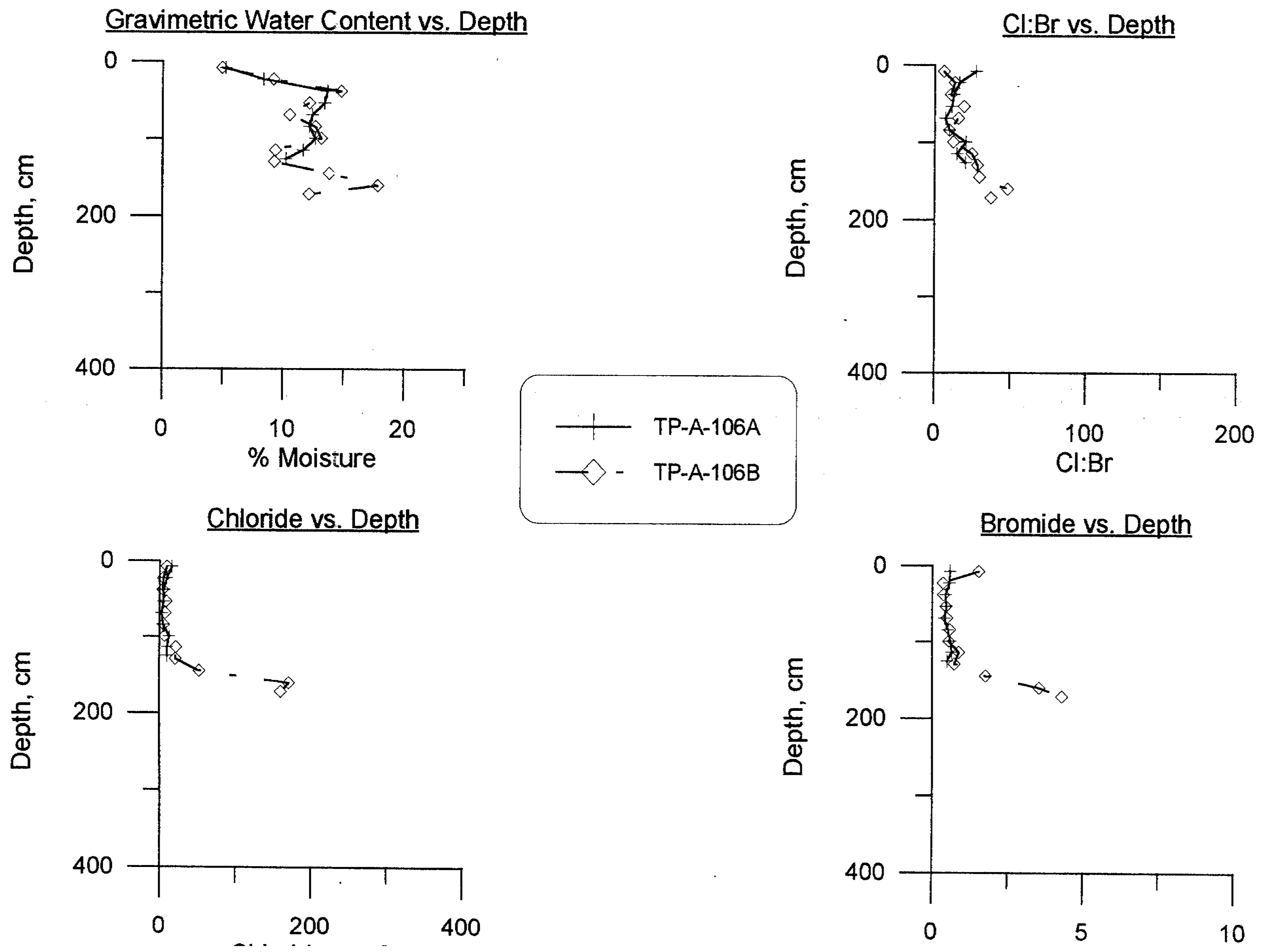


Figure M-4B. TP-A-106 A&B

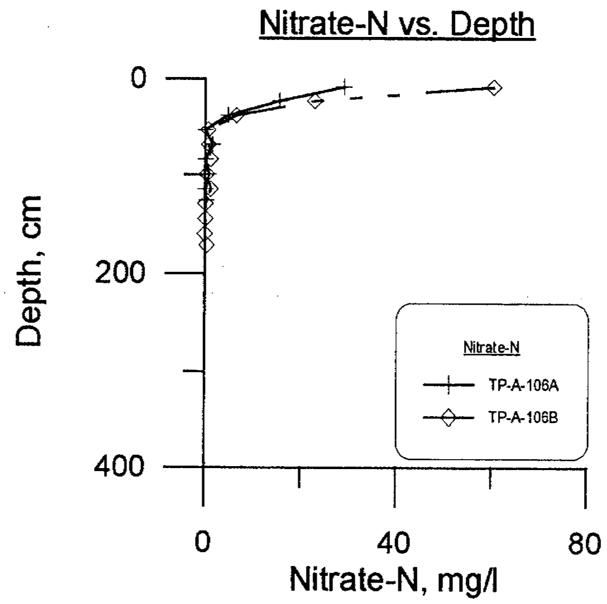
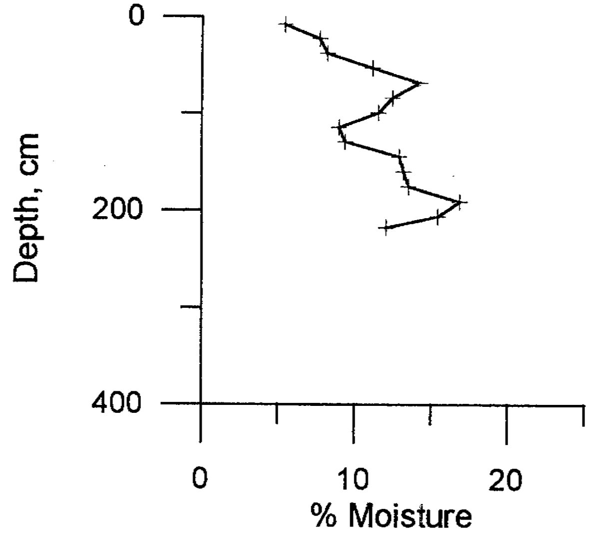
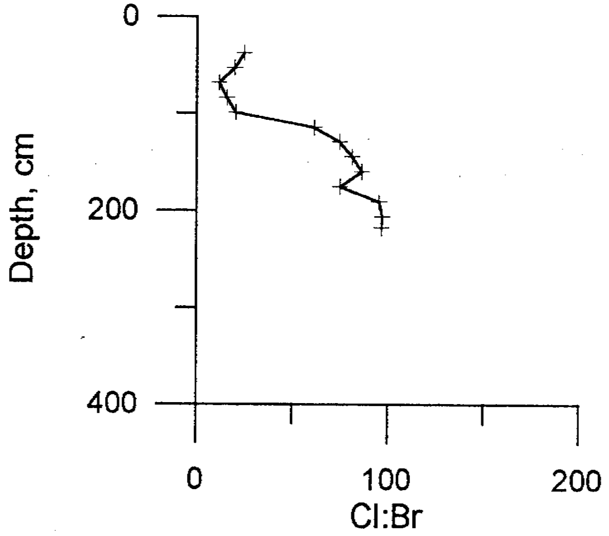
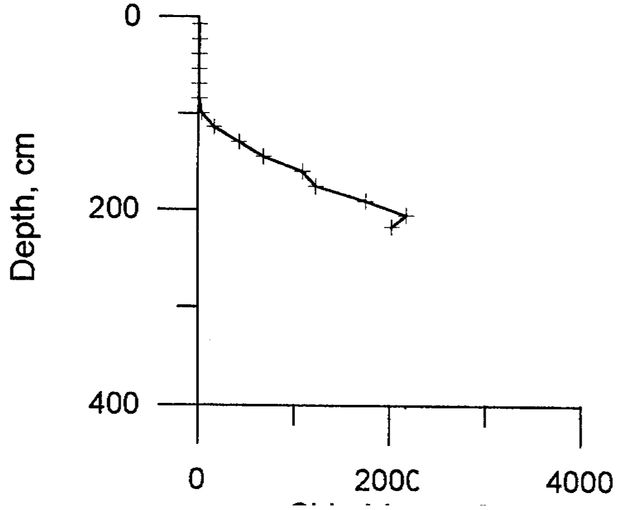


Figure M-5A. TP-A-107


Gravimetric Water Content vs. Depth


Cl:Br vs. Depth


Chloride vs. Depth

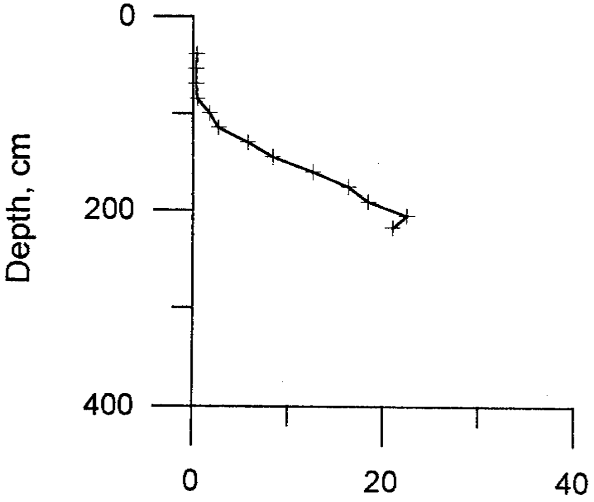

Bromide vs. Depth

Figure M-5B. TP-A-107

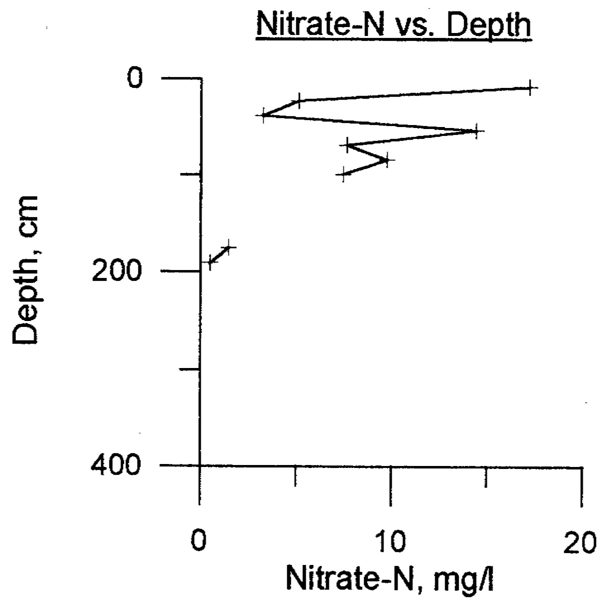
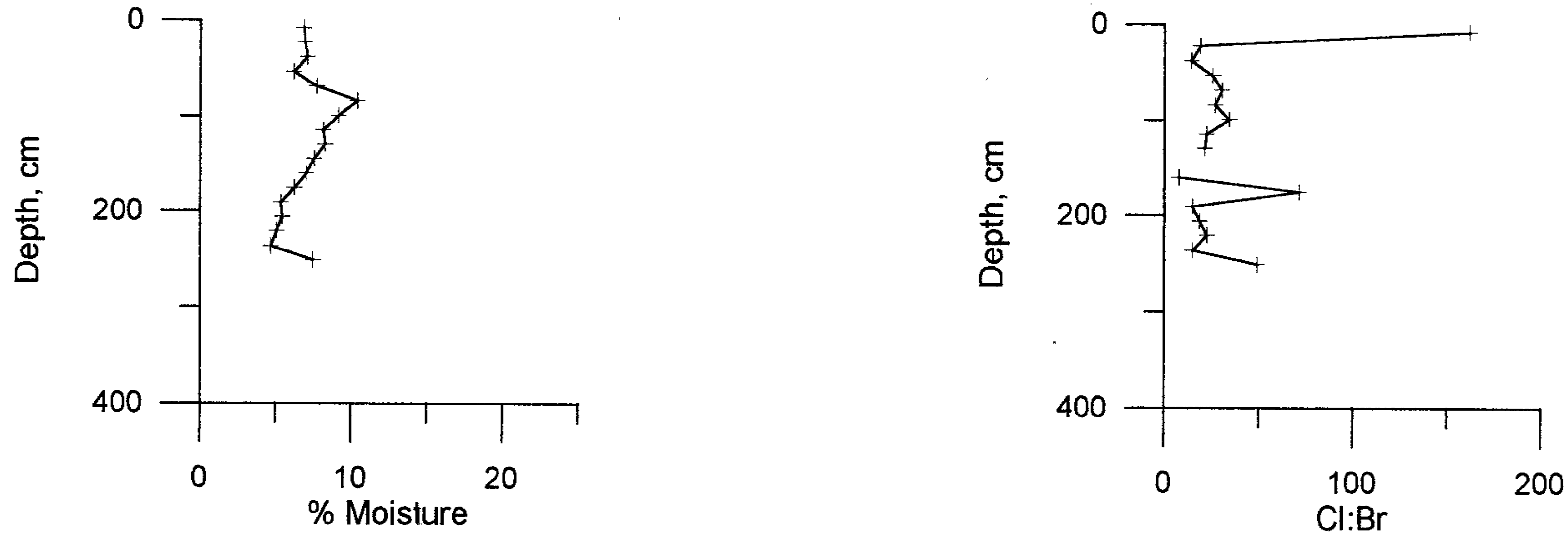
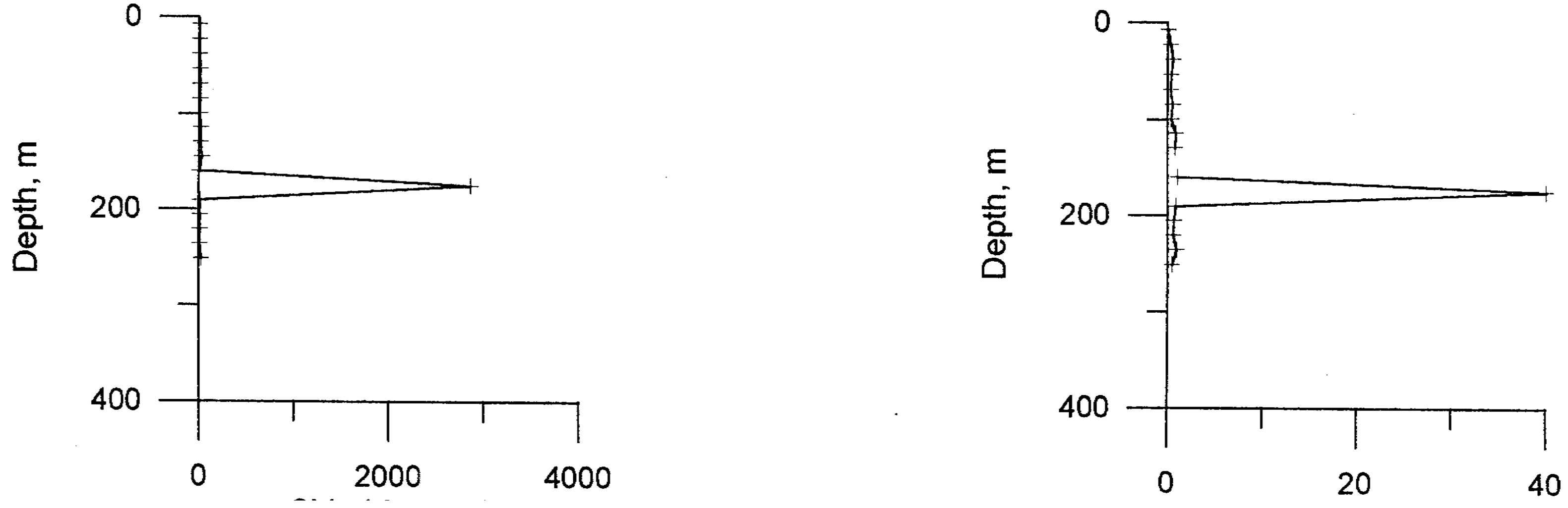


Figure M-6A. TP-A-118



Gravimetric Water Content vs. Depth

Cl:Br vs. Depth



Chloride vs. Depth

Bromide vs. Depth

Figure M-6B. TP-A-118

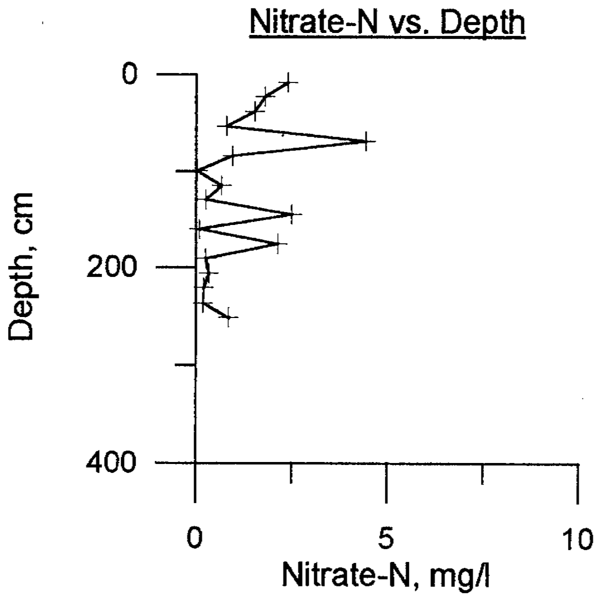
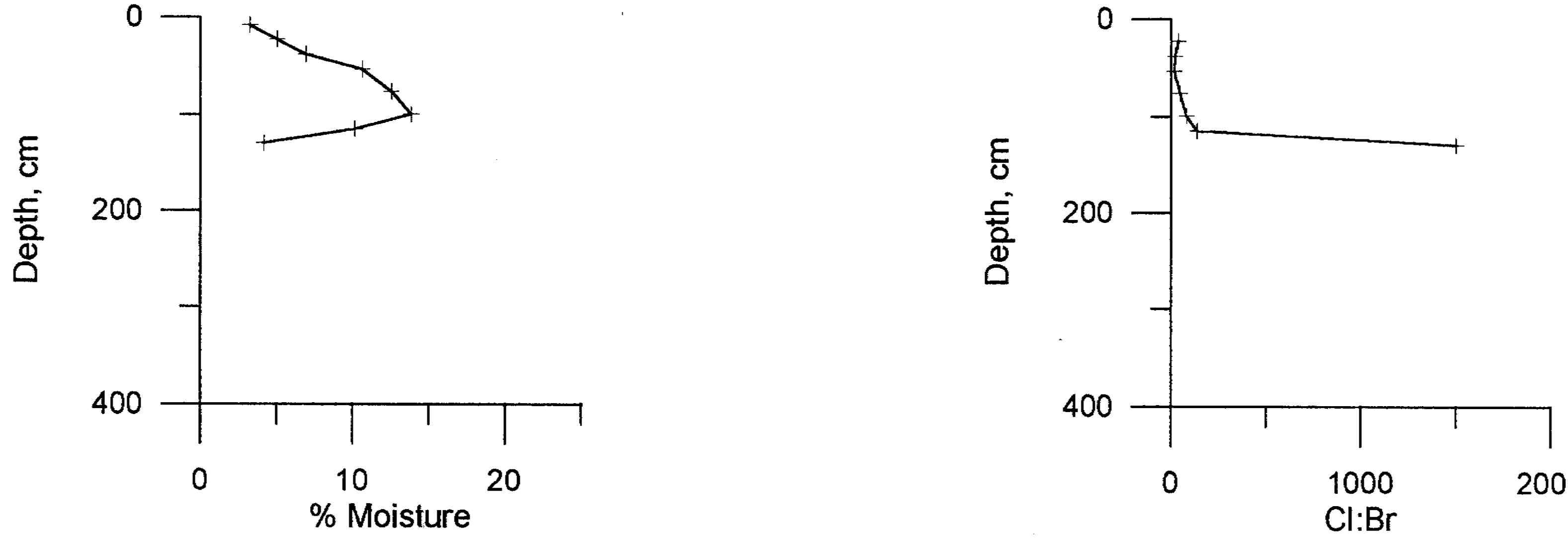
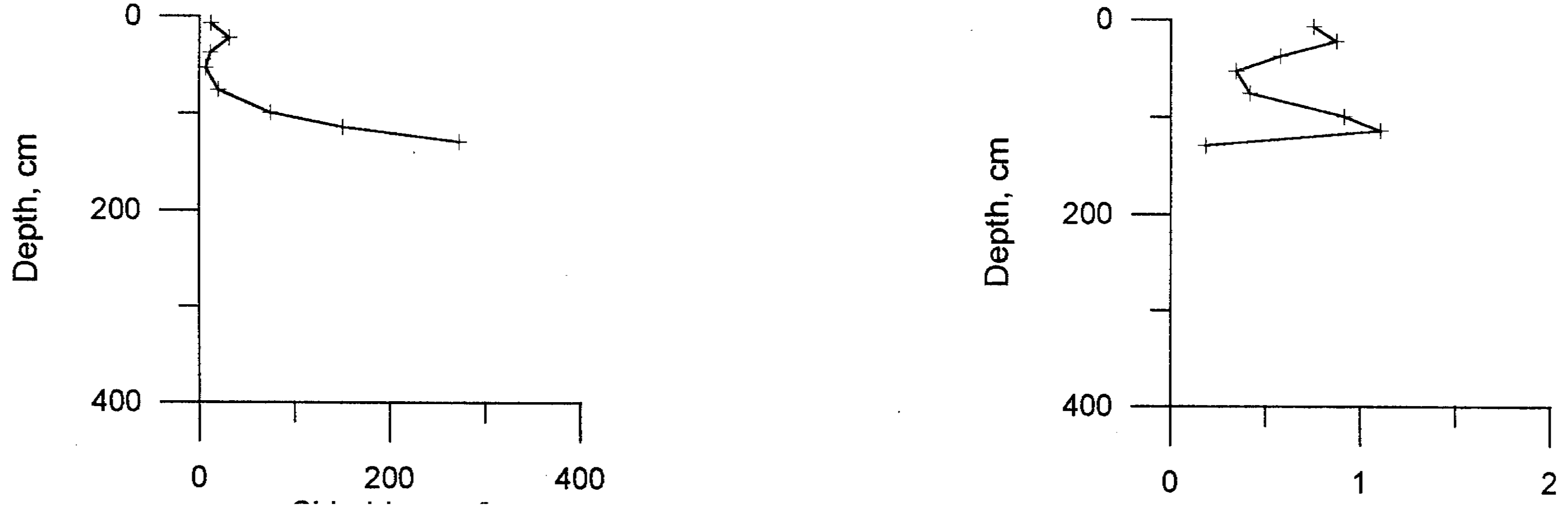


