

HYDROGEOCHEMICAL BOREHOLE STUDIES OF THE MIDWEST AND McCLEAN URANIUM DEPOSIT ENVIRONMENTS, NORTHERN SASKATCHEWAN

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ABSTRACT

Analyses of approximately 500 groundwater samples from 22 boreholes at the Midwest Deposit revealed complex fracture controlled groundwater regimes. The majority of the holes tested were located in unmineralized ground. Water samples from a fence of holes across the ore zone gave highly anomalous concentrations of He, Rn, and ore elements within the ore zone and revealed two distinct groundwater regimes.

At McClean Lake, 70 samples from 8 boreholes, mainly into mineralized ground, contained highly anomalous He and Rn concentrations with hole averages of up to 77,000 nL/L and 104,000 pCi/L, and individual maxima of 188,000 nL/L and 645,000 pCi/L, respectively. In general, concentrations were found to increase with depth.

The Midwest and McClean U-Ni ore deposits generate extremely high concentrations of Rn and He in groundwaters that permeate the deposits. The spatial dispersion of these dissolved gases seems to be controlled by groundwater movement through fractures in the host sandstones giving rise to Rn and He halos extending at least 1 km along fractures and less than 300 m in sandstone. The simultaneous presence of both gases in anomalous amounts in groundwaters (Rn greater than 4,000 pCi/L; He greater than 200 nL/L) is considered a favourable indicator of U mineralization.

The presence of suspended matter in many samples, and the formation of hydrous iron oxides in the open boreholes, and in many samples after collection, presented analytical problems and resulted in approximations of trace element concentrations. Conductivity and major element concentrations were generally higher in samples from the ore zones relative to samples from background areas.

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INTRODUCTION

During the geochemical lake surveys of the NEA/IAEA Test Area the opportunity to study the distribution of elements in groundwaters around the Midwest and McClean deposits presented itself in the form of a number of boreholes into mineralized and unmineralized ground. It was hoped that a sufficient number of holes would be available in mineralized and unmineralized areas to define the extent of secondary trace element dispersion halos around the deposits. The conditions were such however, that the efficacy of this study was only partially realized. However, the excellent cooperation between drillers, explorationists, and research scientists permitted the collection of valuable information about the behavior of elements in groundwater in and around these two deposits. This information was not only useful for mineral exploration but also for environmental impact studies.

SAMPLING AND ANALYTICAL PROCEDURES AND ERRORS

Groundwaters were collected from three sources: (1) boreholes drilled for exploration; (2) boreholes drilled for hydrological-environmental studies; (3) boreholes drilled for camp wells. Camp wells and hydrological-environmental holes were sampled from a tap or hose during pumping tests. Waters from exploration holes were collected with a small diameter Kemmerer type sampler and a portable cable winch. To prevent boreholes from collapsing, they were lined with 49 mm O.D. - 37 mm I.D. plastic pipe (1½ COBRA PVC 1120 PE SCH 80). To permit the water to move through pipe and ground, a 3 m perforated section of pipe was inserted at 15 m intervals down the hole. The perforation consisted of about 50 - 10 mm diameter uniformly spaced holes in a 3 m section of pipe. This method proved successful in keeping holes open in consolidated sandstone; but in the

McClellan North ore zone several holes collapsed before the plastic pipe could be introduced and in several the pipe collapsed after insertion.

The definitions and abbreviations of variables, and detection limits of analytical methods are given in Table 1.

In 1979 determinations of D.O. (dissolved oxygen), He, Rn, Eh, pH and conductivity in waters were carried out in the field laboratory. In 1980 samples were sent to the Ottawa laboratories for these determinations. The remaining variables were determined in the Ottawa laboratories for all samples from both seasons. Helium determinations were carried out with a calibrated He leak detector; DO, Eh, pH, F, and conductivity were determined with electrodes; total alkalinity and HCO_3 by titration; SO_4 and Cl by ion chromatography; Rn by emanometry; and U by fluorometry.

The elements As, Ca, Co, Cu, Fe, Pb, Mg, Mn, Ni, K, Na and Zn were determined by atomic absorption spectrometry. Due to the possible formation of hydrous iron oxides and adsorption of trace elements on these and on walls of containers on standing, old samples were acidified for trace element analyses. To test the effect of acidification, U, Mn, and Fe analyses were carried out before and after acidification.

Comparisons of variables from field duplicate borehole water samples are also shown in Table 1. These duplicates were obtained by lowering the sampler twice to the same depth. The analytical plus sampling precision of dissolved gases and major elements, except SO_4 , are in the 10% to 20% range - quite acceptable for routine geochemical work. The poor precision of SO_4 is probably due to the poor detection limit of the analytical method (5 ppm) and the poor trace element precision probably stems from a similar problem, compounded by acidification and leaching of differing amounts of suspended mineralized matter in the samples.