Figure M-7A. TP-A-123



Gravimetric Water Content vs. Depth

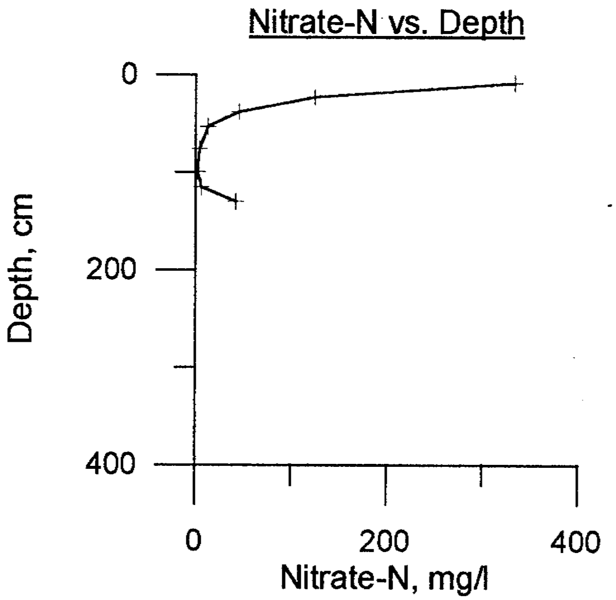
Cl:Br vs. Depth



Chloride vs. Depth

Bromide vs. Depth

Figure M-7B. TP-A-123



APPENDIX N

Hollow Stem Auger Profiles

Figure N-1. BH-1

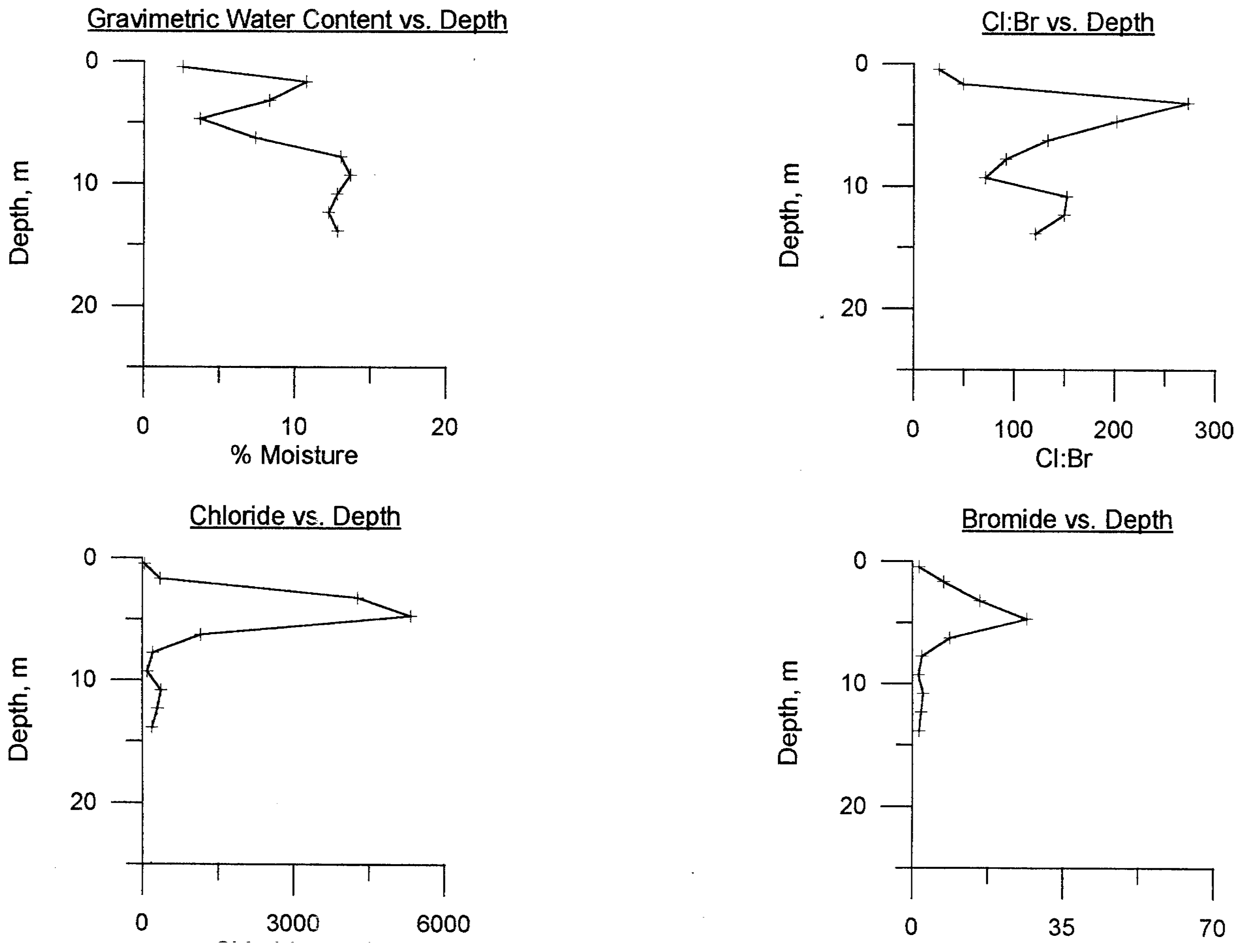


Figure N-2. BH-2

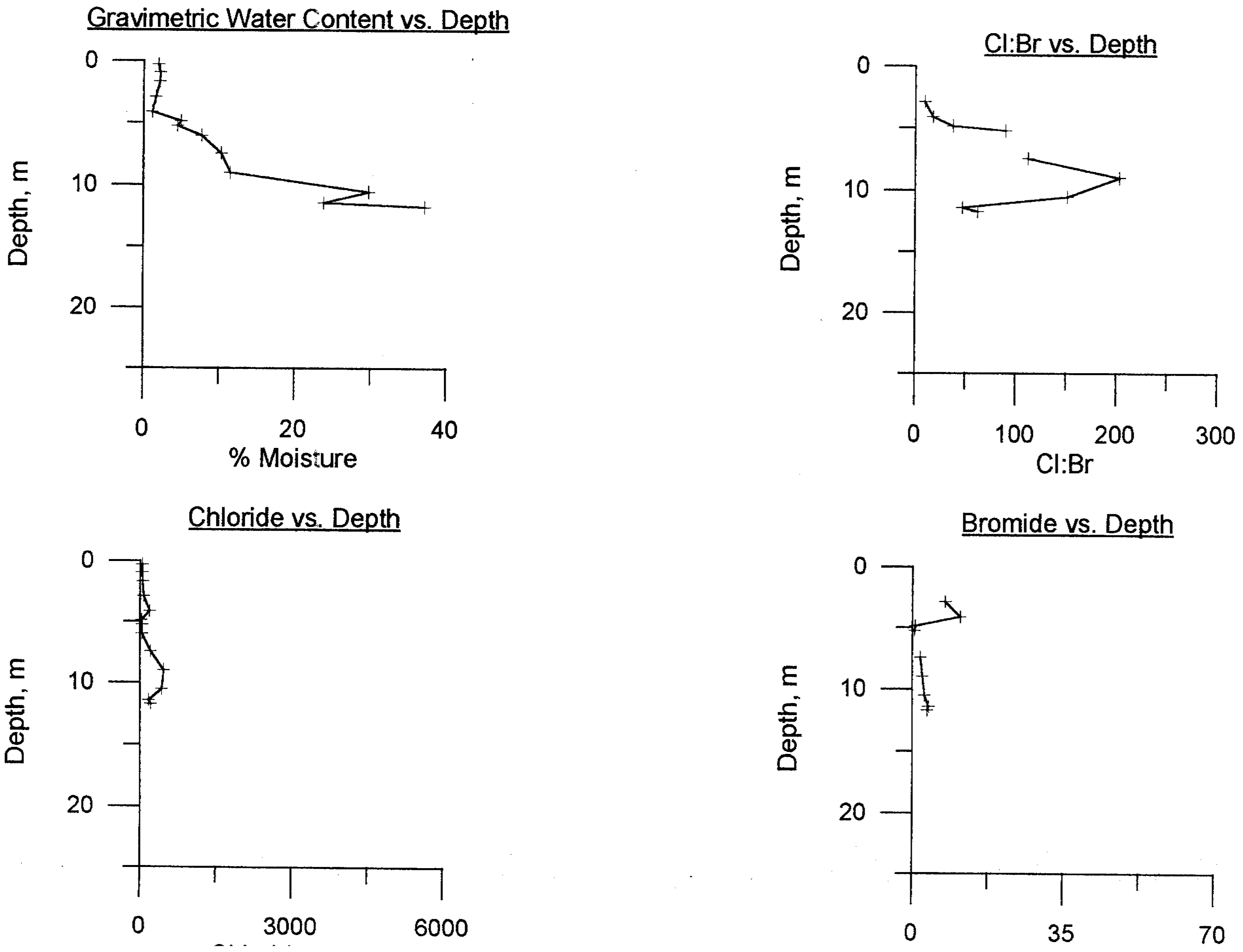
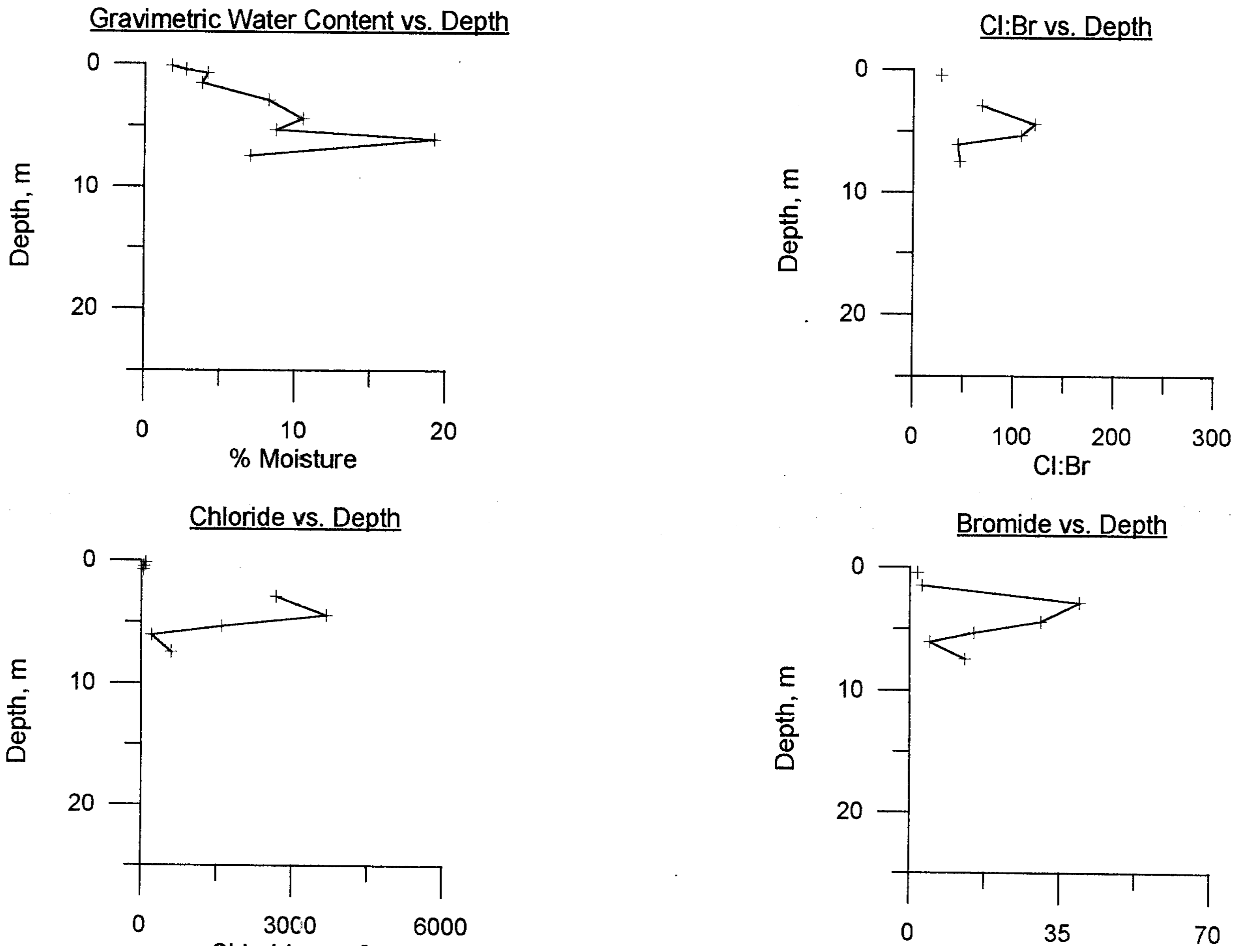


Figure N-3. BH-3



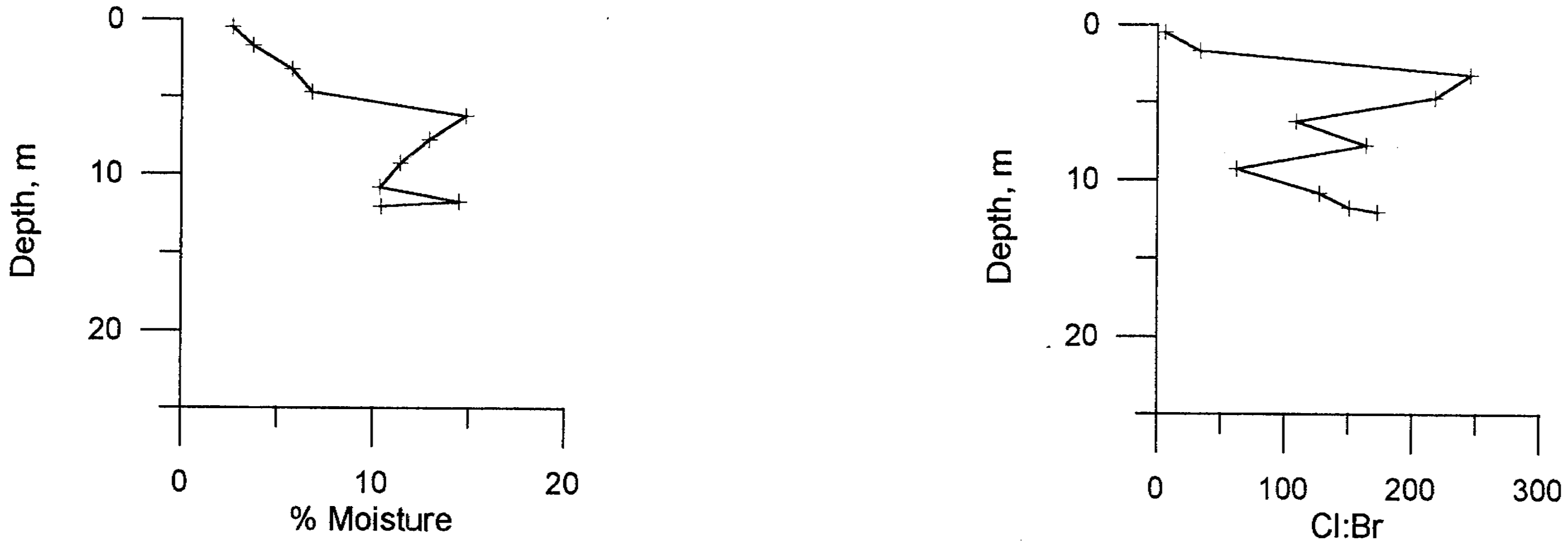
Gravimetric Water Content vs. Depth

Cl:Br vs. Depth

Chloride vs. Depth

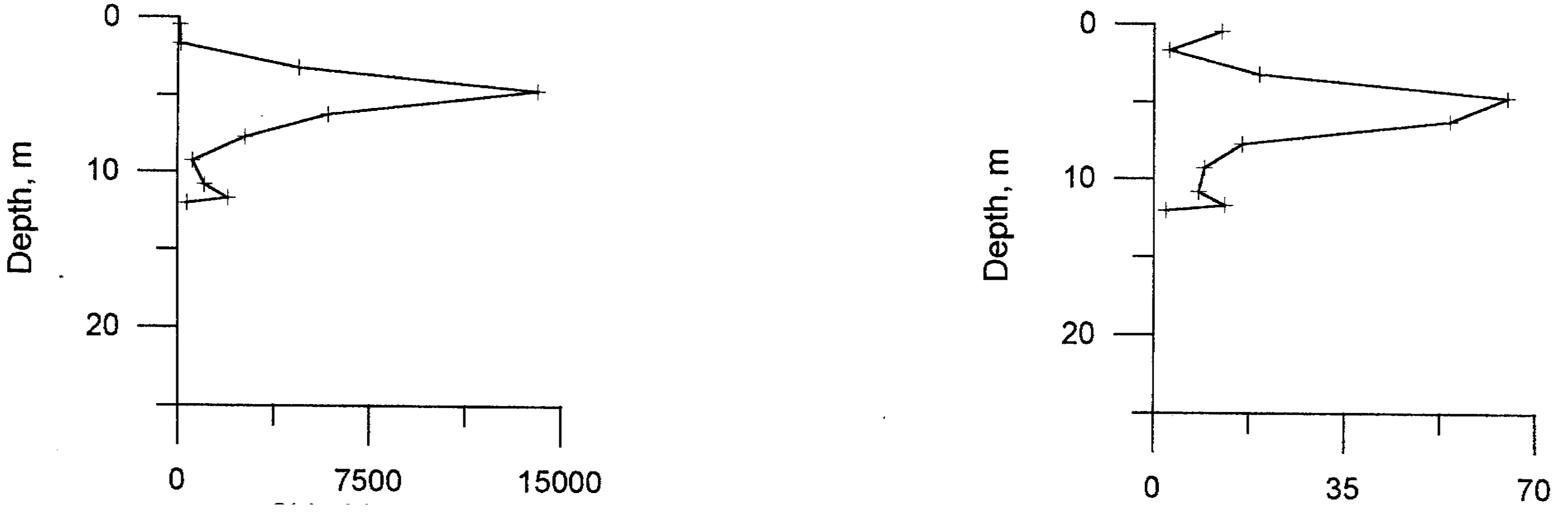
Bromide vs. Depth

Figure N-4. BH-4



Gravimetric Water Content vs. Depth

Cl:Br vs. Depth



Chloride vs. Depth

Bromide vs. Depth

Figure N-5. SOUTH WINDMILL

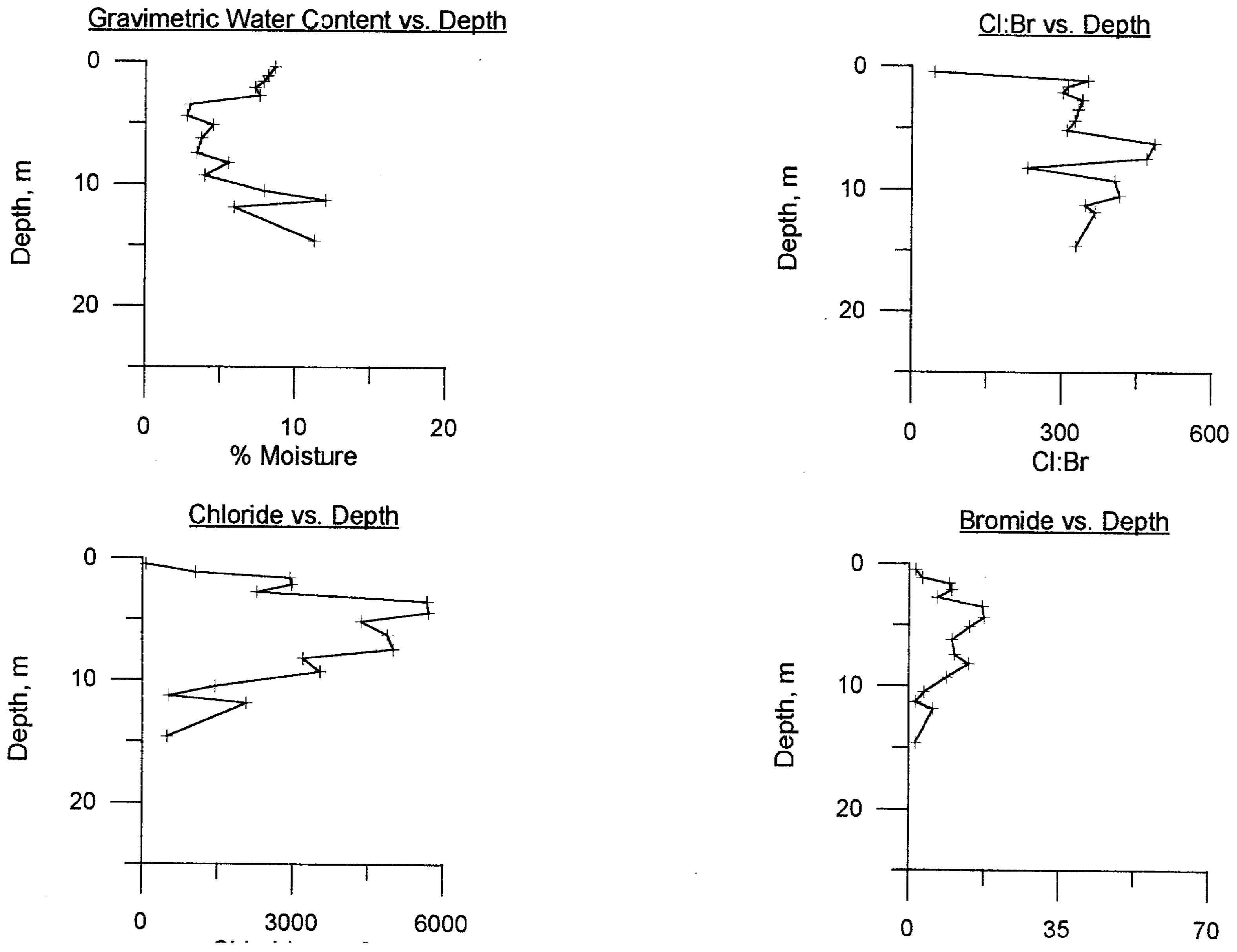
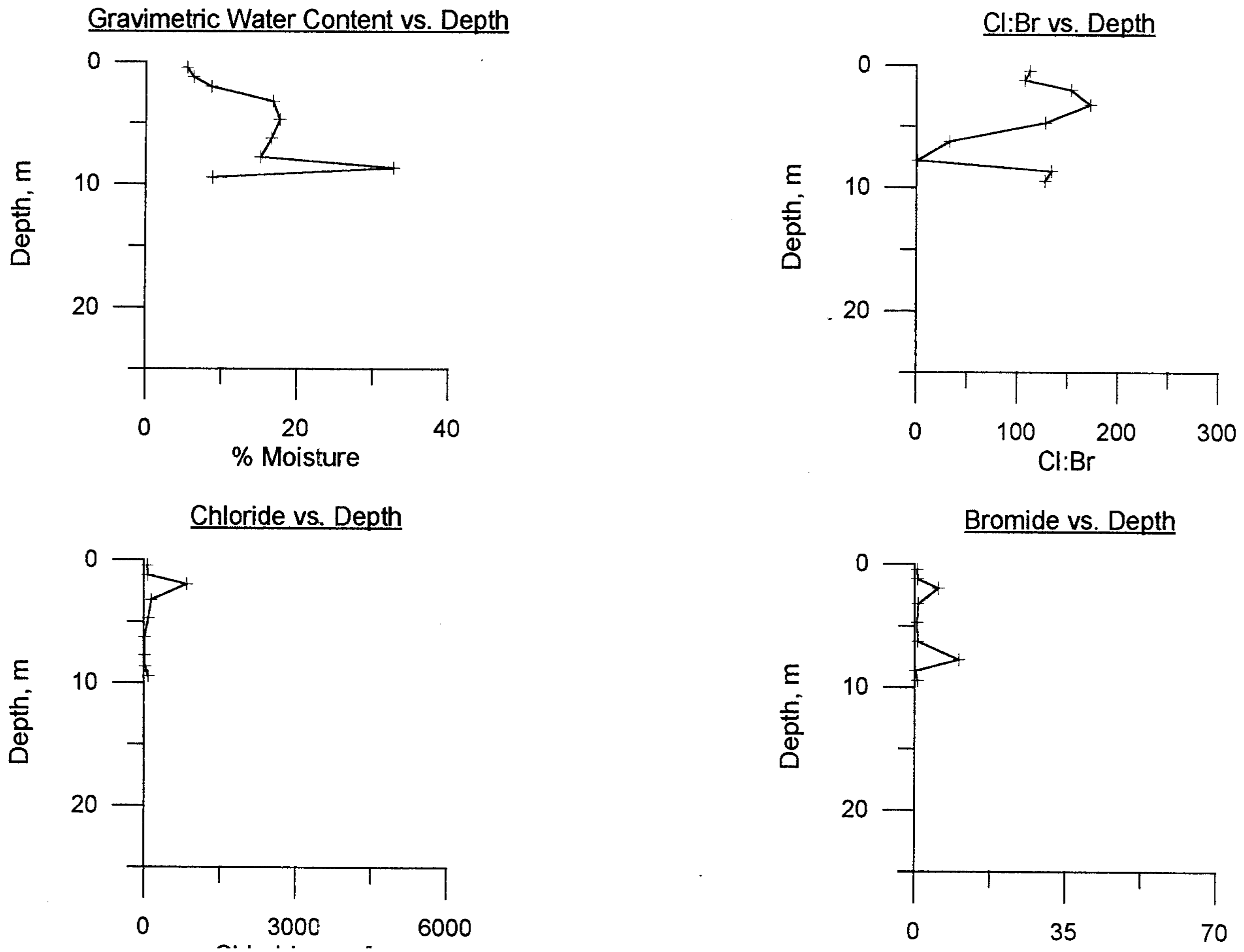


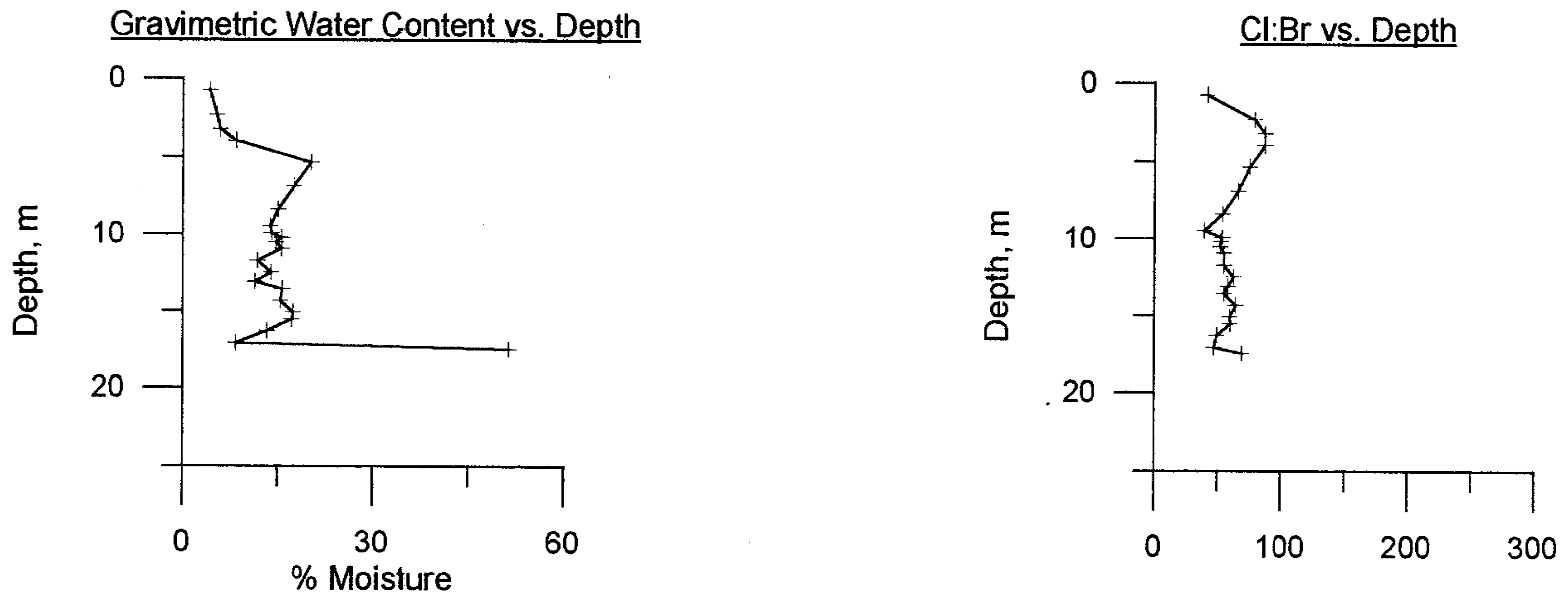
Figure N-6. NORTH WINDMILL



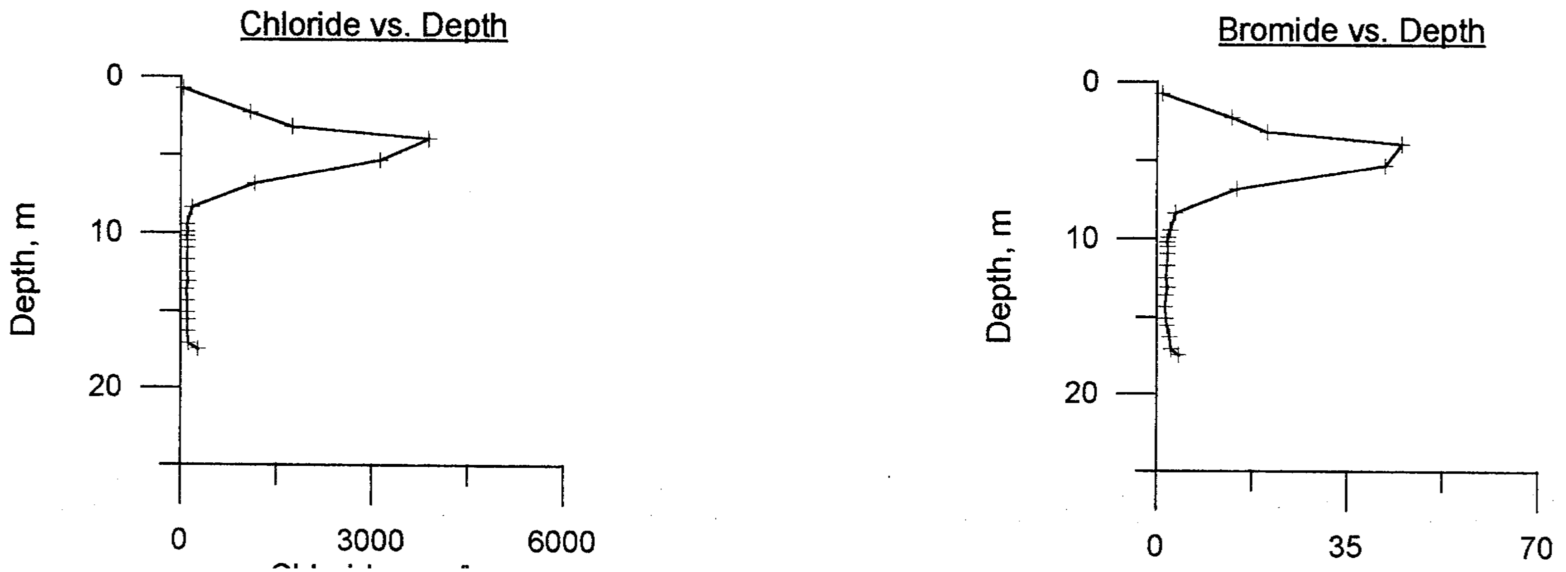
APPENDIX O

Air-Rotary Profiles

Figure O-1. MW-1


Gravimetric Water Content vs. Depth

Cl:Br vs. Depth


Chloride vs. Depth

Bromide vs. Depth

Figure O-2A. TP-B-71

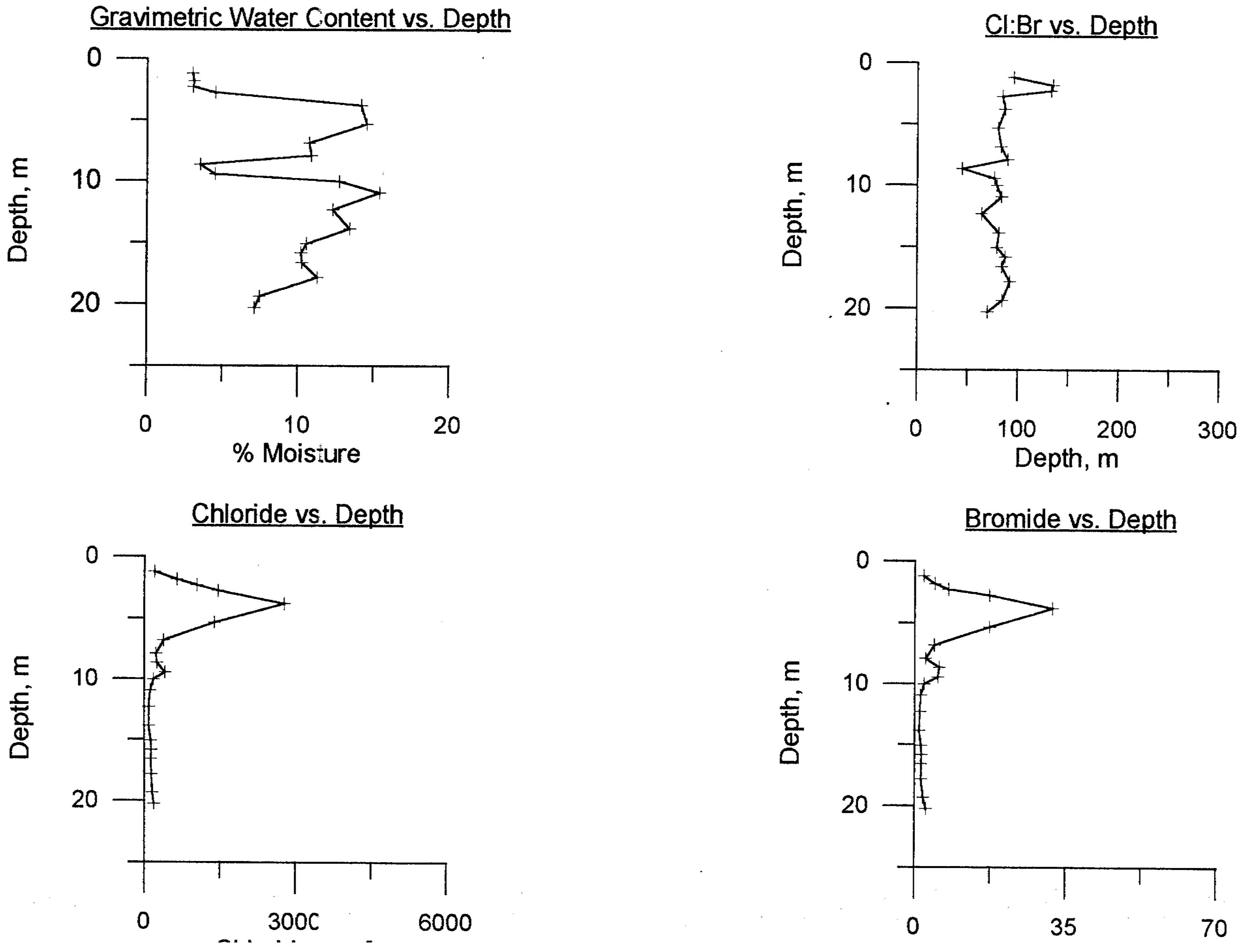


Figure O-2B. TP-B-71

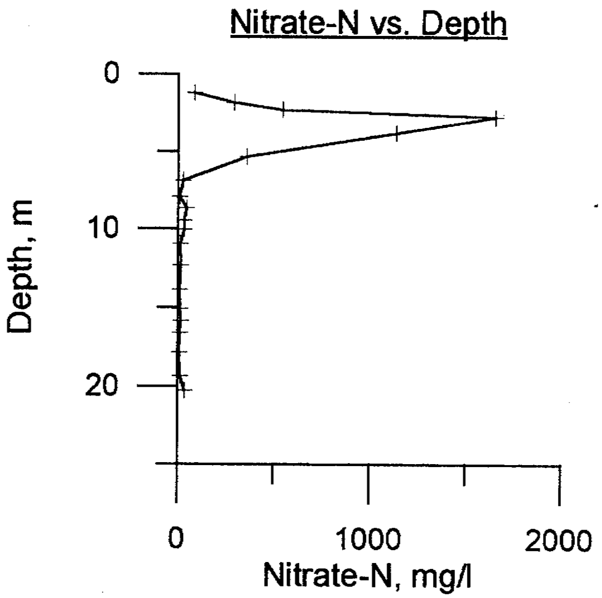
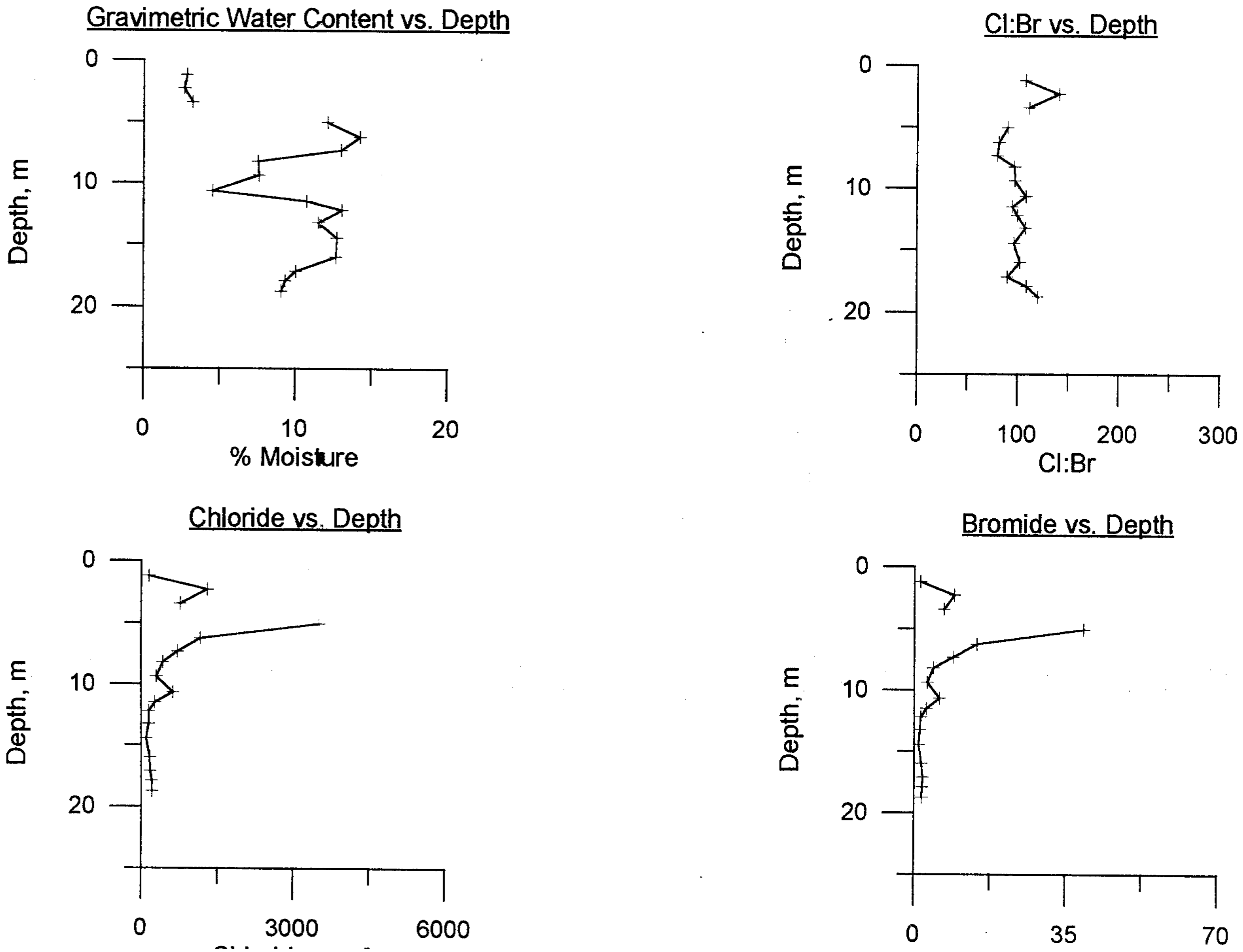


Figure O-3A. TP-B-72


Gravimetric Water Content vs. Depth

Cl:Br vs. Depth

Chloride vs. Depth

Bromide vs. Depth

Figure O-3B. TP-B-72

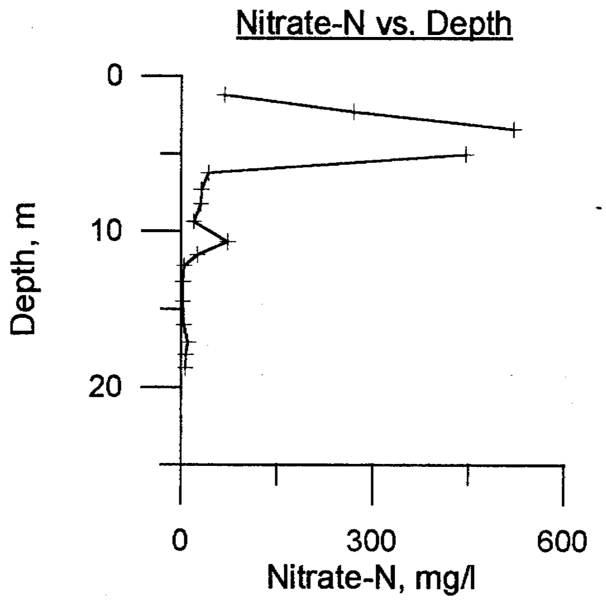
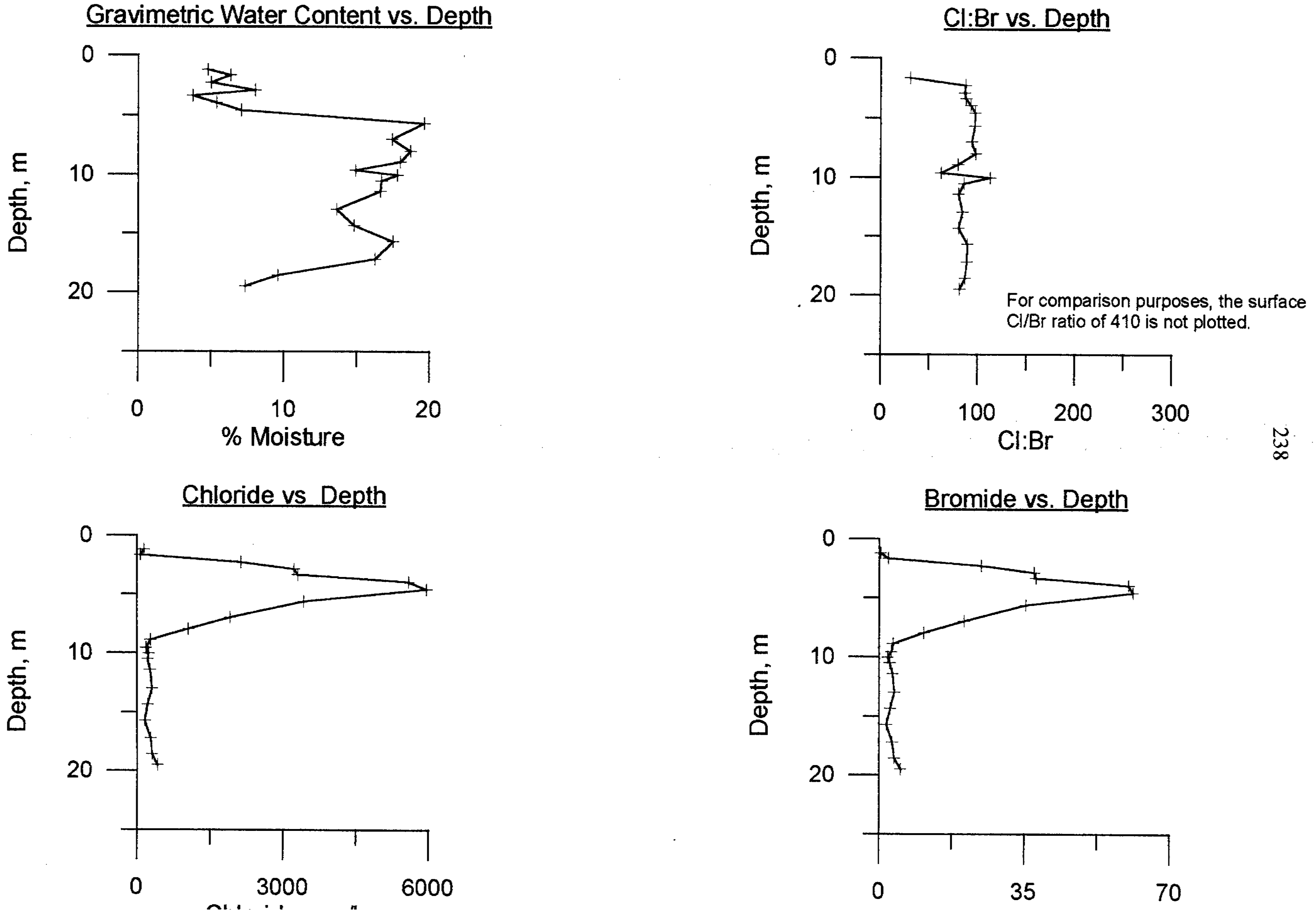


Figure O-4A. TP-B-103



Gravimetric Water Content vs. Depth

Cl:Br vs. Depth

For comparison purposes, the surface Cl/Br ratio of 410 is not plotted.

Chloride vs Depth

Bromide vs. Depth

Figure O-4B. TP-B-103

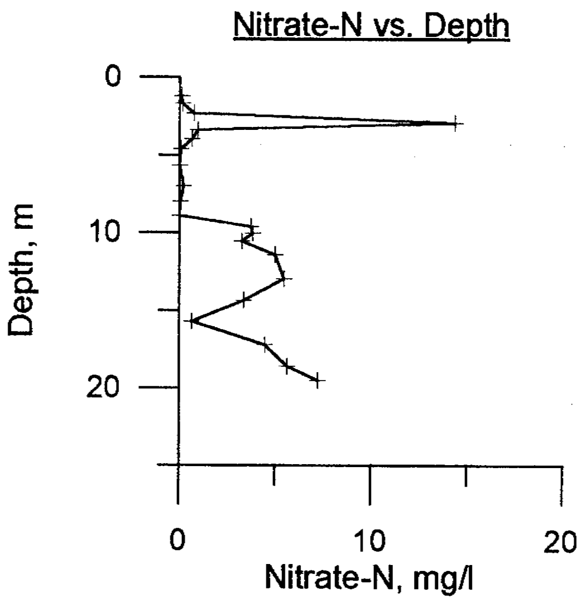


Figure O-5A. TP-B-106

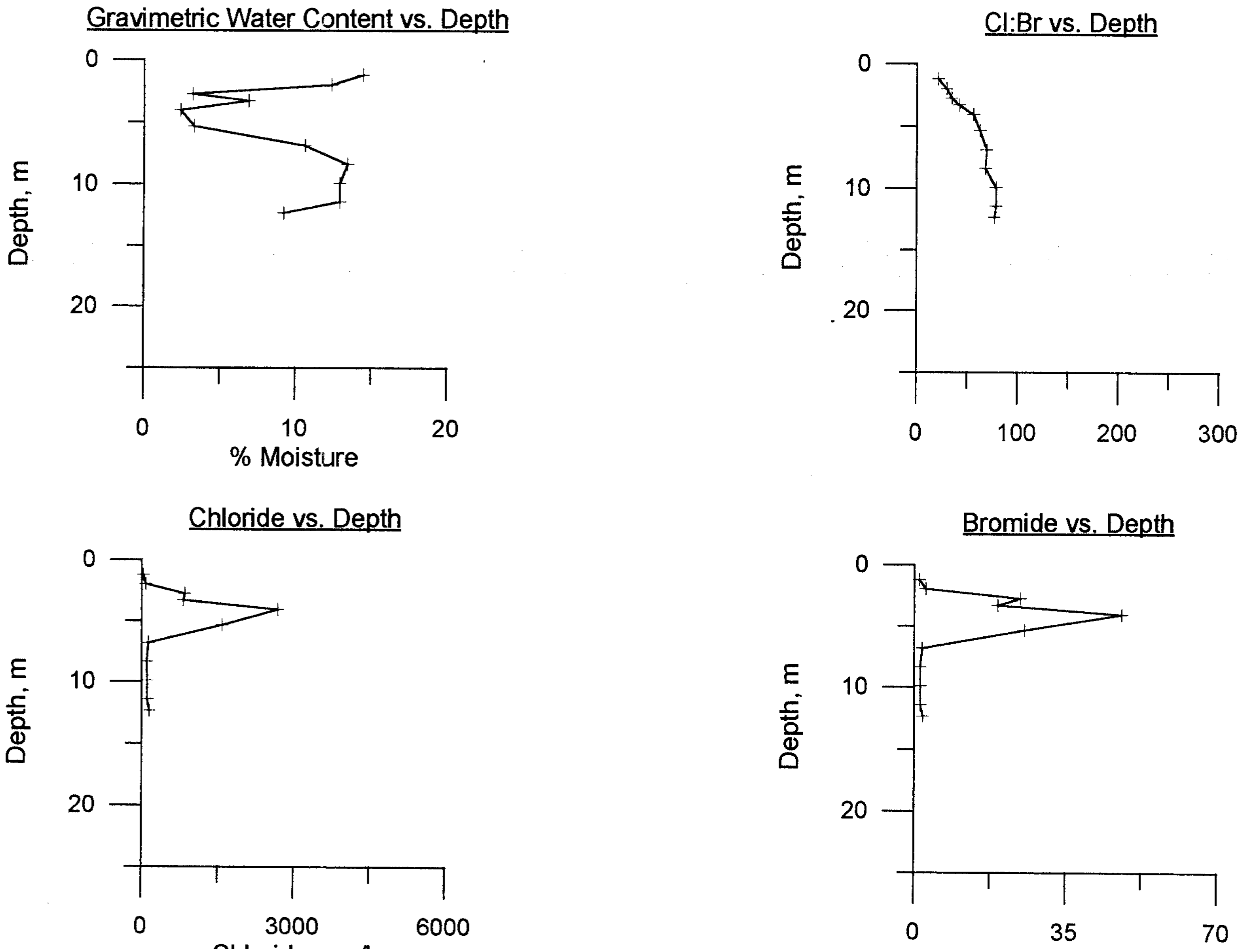


Figure O-5B. TP-B-106

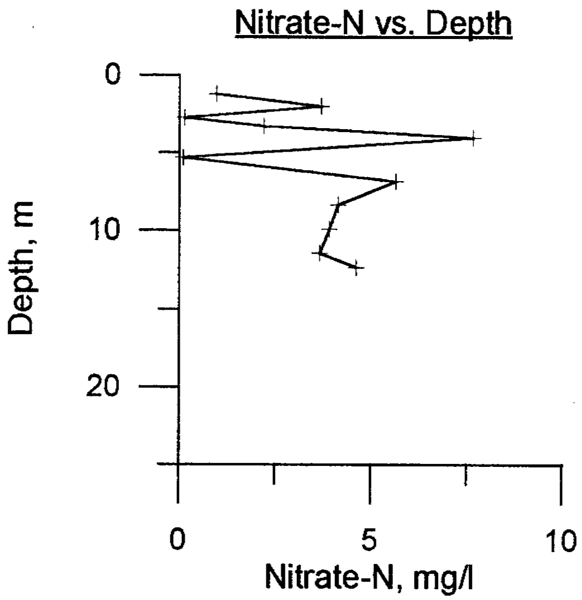
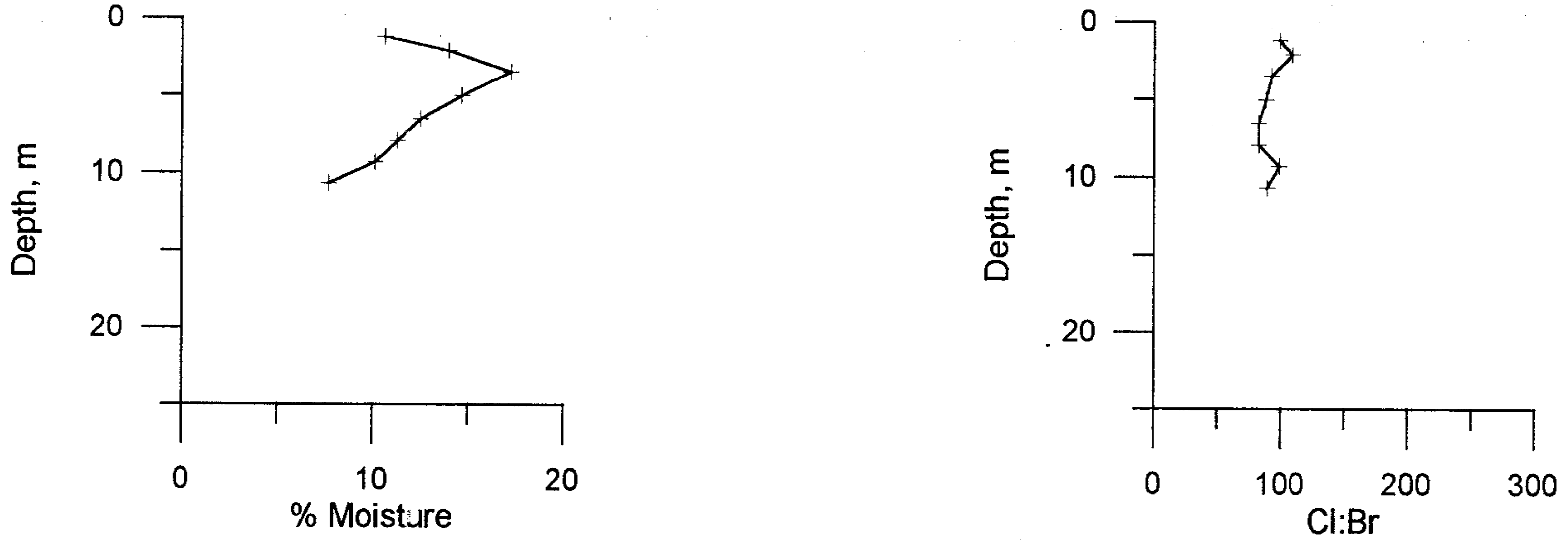