Filtering and acidification of fresh samples would have minimized these problems but filtering was considered too time consuming to be practical. However, acidification without filtering was practical, even necessary. Several months passed between sample collection and analysis and in many samples Fe had precipitated. Even during collection the water in several holes contained flocculent hydrous oxides of iron. No doubt, the heavy metals would have coprecipitated with this Fe. Hence, it was decided to acidify the samples with 1 mL of conc. HCl for the heavy metals analyses. This lowered the pH of the samples to about 1.5 to 2 dissolving the hydroxides. Naturally it also attacked the finely divided suspended rock and mineral matter present in many of the samples, resulting in a bias between samples, not unlike the bias caused by varying amounts of organic matter in lake sediments. As the U results of unacidified and acidified samples indicate, the leaching of fine mineral grains in suspension by the acid seemed to enhance ore elements, U, As, and Ni, in mineralized areas much more than in the background areas (see Tables 4 and 5). Obviously this leaching introduced a bias in the results, depending on the amount and type of suspended matter, and has made quantitative comparisons of heavy metal concentrations between samples and holes rather tentative. However, from the viewpoint of exploration, anomalies resulting from leached mineralized grains could prove beneficial, in much the same way as stains on the surface of boulders reveal mineralization to the naked eye.

RESULTS AND DISCUSSION

For this discussion the groundwater samples have been divided into two groups: (1) exploration borehole waters and (2) hydrological-environment borehole and well waters. The first group of samples was taken from open holes lined with

perforated plastic pipes using a Kemmerer-type sampler and cable winch. The second group of samples was taken from flowing water brought up by pumps.

EXPLORATION BOREHOLE WATER SURVEYS

Midwest Deposit

The location of the sampled boreholes at the Midwest Deposit are shown in Fig. 1. The exploration holes are marked by three digit numbers, and the hydrological-environmental holes, drilled before 1979, are marked by the letters MP and a one digit number. MP3 and MP5 were drilled at an incline toward the deposit. MP2 and all exploration holes are vertical. The holes at the southern end of the lake were drilled prior to 1979, but some were still open to the basement in 1979 and 1980 when they were sampled. The fence of holes along line 124N and holes 309 and 326 near the top of Fig. 1, were all drilled in 1979, and all went several metres into basement rock. Several of the 1979 holes were sampled three times as the opportunity presented itself, two days, two weeks, and nine months after drilling in order to determine any contaminant effects of drilling.

The results of analyses of approximately 500 groundwater samples from 22 boreholes at the Midwest Deposit revealed complex fracture controlled groundwater regimes. Water samples from the fence of holes across the ore zone contained highly anomalous concentrations of He, Rn, U, Ni, and As in the ore zone. The analytical data also revealed two distinct groundwater regimes. Typical concentrations of eight elements, inferred from borehole water data, are summarized in Table 2, and borehole averages are illustrated in Fig. 2. To accomodate the wide ranges, means of logtransformed data are plotted for some elements. The most striking feature of these results, apart from the highly anomalous ore zone sample, are the Eh-pH shifts across the ore zone indicated by the O₂ and pH graphs

(Fig. 2). The division between the groundwater regimes appears to begin in the deposit and is complete between the edge of the drumlin, immediately to the west of the deposit, and the valley further west. The drumlin and valley run parallel to South McMahon Lake. Holes 322 and 323 are right on top of the drumlin and holes 324 and 325, both artesian, are in the valley. This valley also passes through the anomalous part of "Ase" Lake, 2 km south of south McMahon Lake, described in the semi-detailed and detailed lake surveys (Dyck, 1983). All combined, the field and laboratory observations suggest a fracture controlled southwesterly downward flow of oxygenated, acidic groundwater across the ore zone meeting an upwelling, southeasterly flowing, reducing, neutral aquifer in the valley west of the drumlin. Northwesterly and northeasterly flowing and meeting aquifers or a single northeasterly moving aquifer could also explain the observed groundwater chemistry but then a source other than the Midwest Deposit has to be postulated to explain anomalous "Ase" Lake, 2 km south of the deposit (Dyck, 1983). Sinking surface waters east of the deposit are inferred from the high O_2 , low conductivity, and uniform vertical element profiles down to the basement-sandstone interface. In one hole in the area the water level was a little below the bottom end of the steel casing in the overburden, and over a period of two months a trickling sound indicated that water was leaving the hole at about the same rate as it was trickling in. Rising waters west of the deposit were evident from the artesian boreholes in the valley beyond the drumlin. The uniform vertical element profiles in these holes indicated that most of the water came from the basement-sandstone interface.

Element concentrations in borehole waters showed measurable changes with time. Rn and He concentrations rose, and O_2 concentrations dropped markedly in samples collected in the spring of 1980 compared to the summer 1979 samples. However, relative trends along the fence of drill holes across the Midwest Deposit

remained the same. Although there were noticeable changes between element contents of samples collected two days and those collected two weeks after completion of a hole, the changes in the trace element concentrations were no greater than those observed between samples taken two weeks and samples taken one year apart (see Fig. 2 and legend). Examination of trends in the major elements showed that steady state conditions in boreholes had occurred within two weeks of completion of drilling. However, flat vertical element profiles in most boreholes suggests fairly rapid vertical flow in holes (Fig. 3). Experimental temperature profiles of holes also indicated that flow in holes was faster than in the surrounding rocks (Q. Bristow, Geological Survey of Canada, personal communication). This, in turn suggests that the steady state condition in the holes is only an approximation of the steady state flow in the rocks. Thus the element concentrations in open boreholes reflect mainly the dominant and most active aquifer in the formation.