Figure O-6A. TP-B-107

Gravimetric Water Content vs. Depth

Cl:Br vs. Depth



Chloride vs. Depth

Bromide vs. Depth

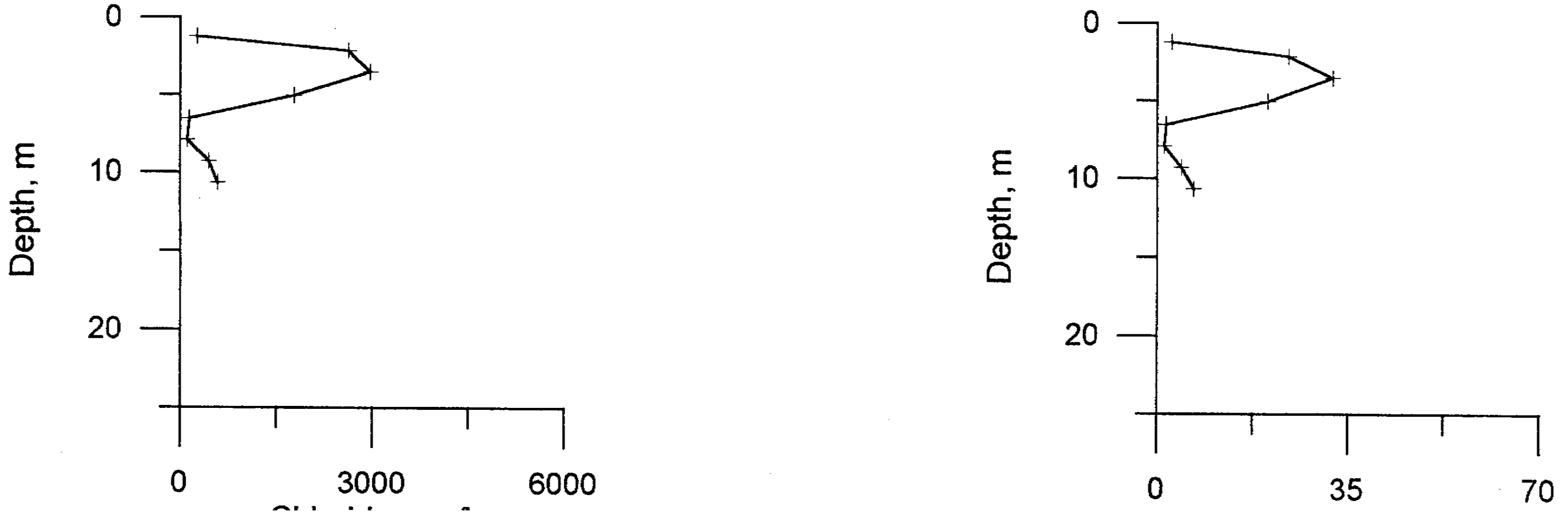


Figure O-6B. TP-B-107

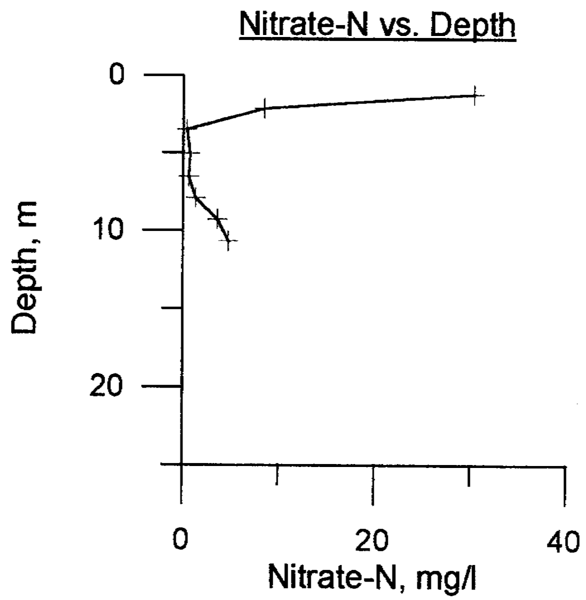
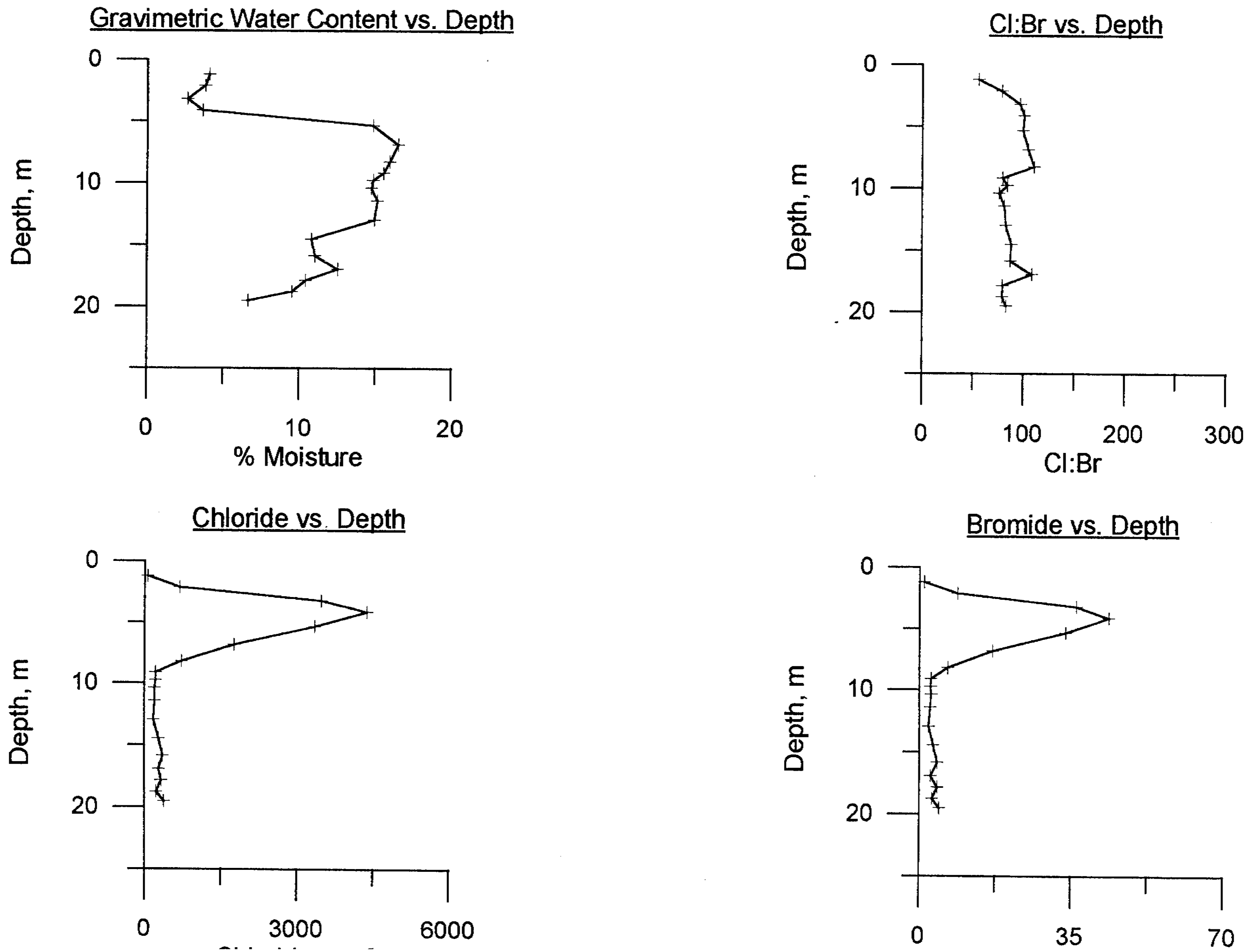


Figure O-7A. TP-B-118



Gravimetric Water Content vs. Depth

Cl:Br vs. Depth

Chloride vs. Depth

Bromide vs. Depth

Figure O-7B. TP-B-118

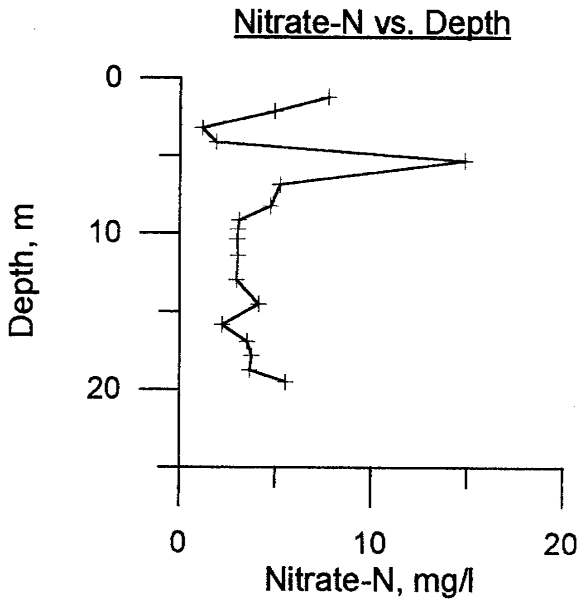


Figure O-8A. TP-B-123

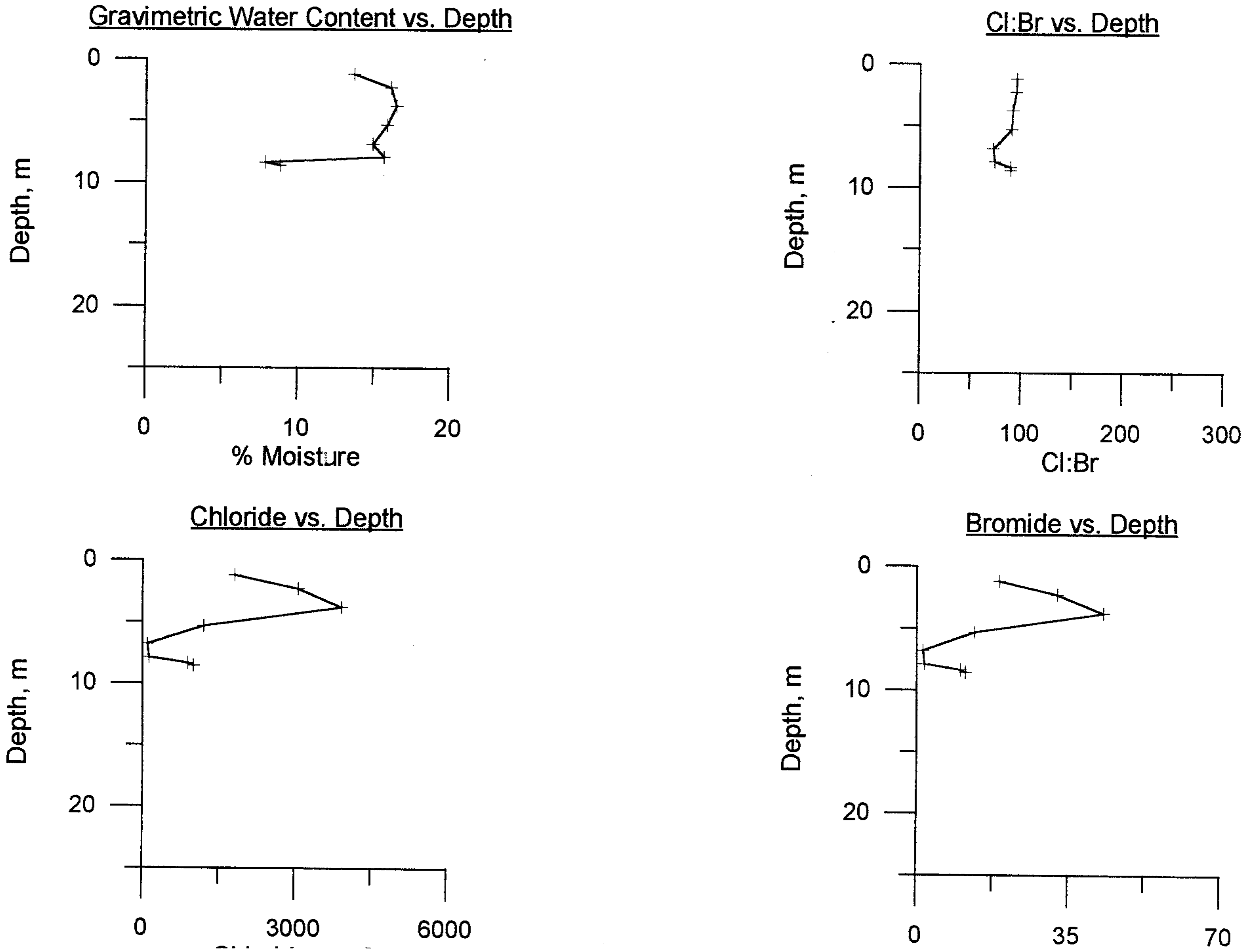
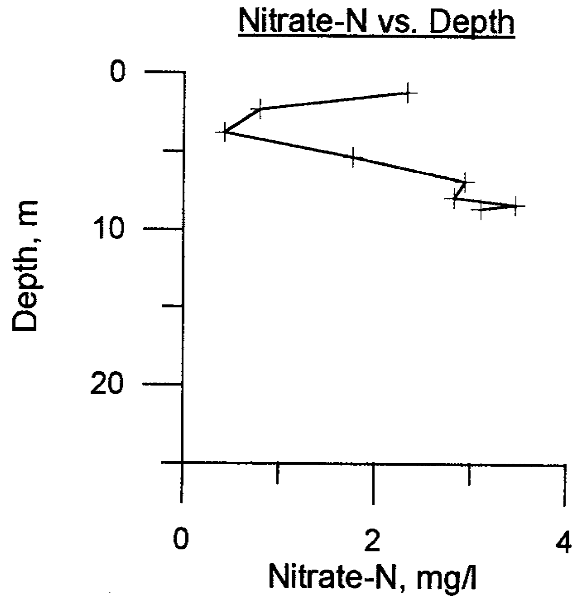


Figure O-8B. TP-B-123



Nitrate-N vs. Depth

APPENDIX P

Comparisons between MW-1 and BH-4

Figure P-1. BH-4 and MW-1
Gravimetric Water Content vs. Depth

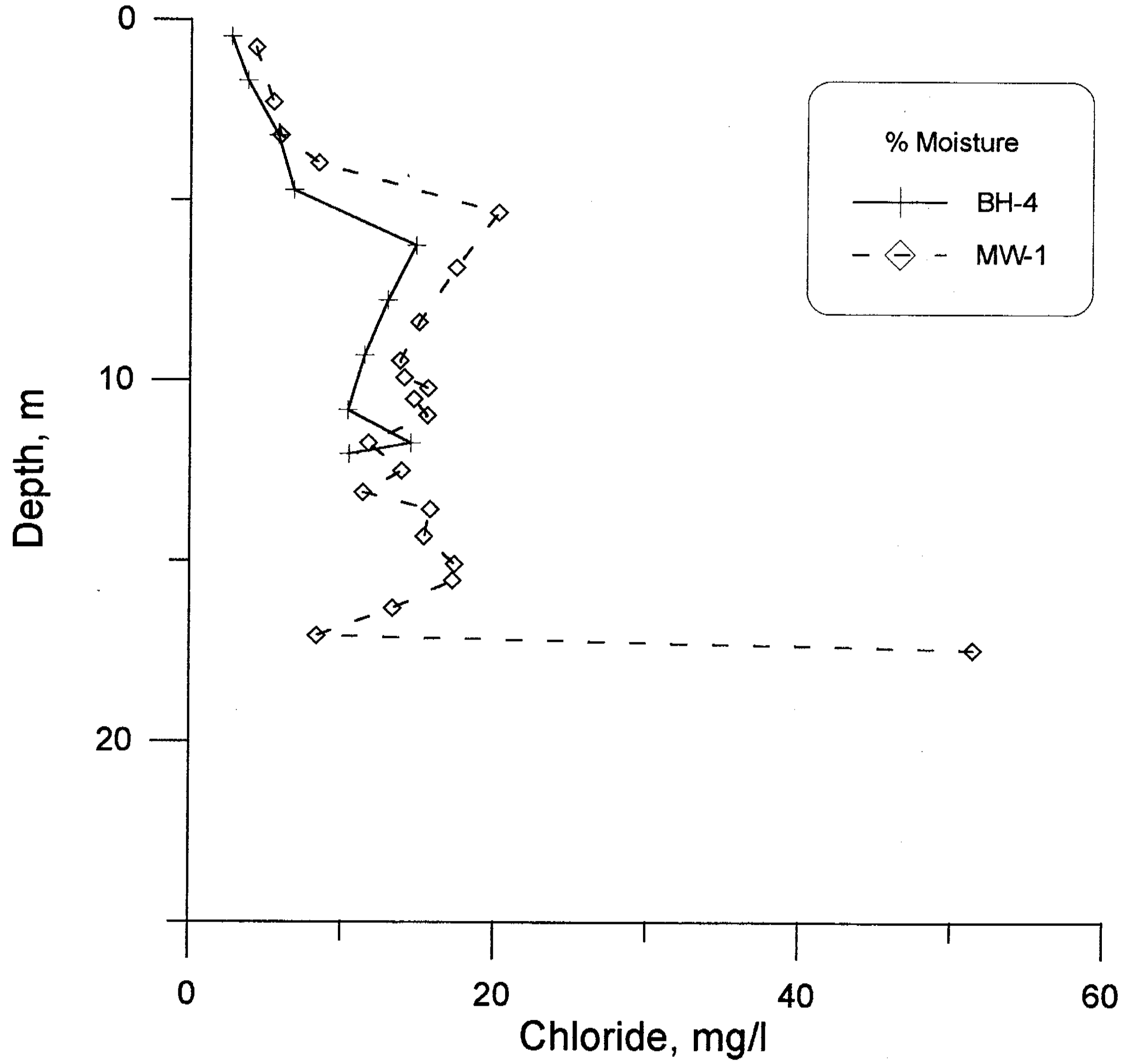


Figure P-2. BH-4 and MW-1
Chloride vs. Depth

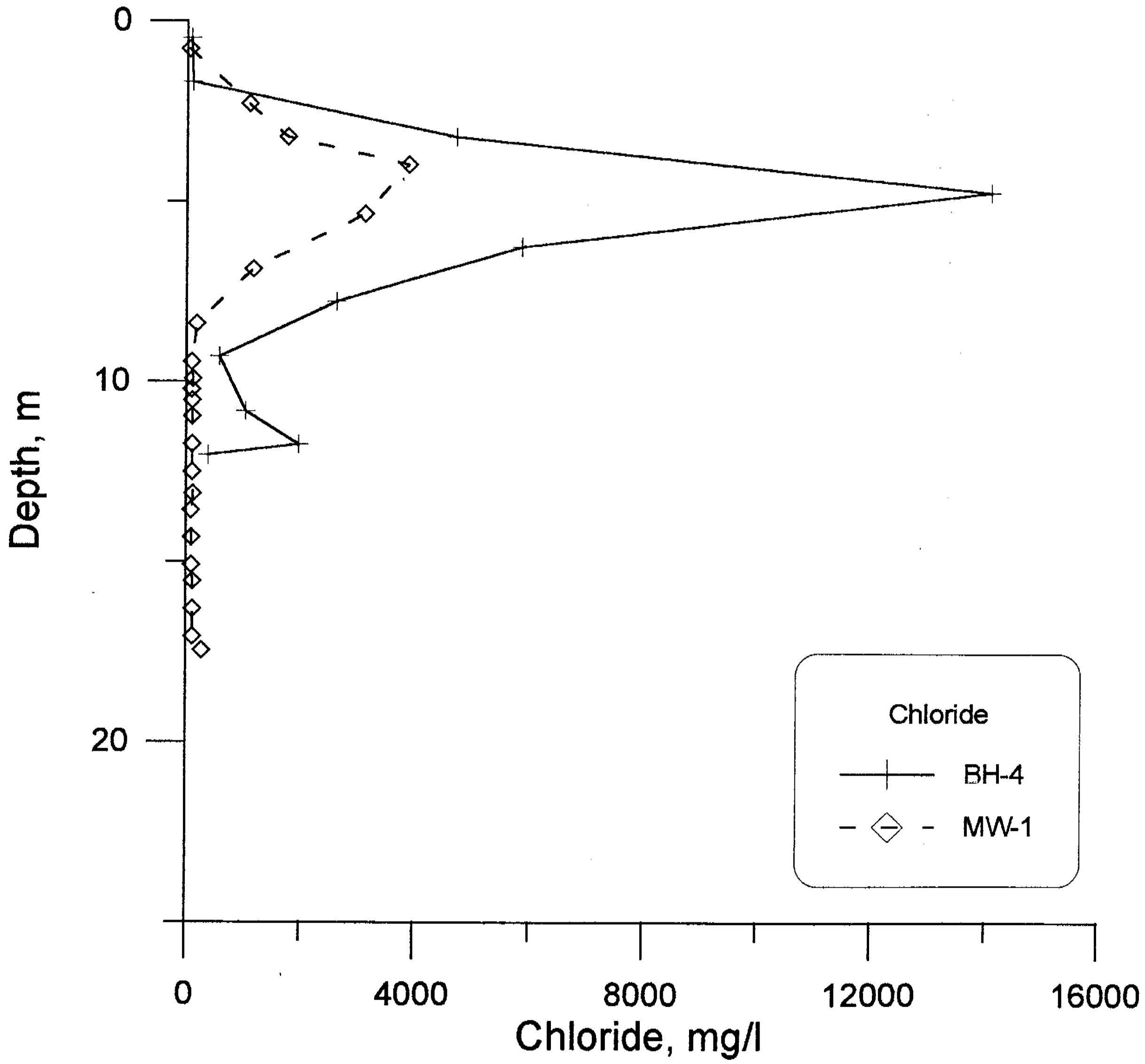


Figure P-3. BH-4 and MW-1
Bromide vs. Depth

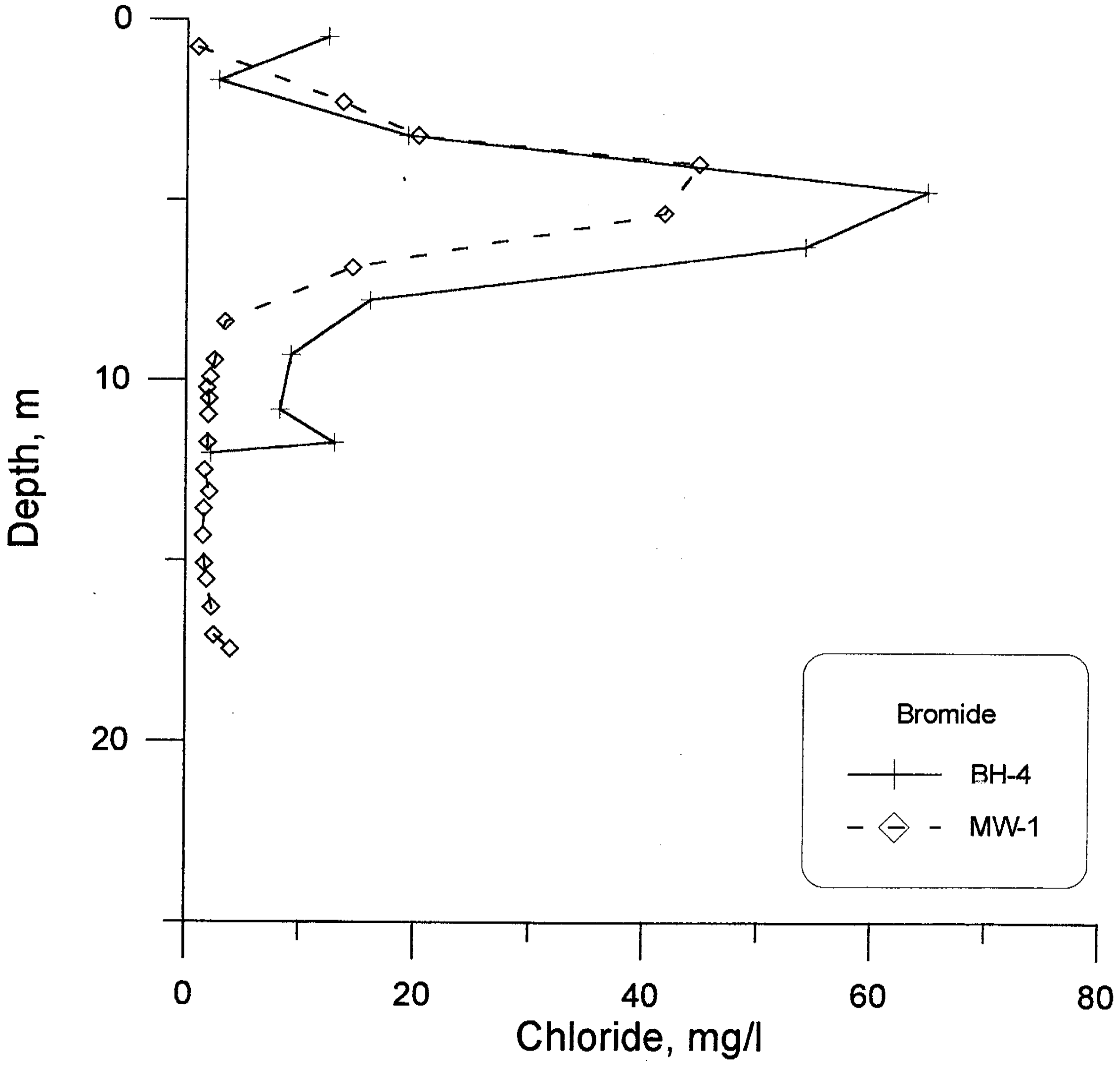
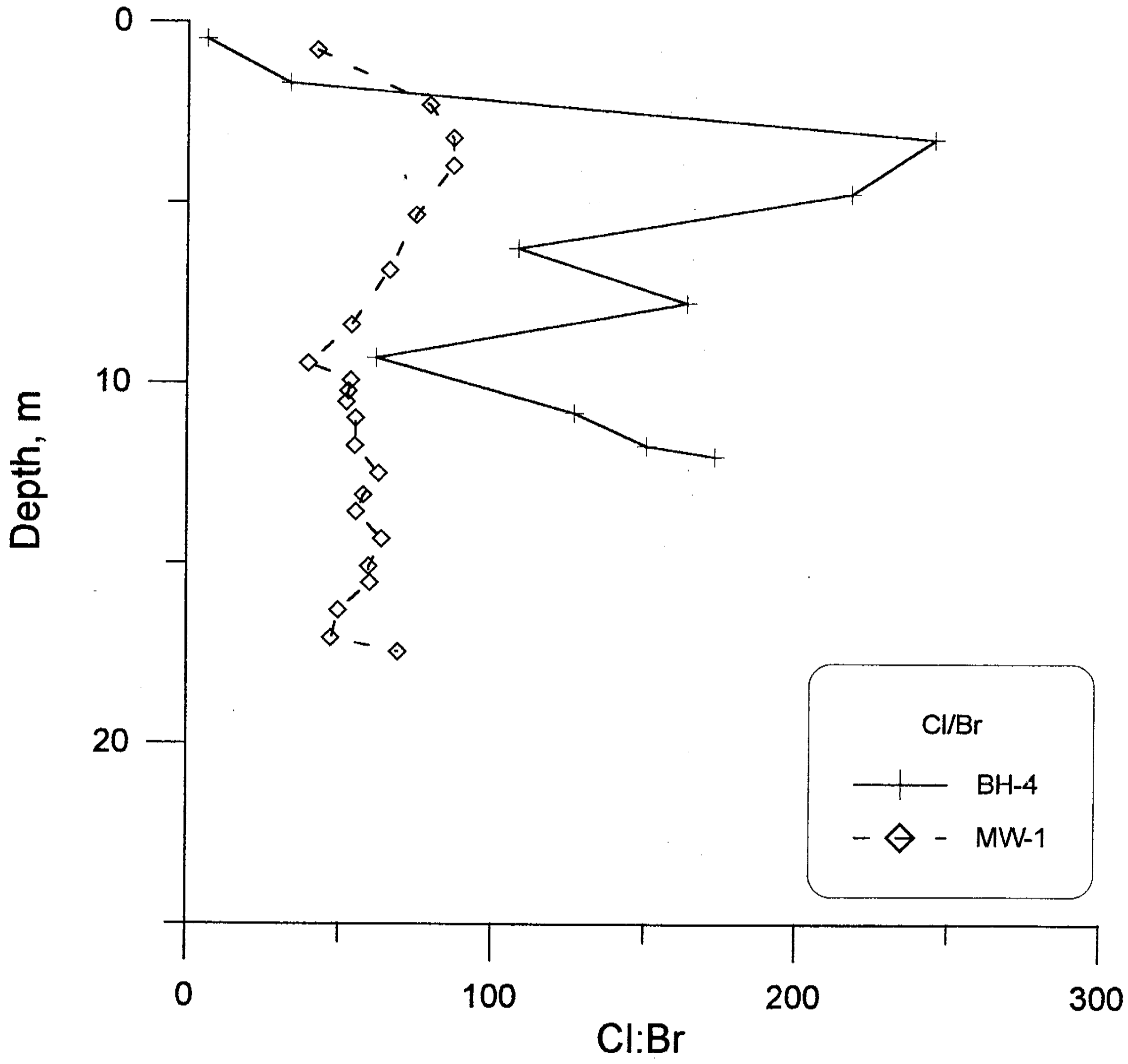


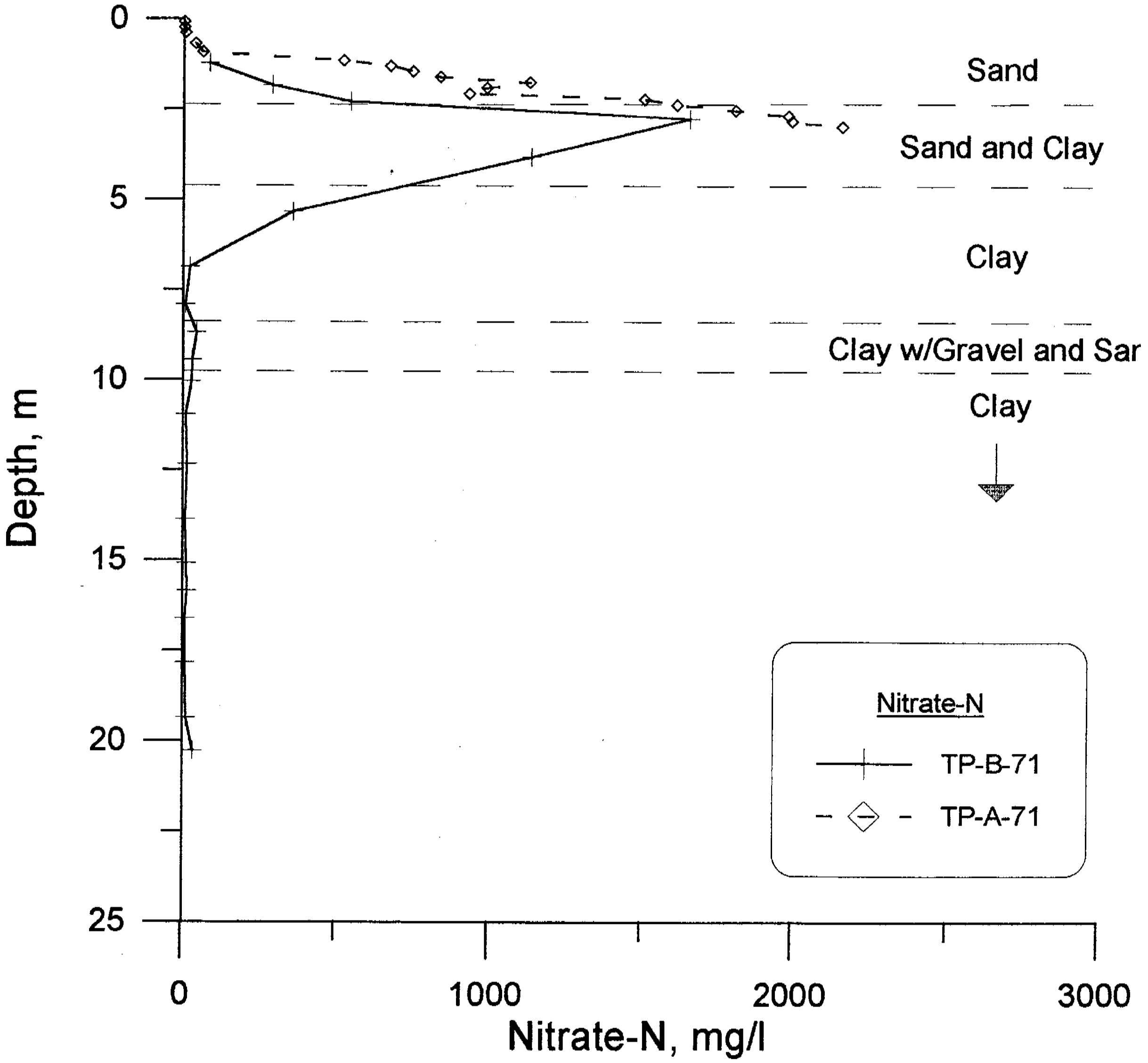
Figure P-4. BH-4 and MW-1 Chloride/Bromide vs. Depth



APPENDIX Q

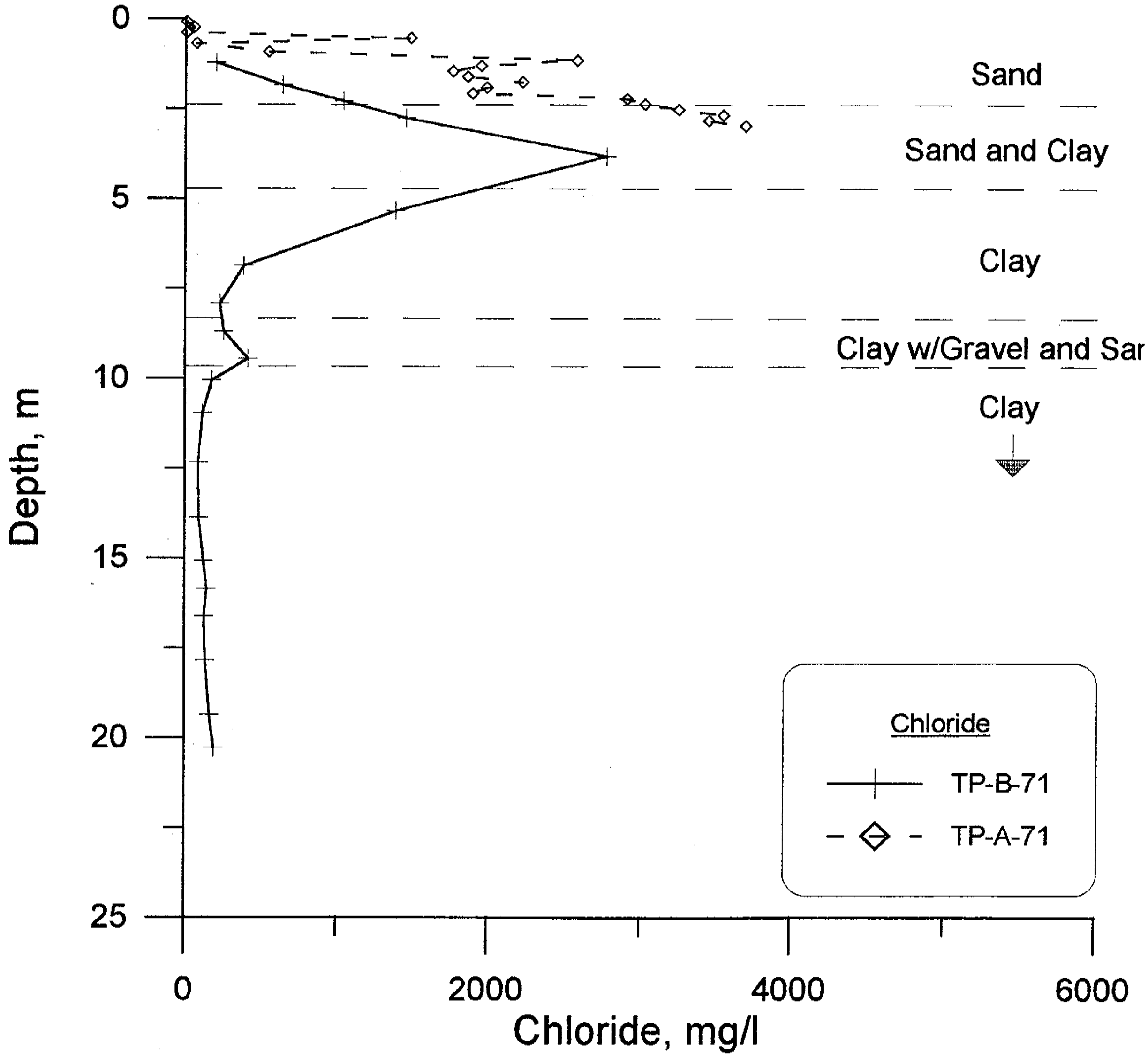
Combined TP-A
and TP-B Profiles

Figure Q-1A. TP-71
Nitrate-N vs. Depth



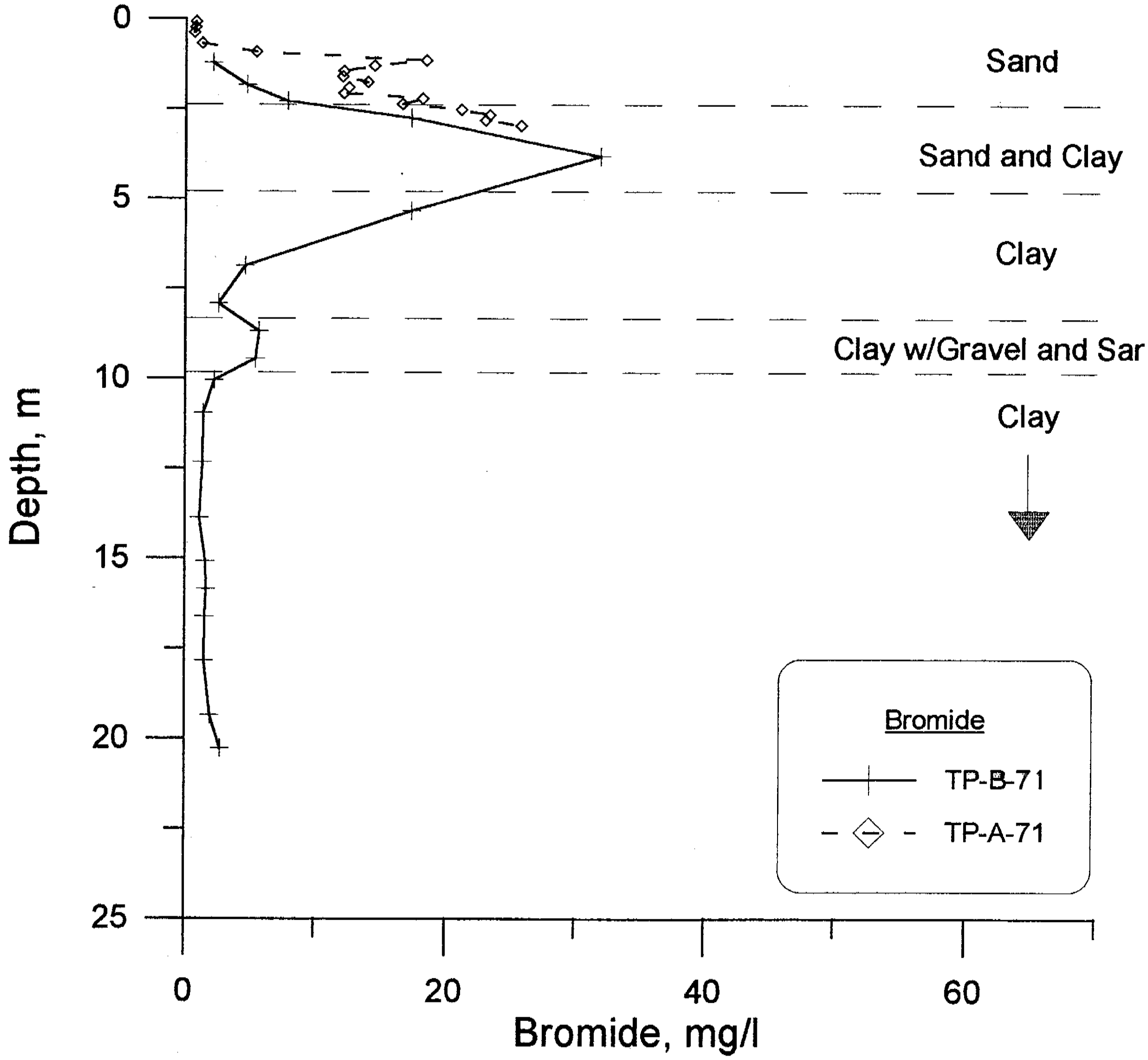
Lithologies shown are for TP-B-71
Descriptions based on Lithologic Log

Figure Q-1B. TP-71
Chloride vs. Depth



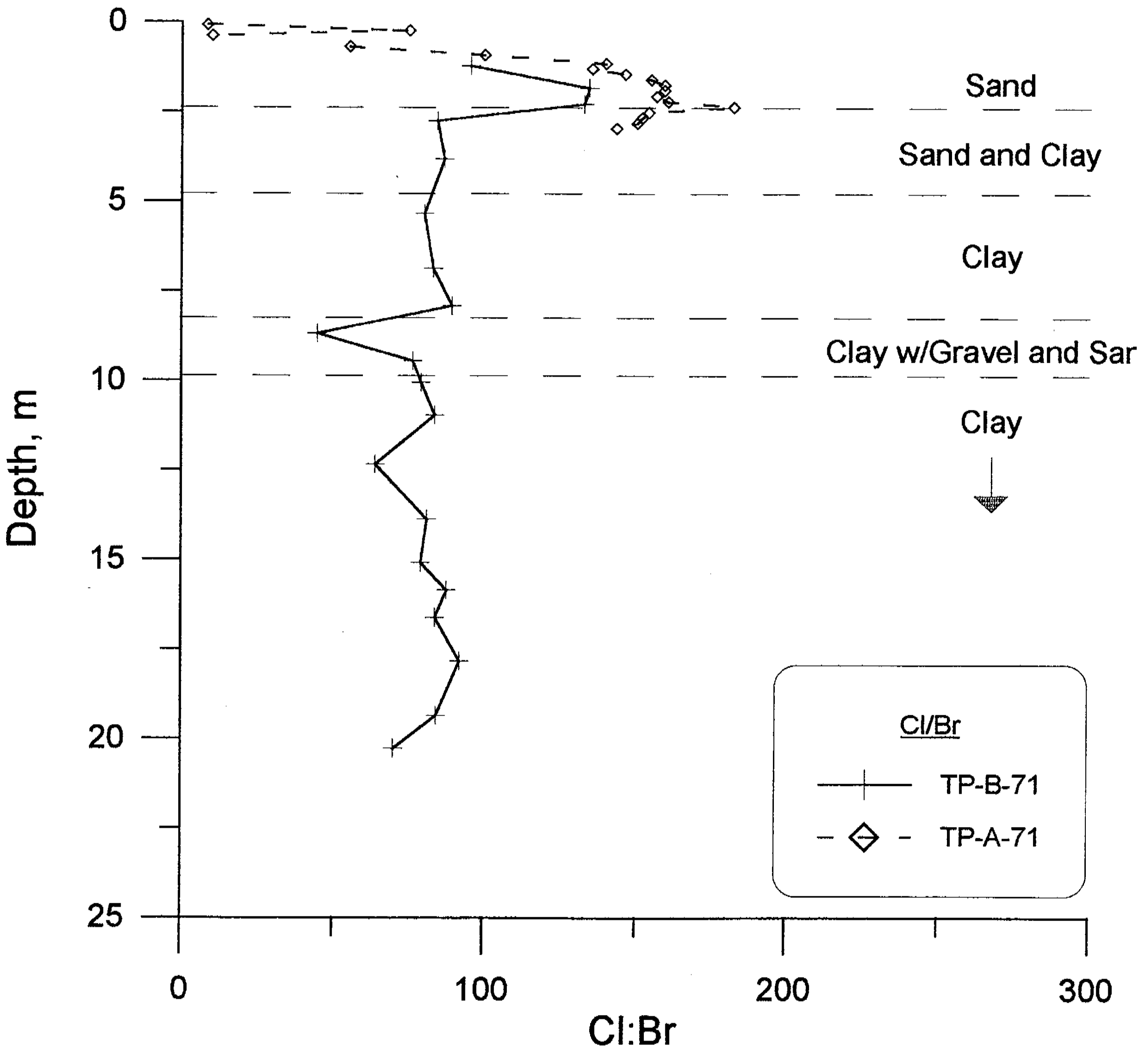
Lithologies shown are for TP-B-71
Descriptions based on Lithologic Log

Figure Q-1C. TP-71
Bromide vs. Depth



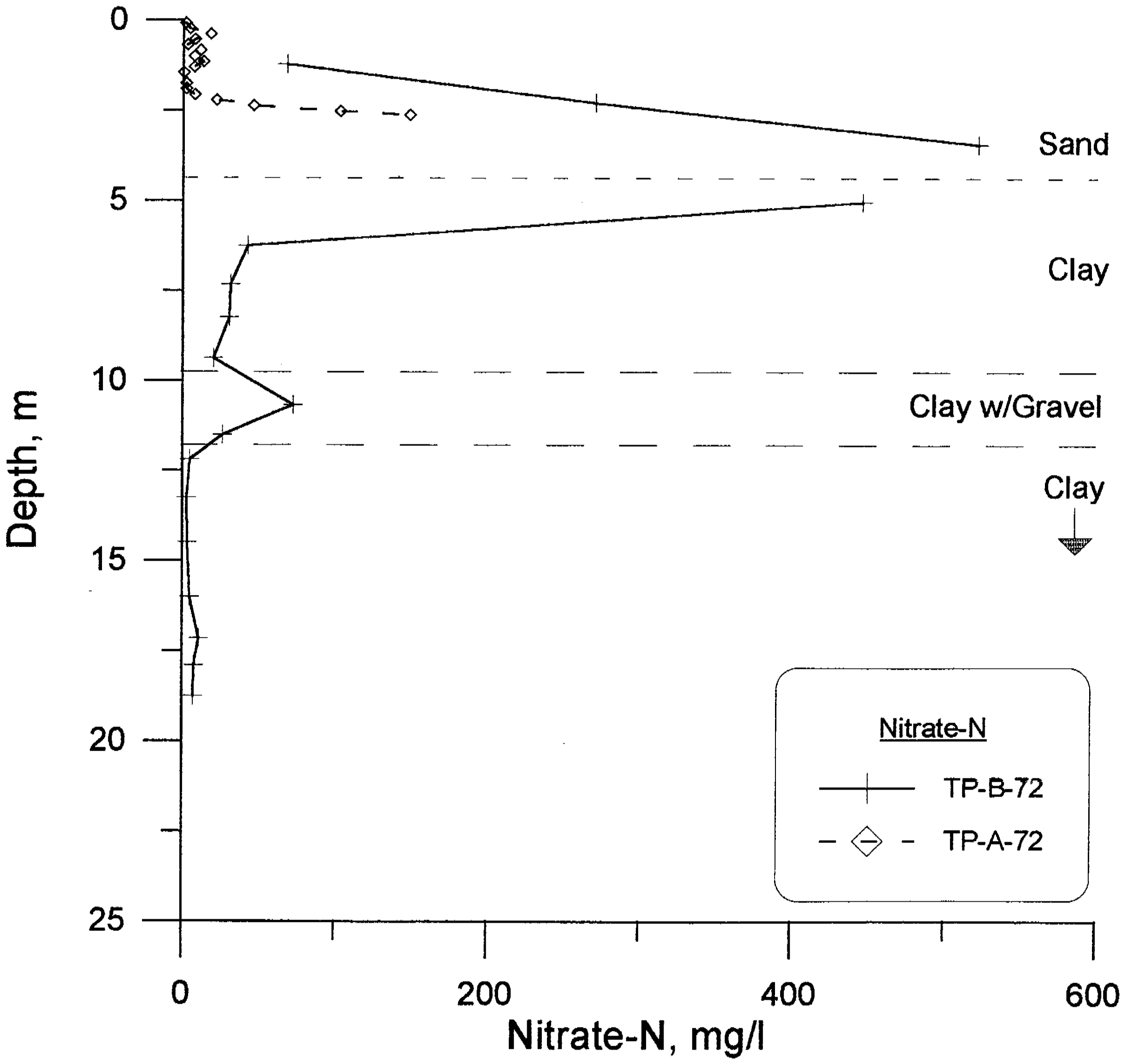
Lithologies shown are for TP-B-71
Descriptions based on Lithologic Log

Figure Q-1D. TP-71
Cl:Br vs. Depth



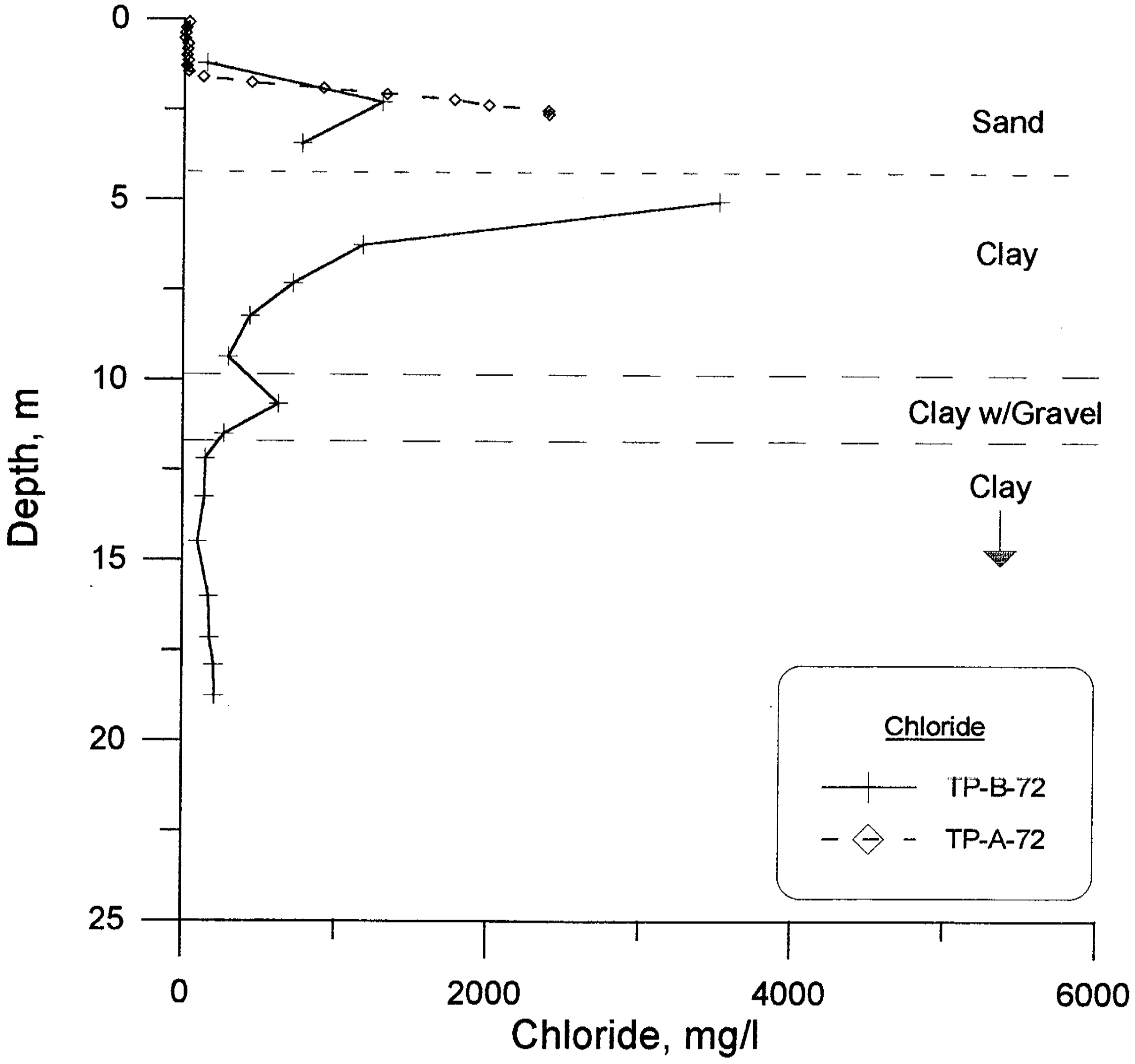
Lithologies shown are for TP-B-71
Descriptions based on Lithologic Log

Figure Q-2A. TP-72
Nitrate-N vs. Depth



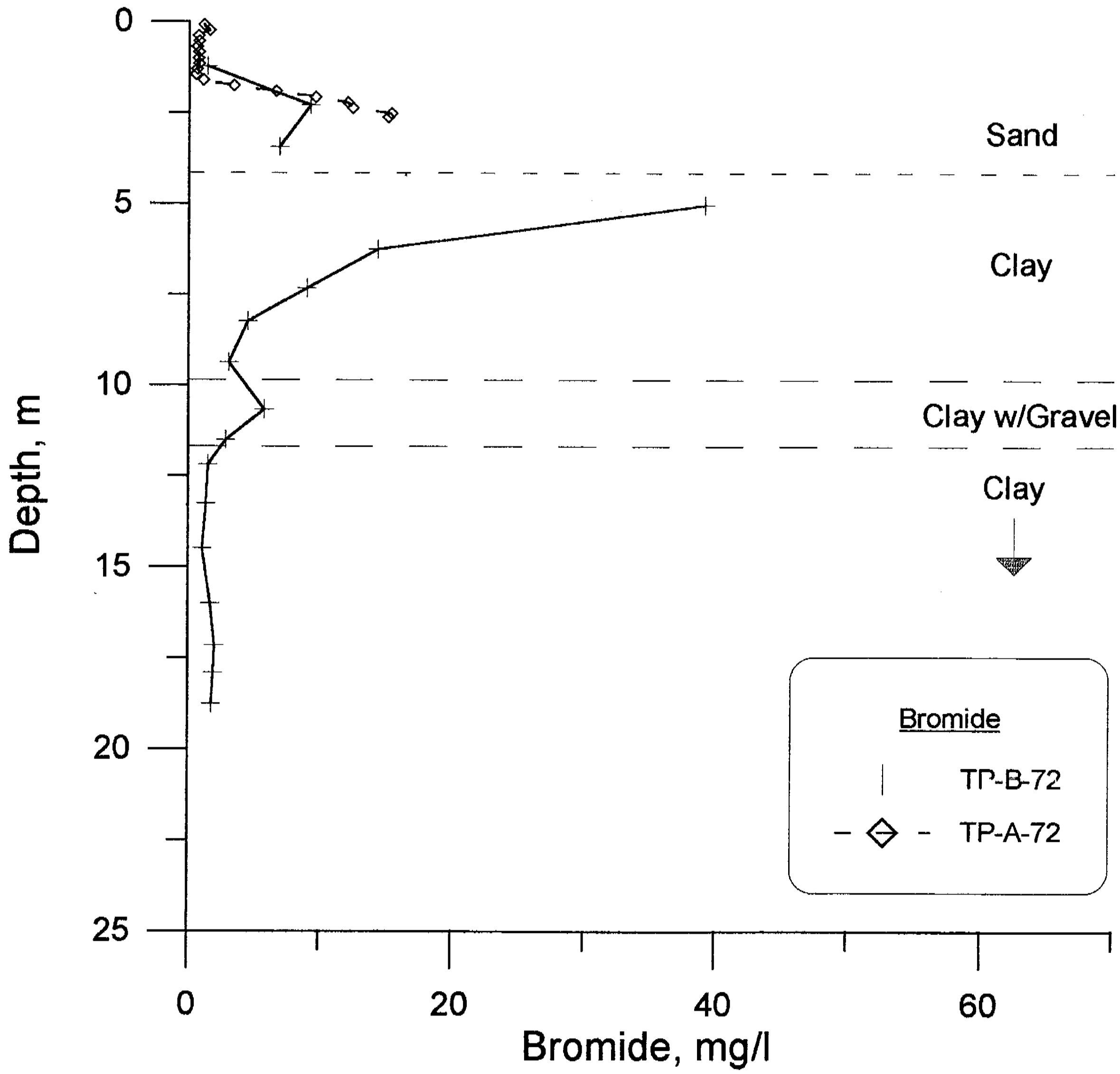
Lithologies shown are for TP-B-72
Descriptions based on Lithologic Log
– – – – – inferred contact

Figure Q-2B. TP-72
Chloride vs. Depth



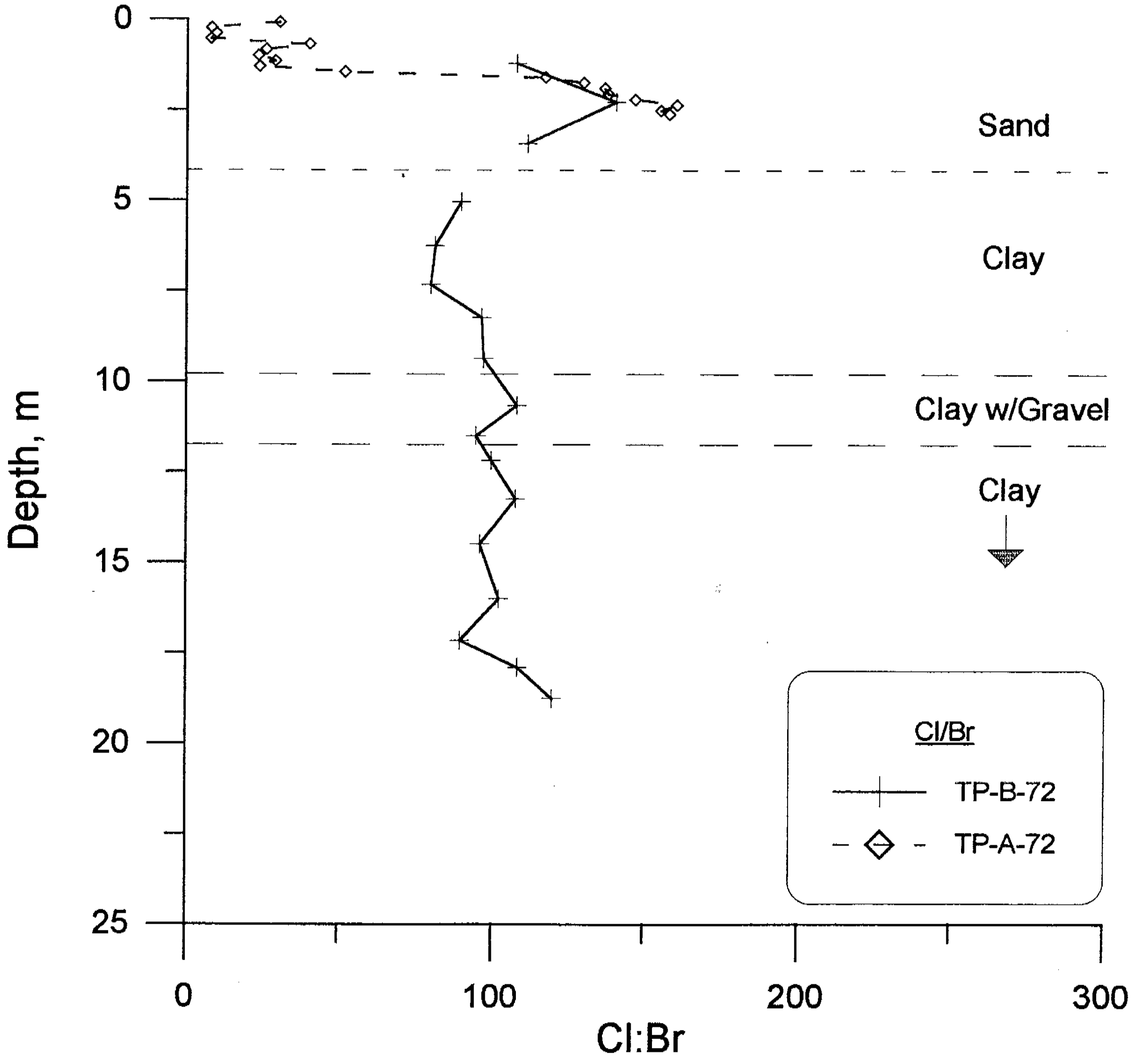
Lithologies shown are for TP-B-72
Descriptions based on Lithologic Log
– – – – inferred contact

Figure Q-2C. TP-72
Bromide vs. Depth



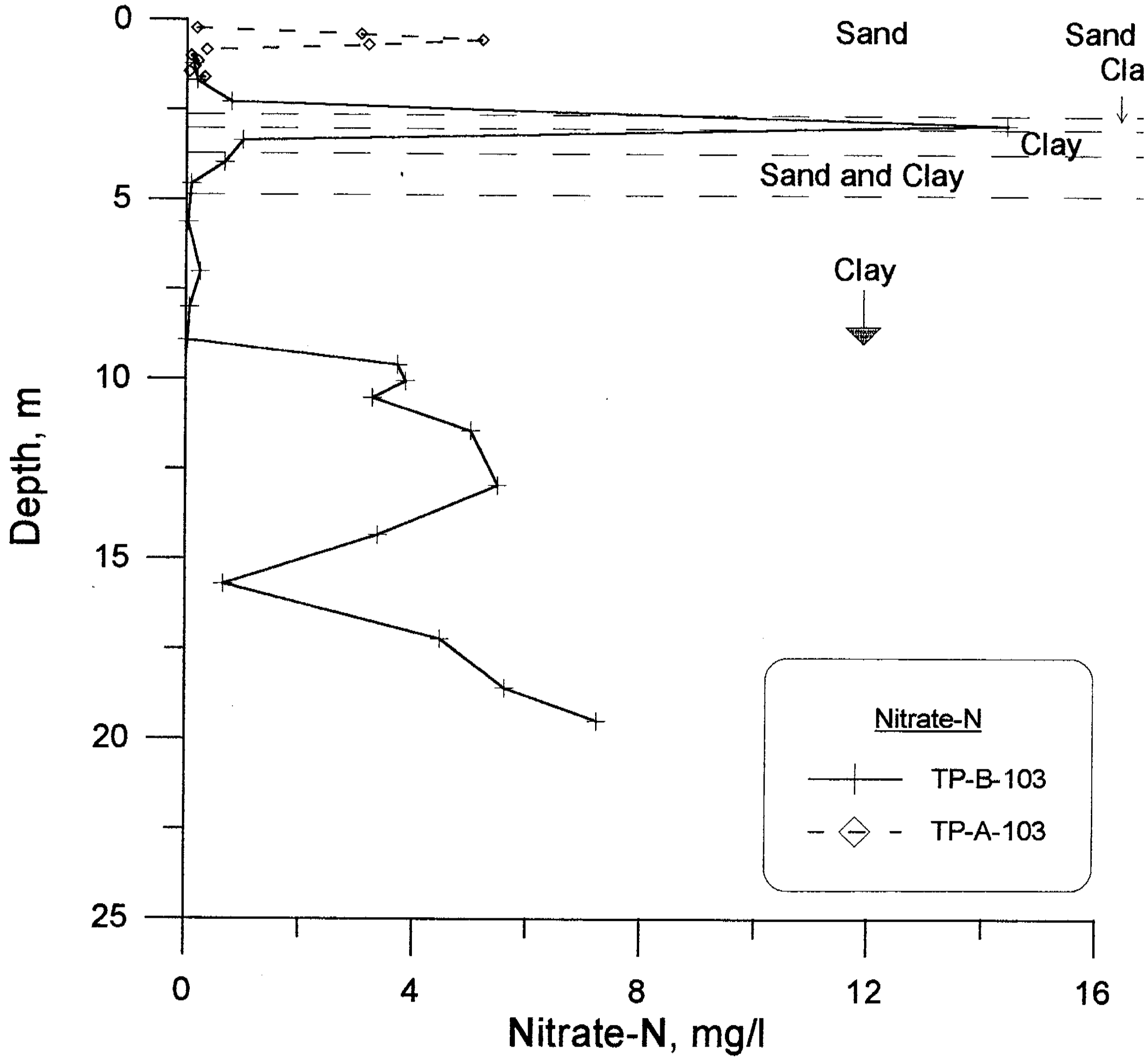
Lithologies shown are for TP-B-72
Descriptions based on Lithologic Log
– – – – inferred contact

Figure Q-2D. TP 72
Cl:Br vs. Depth



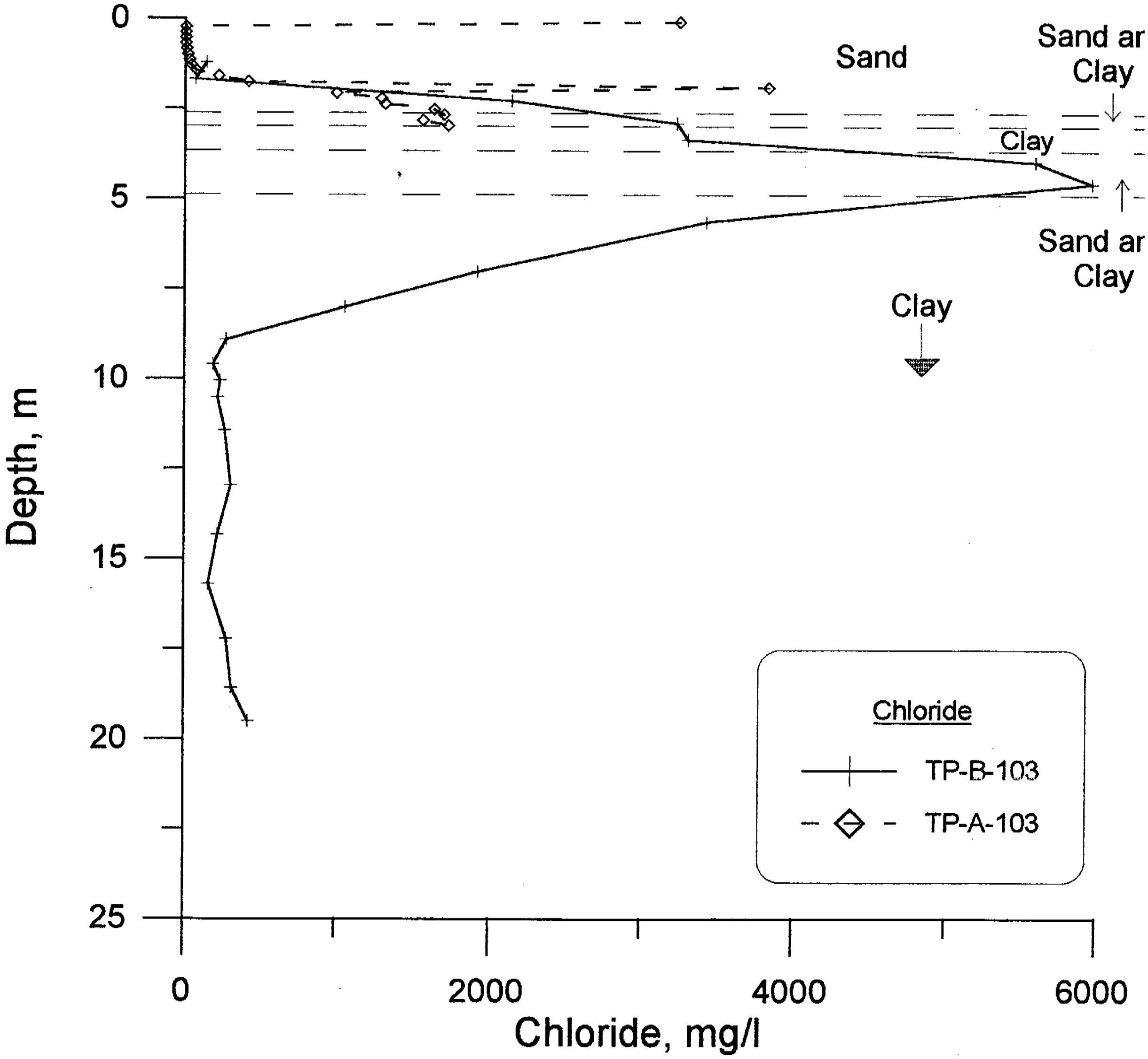
Lithologies shown are for TP-B-72
Descriptions based on Lithologic Log
– – – – inferred contact

Figure Q-3A. TP-103
Nitrate-N vs. Depth



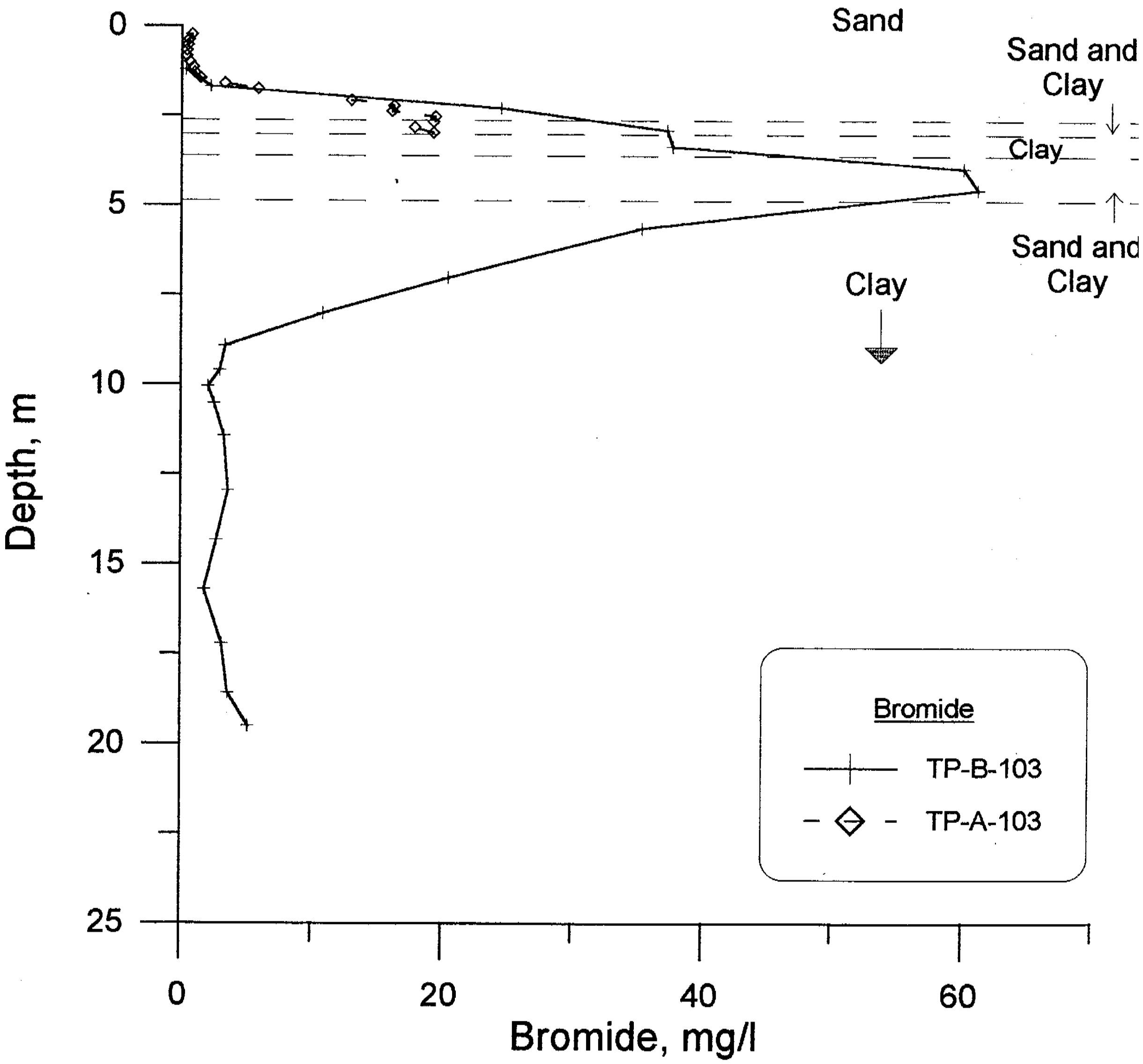
Lithologies shown are for TP-B-103
Description based on Lithologic Log

Figure Q-3B. TP-103
Chloride vs. Depth



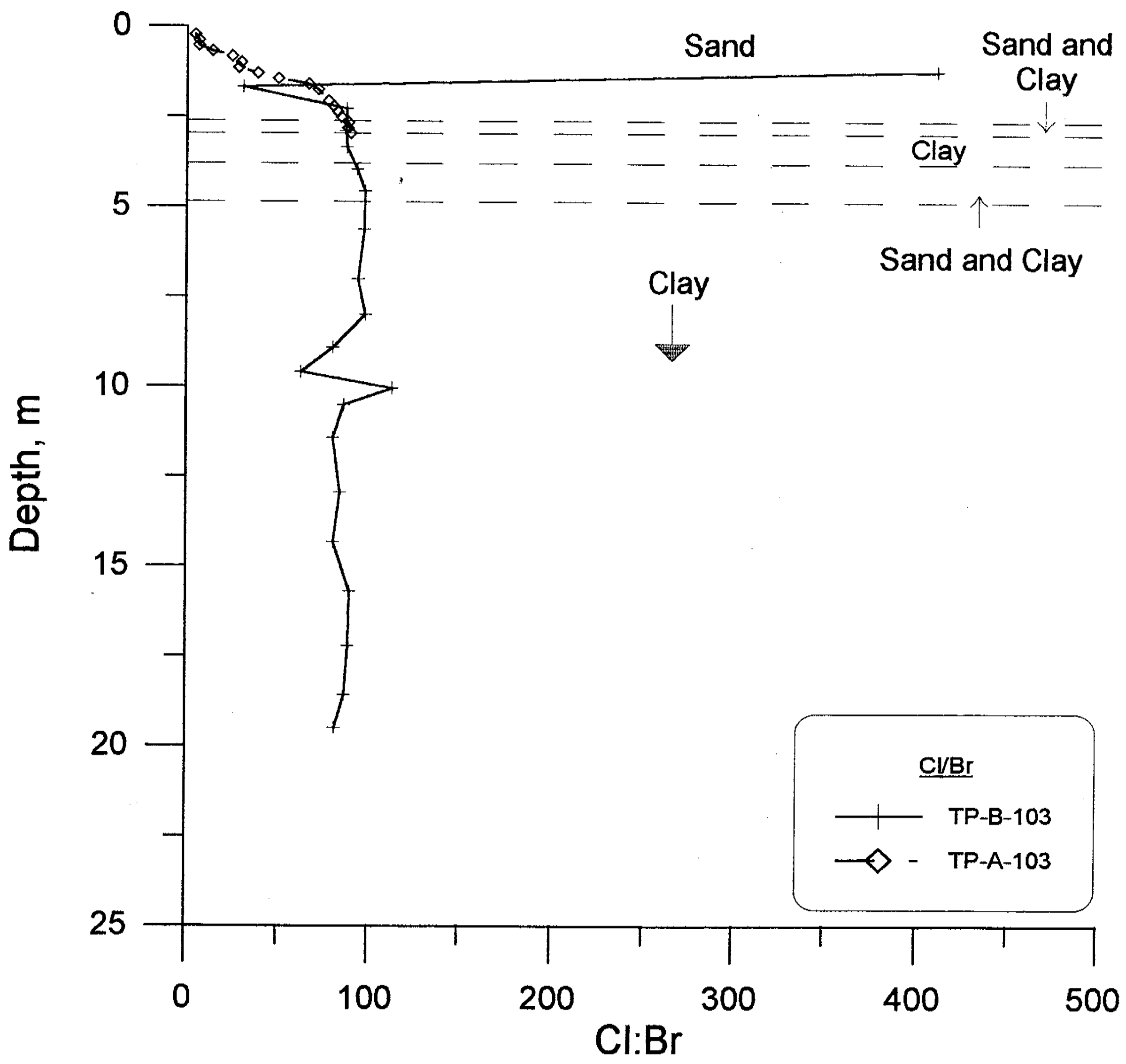
Lithologies shown are for TP-B-103
Descriptions based on Lithologic Log

Figure Q-3C. TP 103
Bromide vs. Depth



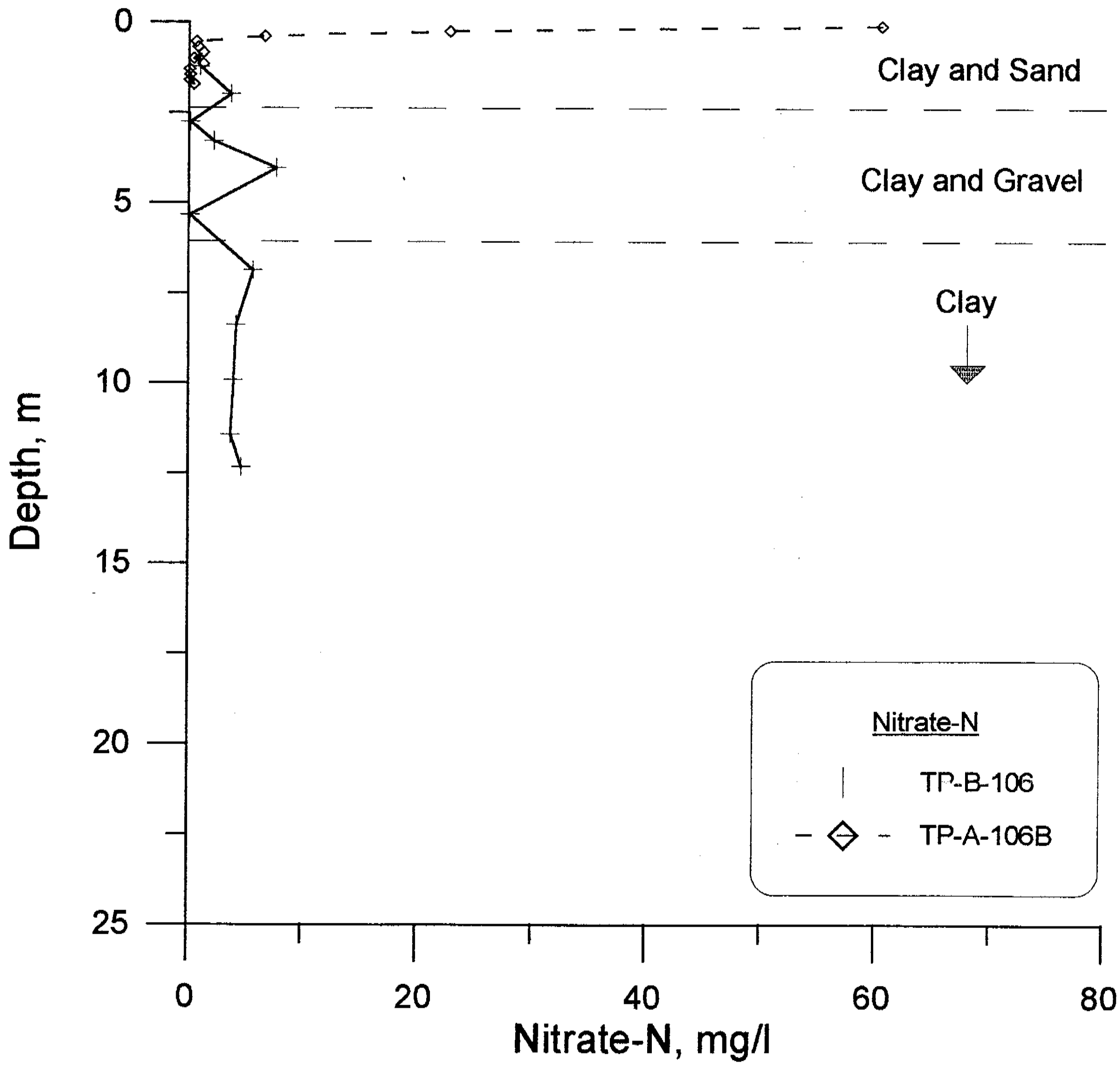
Lithologies shown are for TP-B-103
Descriptions based on Lithologic Log

Figure Q-3D. TP-103
Cl:Br vs. Depth



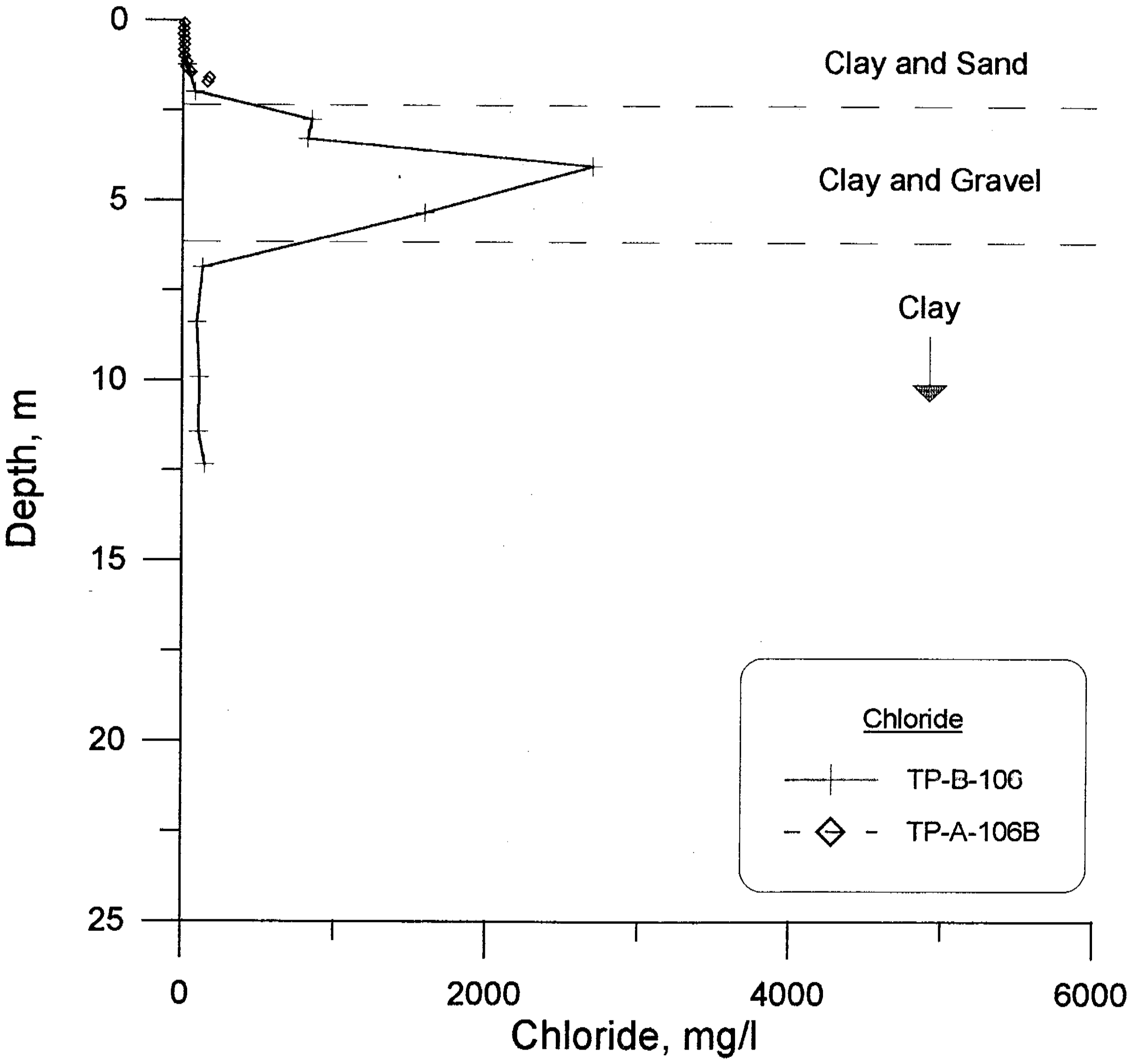
Lithologies shown are for TP-B-103
Descriptions based on Lithologic Log

Figure Q-4A. TP-106
Nitrate-N vs. Depth



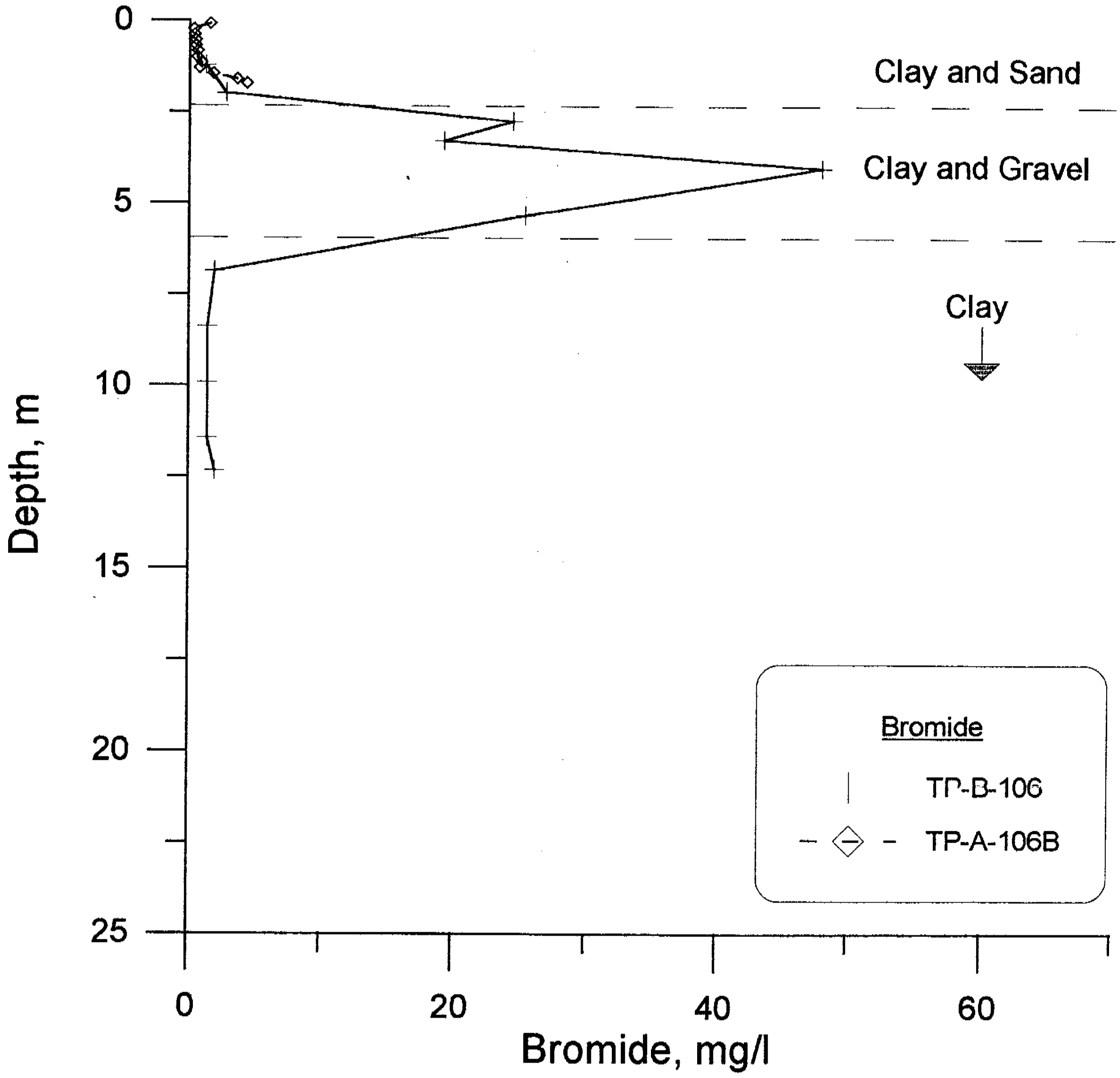
Lithologies shown are for TP-B-106
Descriptions based on Lithologic Log

Figure Q-4B. TP-106
Chloride vs. Depth



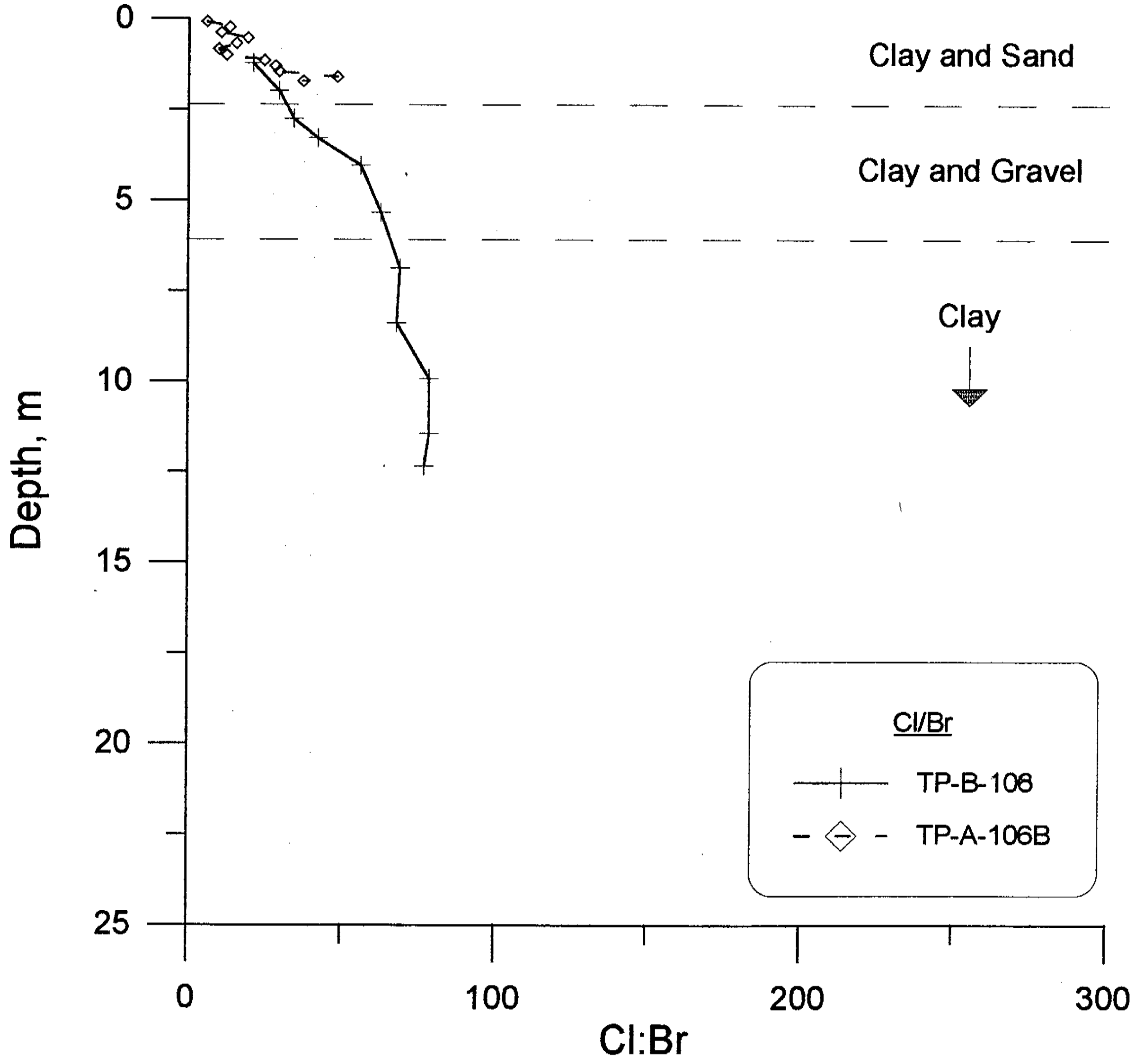
Lithologies shown are for TP-B-106
Descriptions based on Lithologic Log

Figure Q-4C. TP-106
Bromide vs. Depth



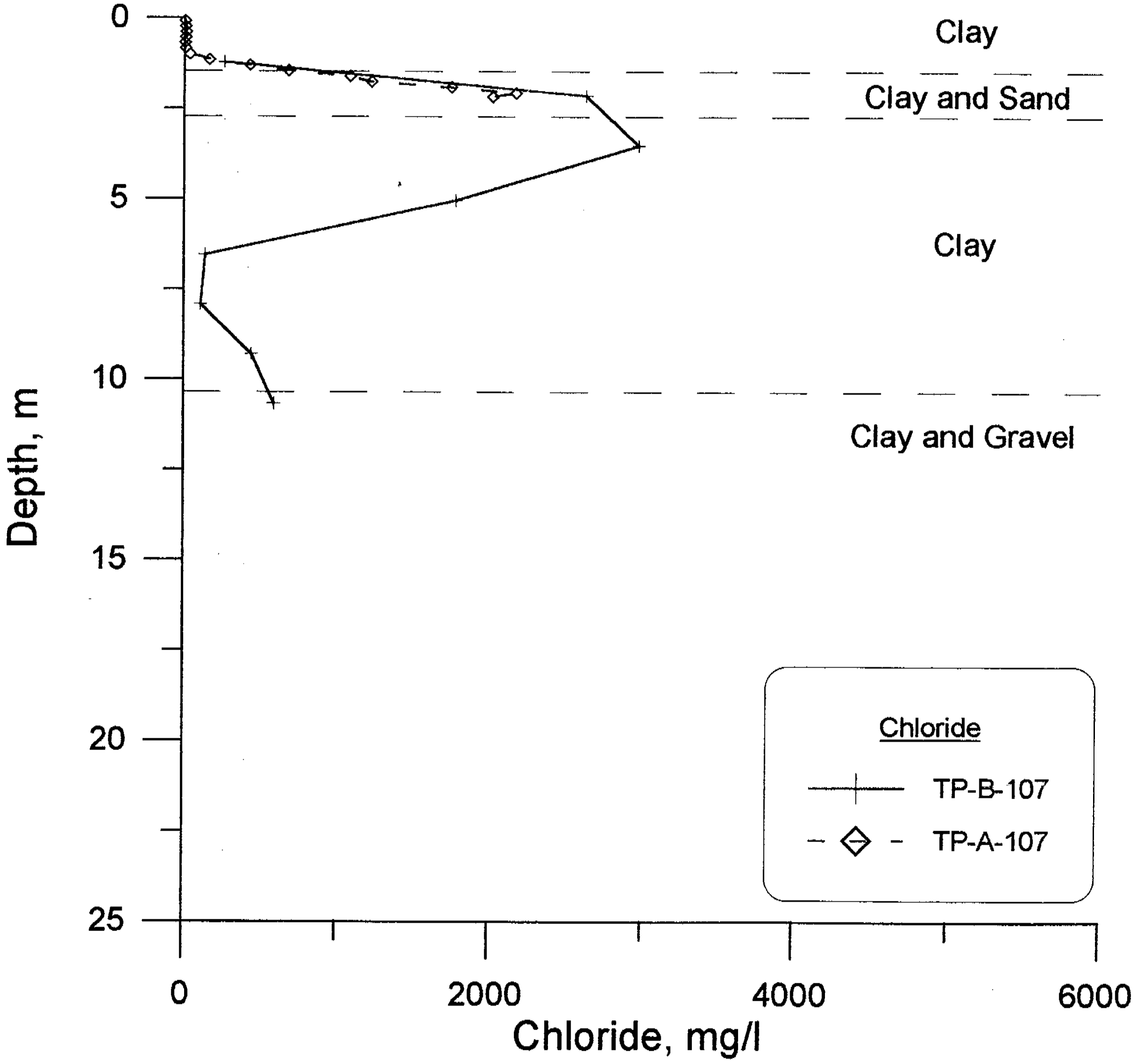
Lithologies shown are for TP-B-106
Descriptions based on Lithologic Log

Figure Q-4D. TP-106
Cl:Br vs. Depth



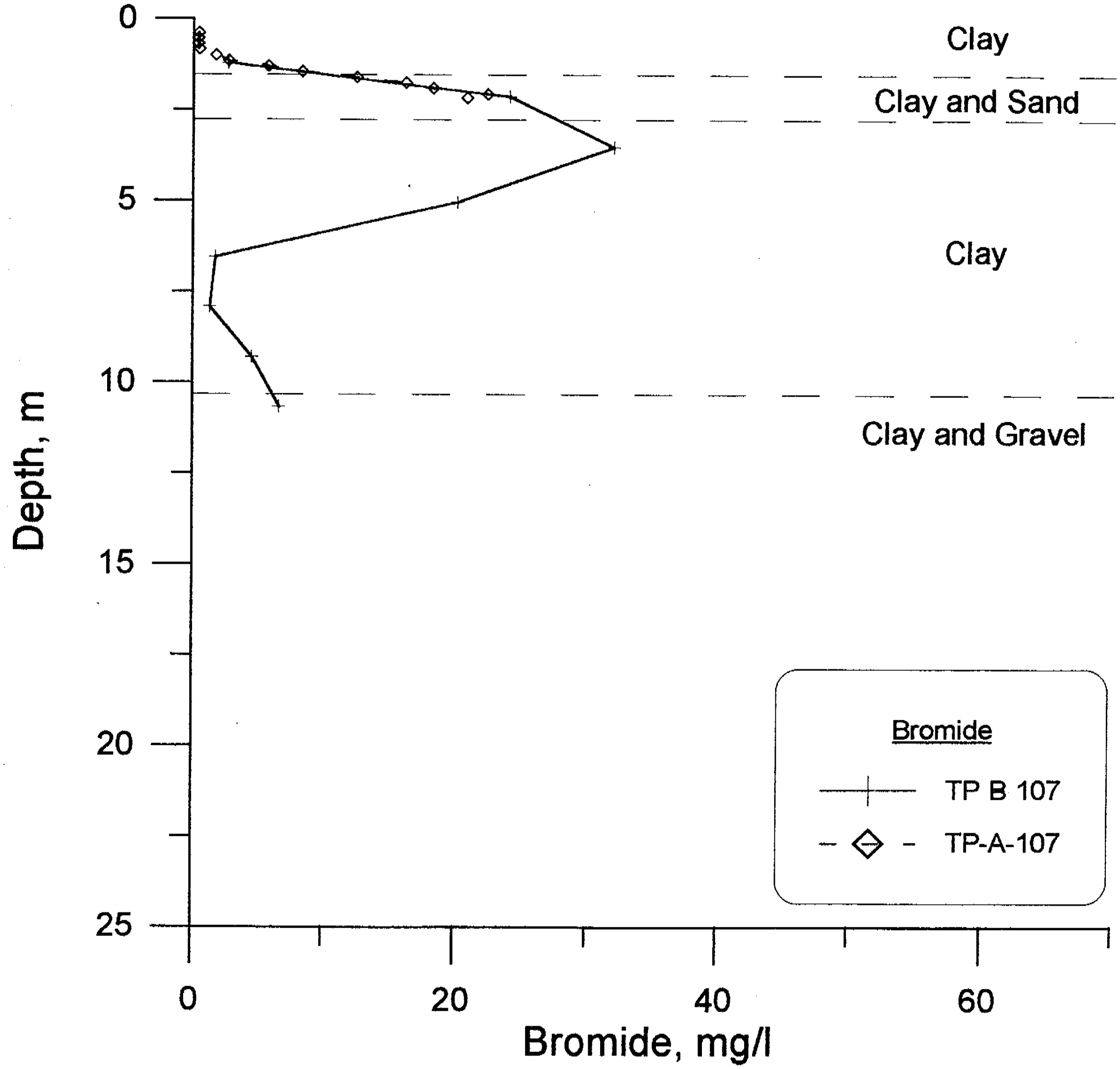
Lithologies shown are for TP-B-106
Descriptions based on Lithologic Log

Figure Q-5B. TP-107
Chloride vs. Depth



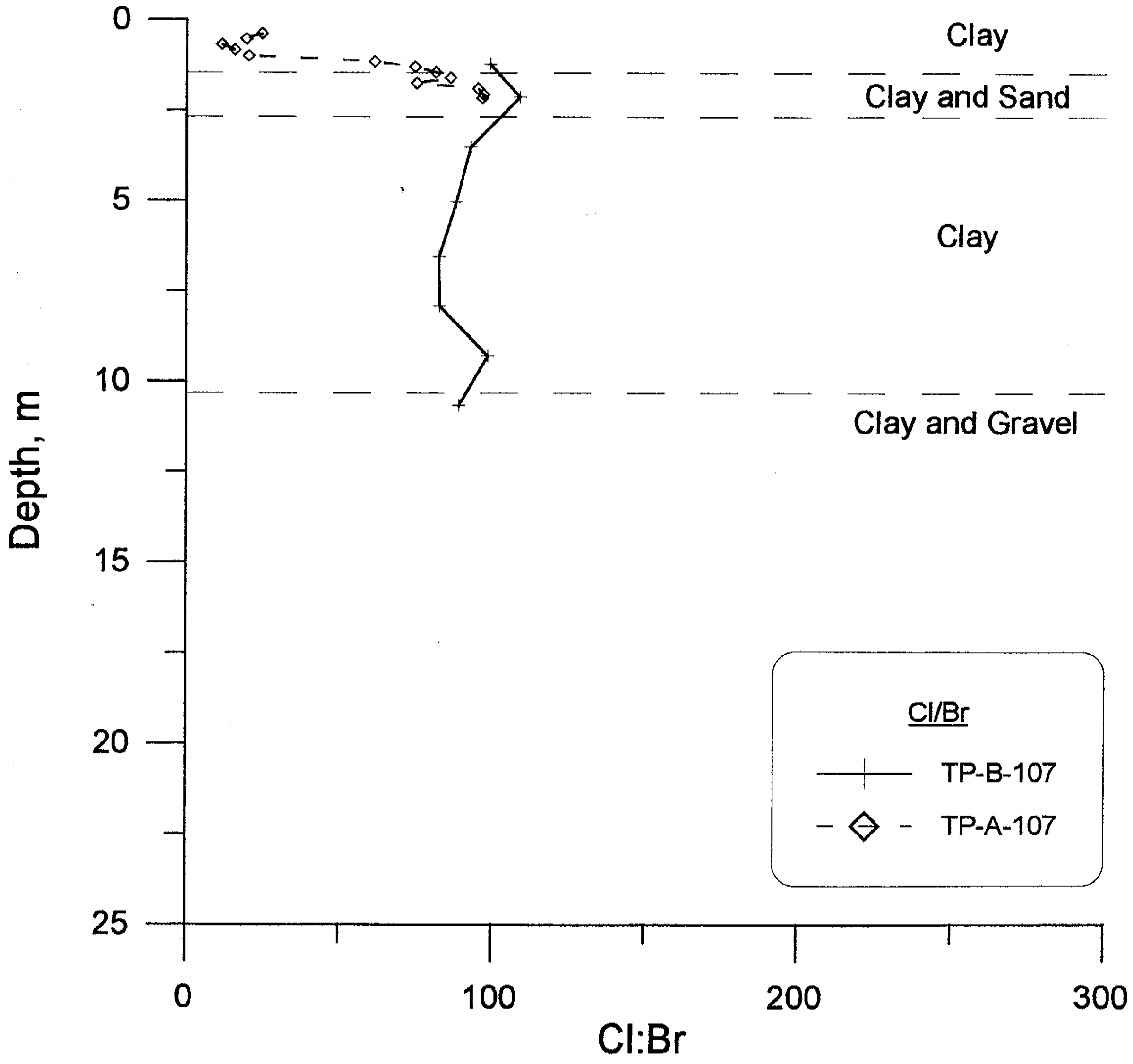
Lithologies shown are for TP-B-107
Descriptions based on Lithologic Logs

Figure Q-5C. TP-107
Bromide vs. Depth



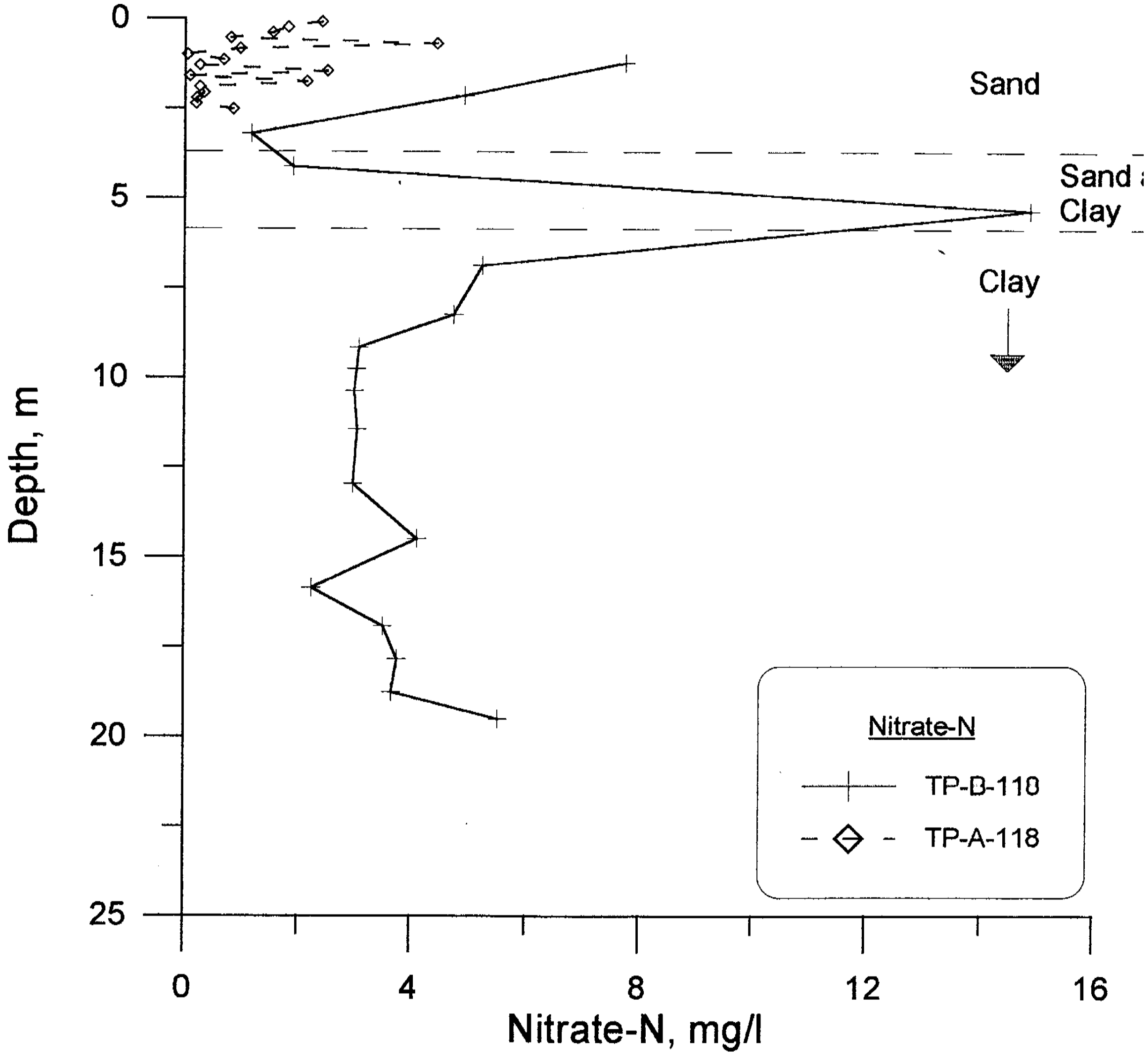
Lithologies shown are for TP-B-107
Descriptions based on Lithologic Log

Figure Q-5D. TP-107
Cl:Br vs. Depth



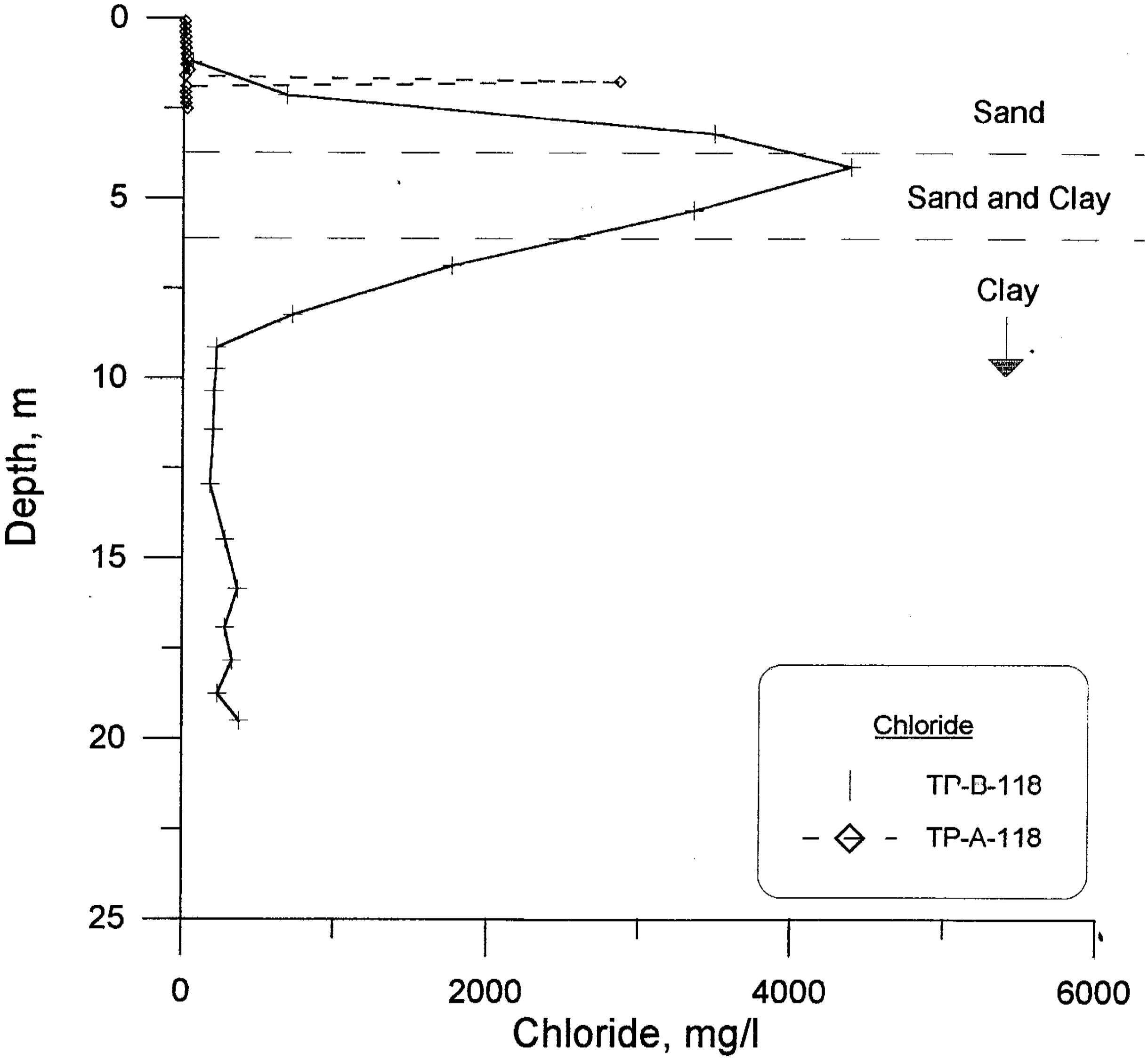
Lithologies shown are for TP-B-107
Descriptions based on Lithologic Log

Figure Q-6A. TP-118
Nitrate-N vs. Depth



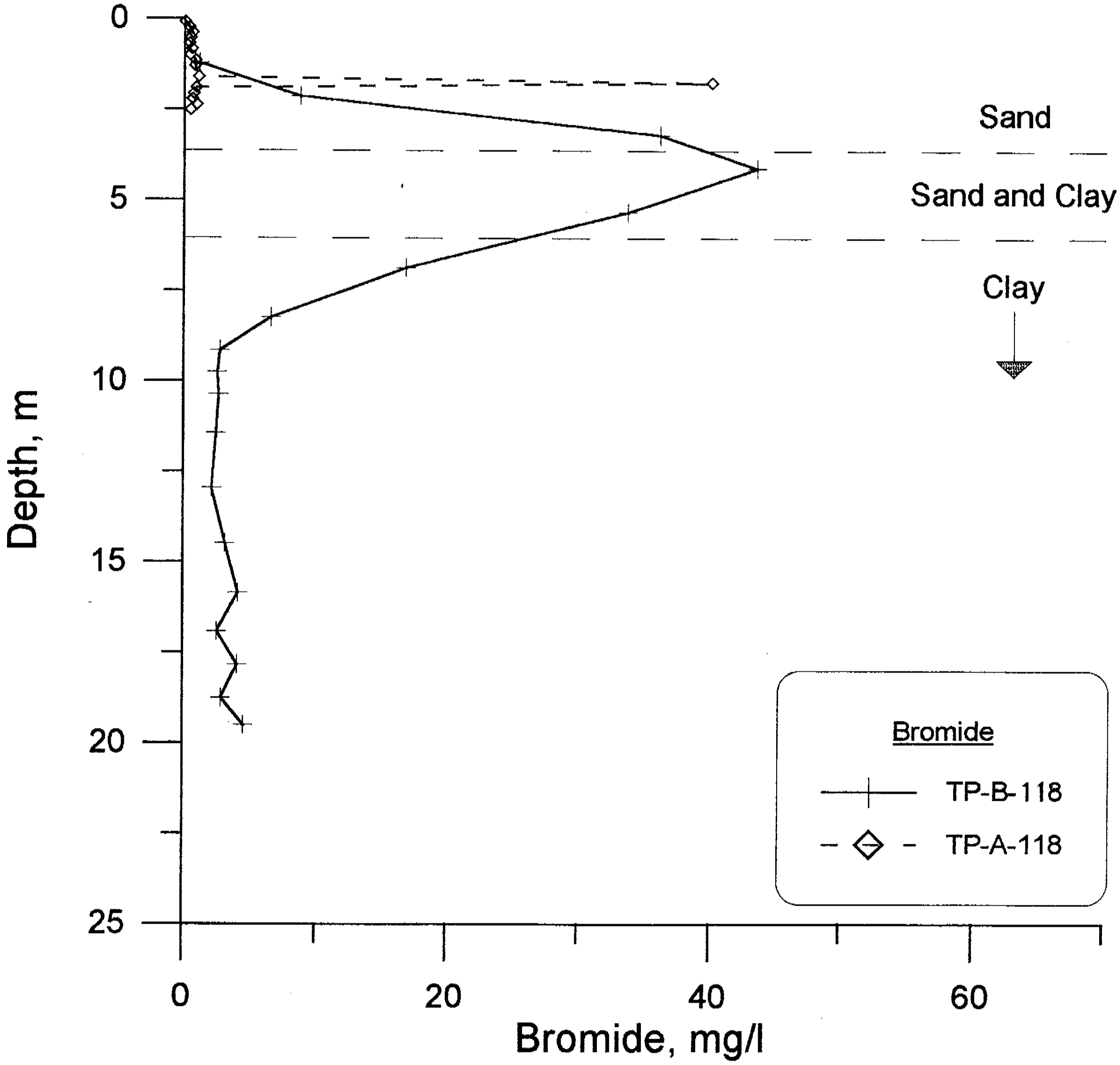
Lithologies shown are for TP-B-118
Descriptions bases on Lithologic Log

Figure Q-6B. TP-118
Chloride vs. Depth



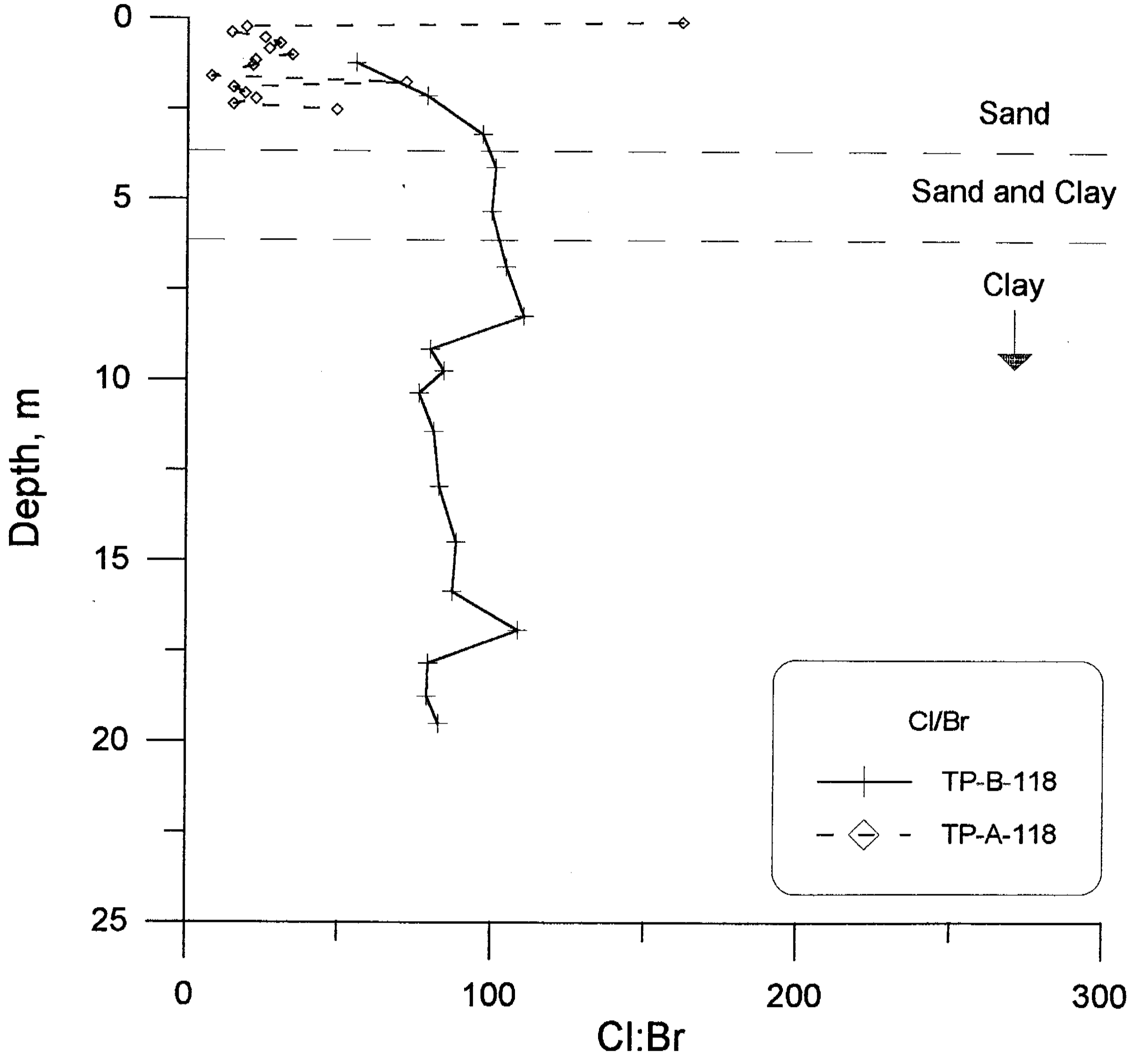
Lithologies shown are for TP-B-118
Descriptions based on Lithologic Log

Figure Q-6C. TP-118
Bromide vs. Depth



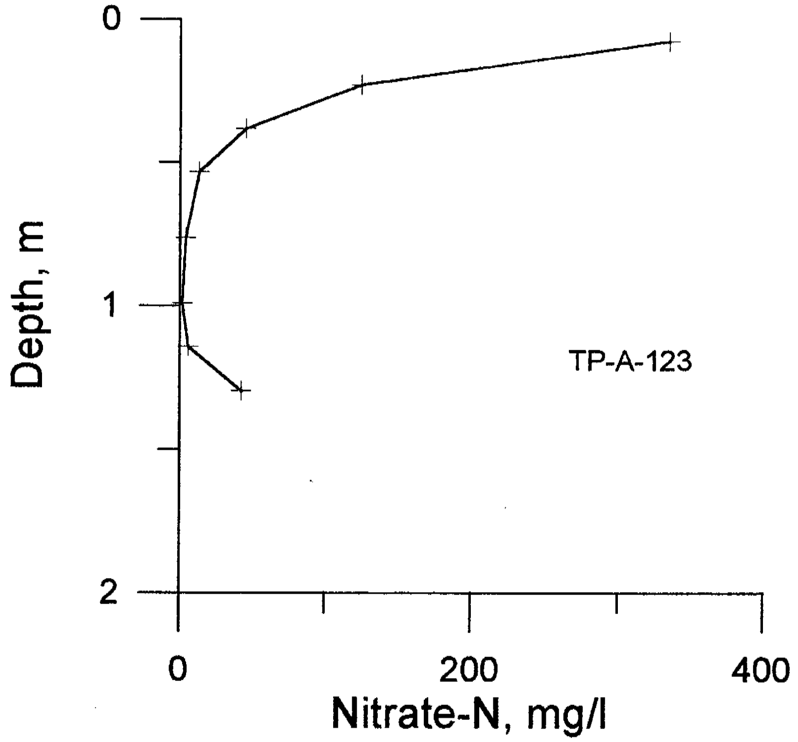
Lithologies shown are for TP-B-118
Descriptions based on Lithologic Log

Figure Q-6D. TP-118
Cl:Br vs. Depth



Lithologies shown are for TP-B-118
Descriptions based on Lithologic Log

Figure Q-7A. TP-123
Nitrate-N vs. Depth



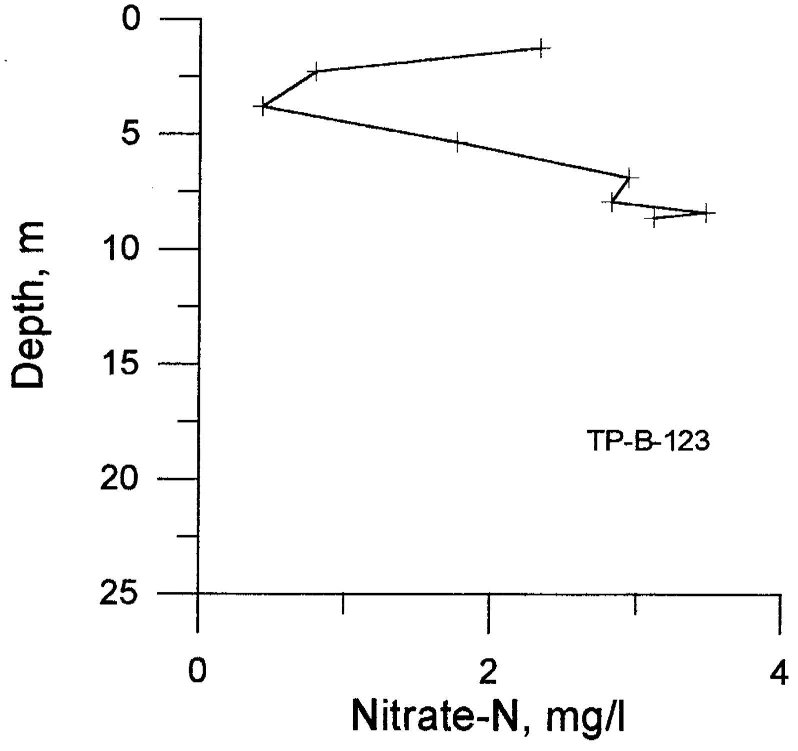
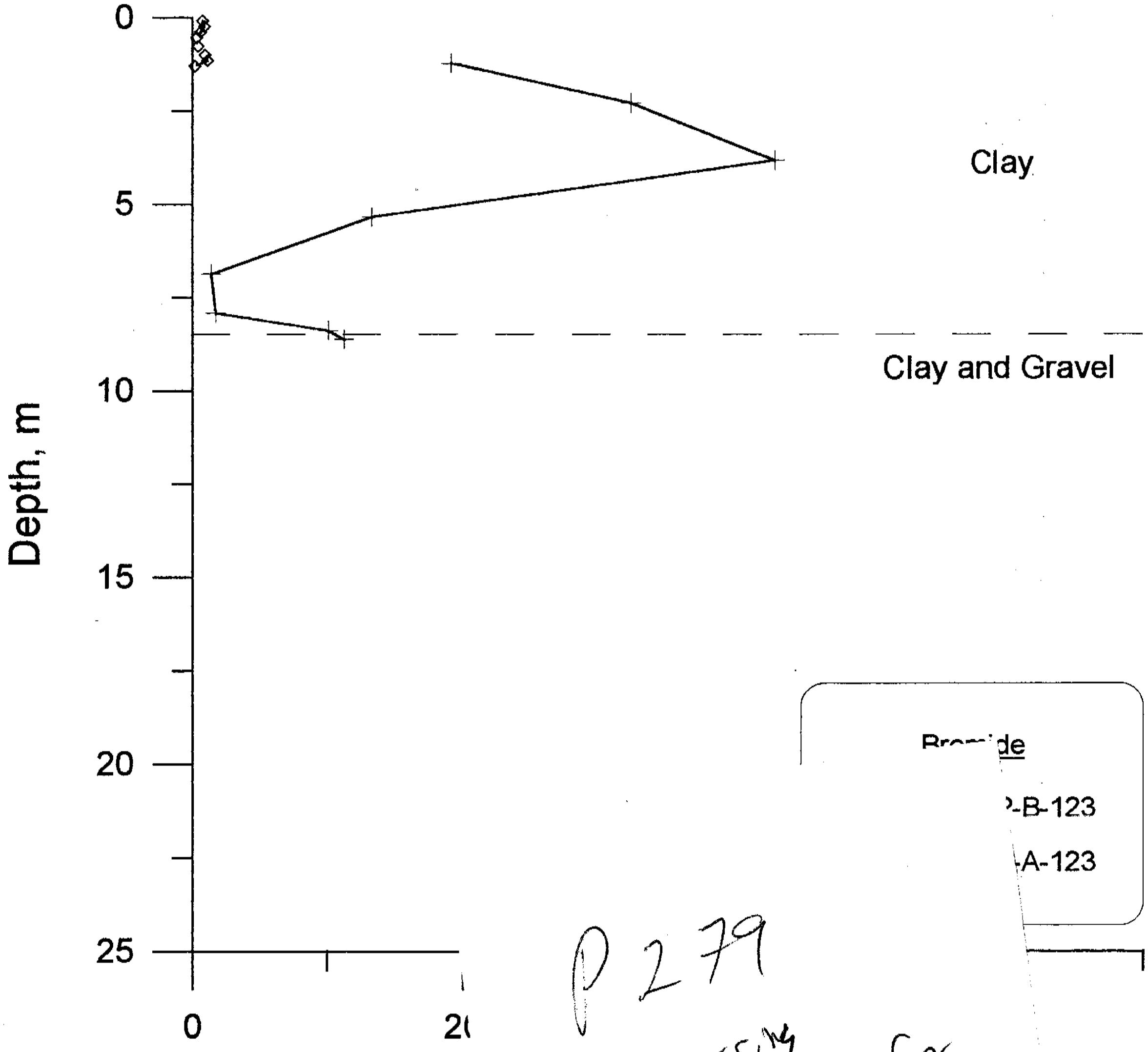


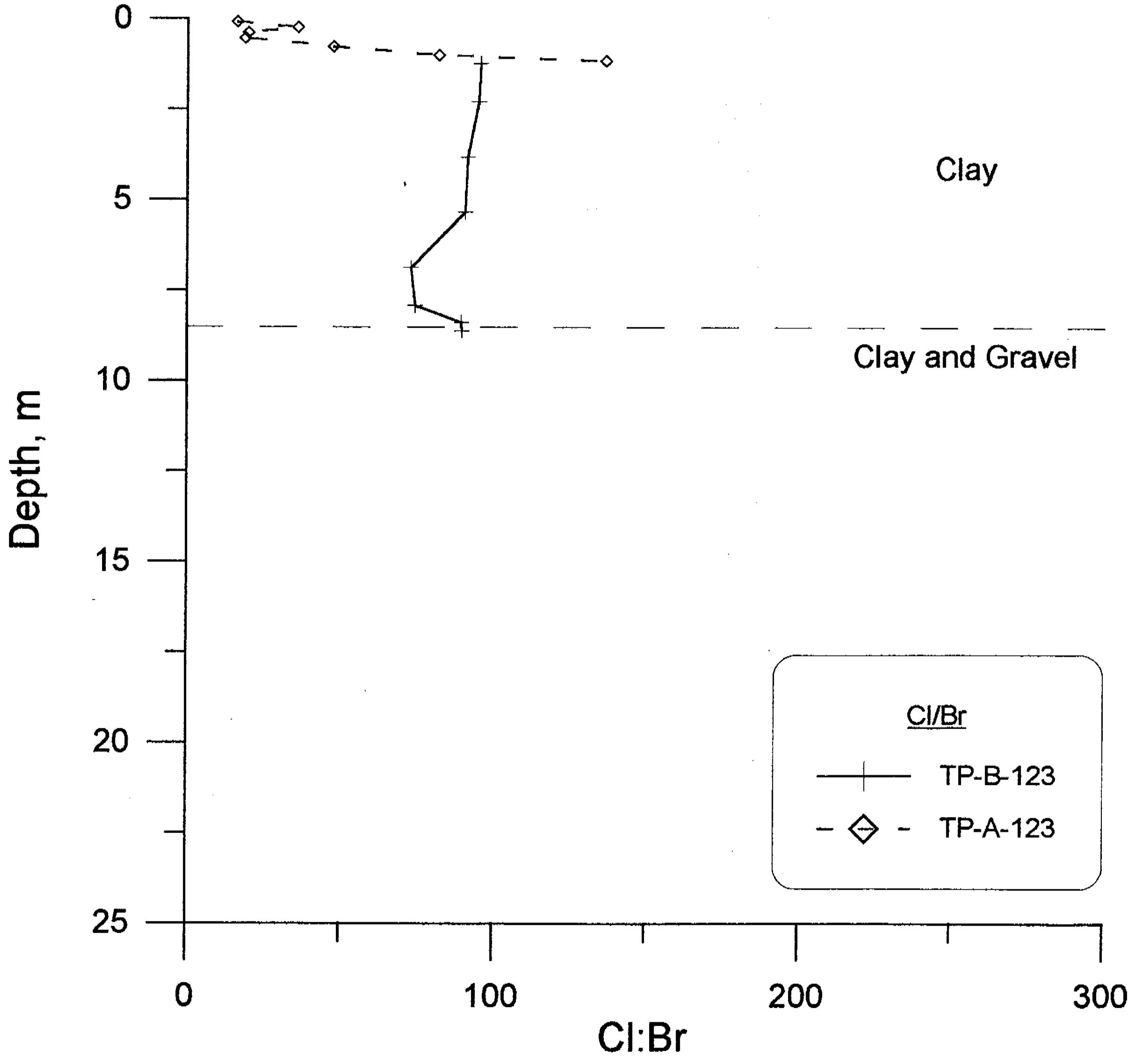
Figure Q-7C. TP-123
Bromide vs. Depth



Lithologies shown are fo
Descriptions based on Li

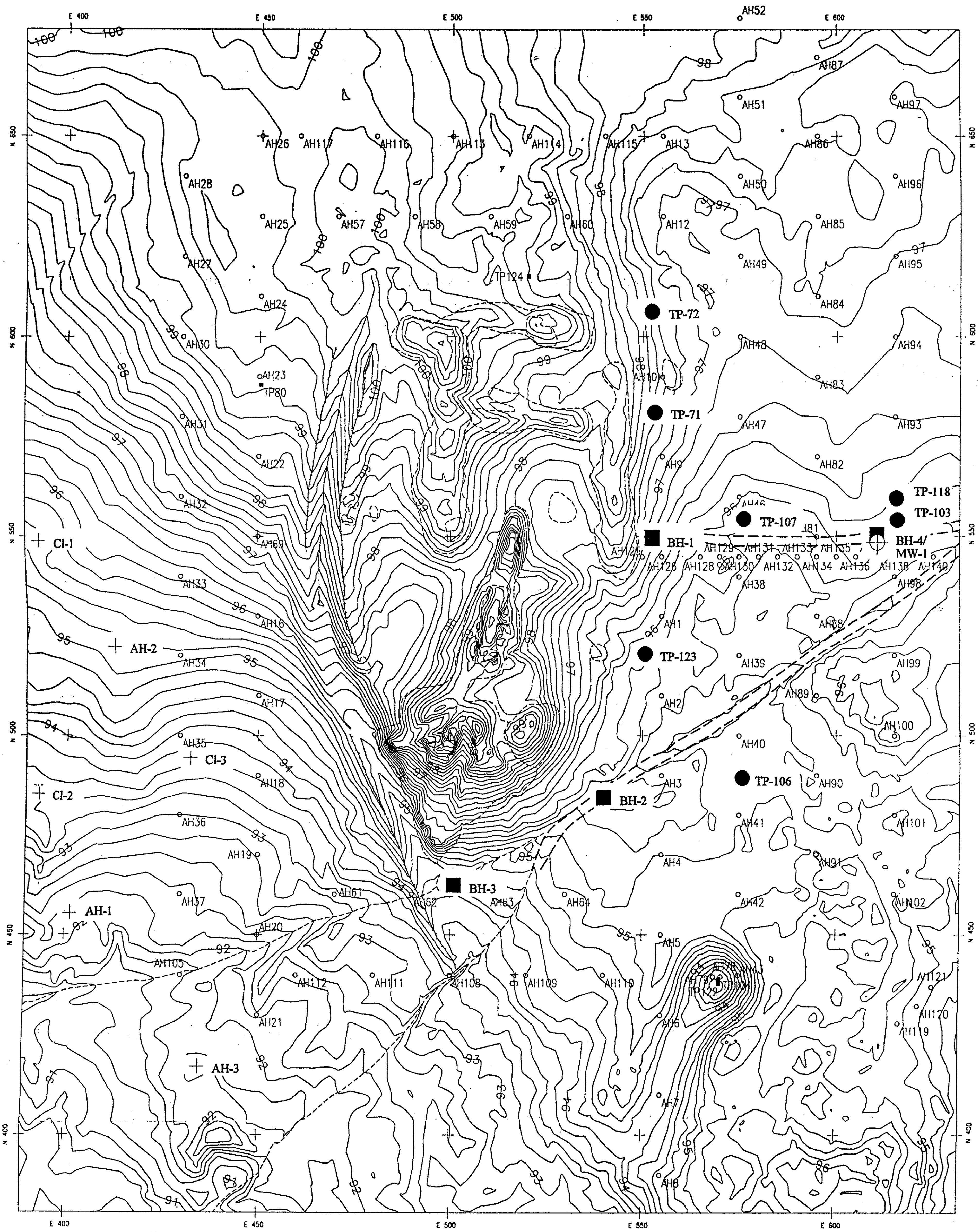
P 279
missing
(Cl vs depth for
TP-123)

Figure Q-7D. TP-123
Cl:Br vs. Depth



Lithologies shown are for TP-B-123
Descriptions based on Lithologic Logs

FERNANDEZ PUEBLO - LA 781



N

0 10 20 30 40 50
METERS
CONTOUR INTERVAL 20 CENTIMETERS

△ OCA site datum
E 500m, N 500m
Elev.: 100m

Figure 3-1. Destructive Sampling Locations at Fernandez Pueblo

Legend
- ○ OCA auger hole
- ▪ OCA test pit
- ▣ Bore hole

EXPLANATION

- ● Test Pit Borehole and Hand Auger Locations
- ■ Exploration Borehole
- + Background Sampling Locations