The U, Ni and As levels in the water samples, for the most part, straddled the detection limit of the analytical methods. Sporadic anomalous values were observed in, or near, the ore zone borehole samples, particularly those that were acidified. These are believed to be due to the dissolution of fine ore-grade grains or adsorbed trace elements on sandstone grains and hydrous oxides present in many samples.

In unmineralized ground, element concentrations changed little with depth, except for dissolved gas levels in samples near the surface, suggesting relatively strong vertical flow in holes. Trace elements gave erratic values, but for the most part straddled the detection limits of analytical techniques. A marked rise in conductivity, He and Rn and a drop in O₂ was observed in waters from the mineralized trend (see vertical profiles of holes 48 and 326, Fig. 3). The rise in He

in the bottom sample of many holes indicates fairly stagnant water at those sites and gives an indication of the steady state He flux in basement rocks.

At Midwest the trace and minor element concentrations were higher in the groundwaters than in the lake waters but lower than in the groundwaters at McClean. Samples from McClean came mainly from mineralized ground; samples from Midwest mainly from barren ground. The Cl problem, noted in lake waters, (Dyck, 1983) seemed also present in groundwaters. For example, the average Cl content in samples from two day, two week, and one year old hole #302 was 6.6, 1.4, and 1.7 ppm, respectively. Similar, but less pronounced drops were present for Na, K, Ca, Mg, and conductivity for the same and other holes. Whether the higher initial concentrations were due to drilling activities or whether the drop with time resulted from flushing of holes by near surface waters could not be determined.

As the results in Table 3 and 4 show, the effect of acidification on trace elements concentrations is noticeable and quite dramatic for individual samples. The two data sets cannot be compared rigorously because not quite the same holes were sampled in 1979 as in 1980. However, the means of the major elements, except SO_4 , in the two sample suits are close enough to each other to suggest that they are similar and hence comparable.

McClean North Ore Zone

At McClean Lake, 70 samples from eight drill holes, mainly through the mineralized McClean North zone were collected and analyzed (Fig. 4). Highly anomalous He and Rn concentrations with individual hole averages of up to 77,000 nL/L and 104,000 pCi/L, and individual sample maxima of 188,000 nL/L and 645,000 pCi/L, respectively were observed. Average trace element contents and individual results for four holes are shown in Figs. 5 and 6, respectively. Table 5

lists analytical results for all samples from the McClean North Deposit. In general, concentrations were found to increase with depth. Rn concentrations decreased with distance from the richest part of the ore zone, whereas He increased slightly with distance from the richest known ore zone, suggesting the presence of a second source, or traps where He could accumulate. U, Ni, and As exhibited trends similar to that of Rn. Their presence in highly anomalous amounts in the borehole waters is believed to be due, in part, to finely divided particulate ore, as a result of drilling. The elements were subsequently liberated when the samples were acidified to dissolve hydrous oxides. As at Midwest, conductivity of the McClean Deposit waters was considerably higher than that of background rocks, suggesting more active metamorphism of ground waters in mineralized zones.

During the sampling of waters from the McClean North Deposit a number of holes along the winter road between McClean Lake and Wollaston Lake were found. Although the owner of these holes could not be traced, four were sampled in the hope of obtaining background values with which to compare the samples from the ore zone in McClean. The holes were about 200 m apart and started about ½ km southeast of "Candy" Lake (see Fig. 4). As the results in Table 6 indicate, these groundwaters have much lower average trace element concentrations than those samples from the McClean deposit and are similar in composition to borehole waters around the Midwest Deposit, particularly those east of the deposit. The low pH, low conductivity, and high O₂ and Rn levels are all indicators of actively circulating young waters. Surprisingly, Rn contents decreased and He content increased with depth in these holes, confirming active circulation of waters near the surface and suggesting higher than average radioactivity in these rocks.

During the hydrochemical investigations a new mass spectrometer became available for the study of H₂, CH₄, and other dissolved gases. Unfortunately, it

was operative during a few brief periods only. The results obtained with this instrument are summarized in Table 7. None of the results from the Midwest area came from samples taken in the ore zone. However, some of the samples from the McClean Deposit area came from the ore zone and the presence of H_2 and CH_4 there suggests that these gases are being generated there, possibly by radiation-induced reactions of water and graphite.

HYDROLOGICAL-ENVIRONMENTAL BOREHOLE AND WELL WATER SURVEYS

For purposes of comparison and general curiosity, a number of hydrological boreholes and drilling camp wells were sampled as they became available. The holes marked MP2, MP3 and MP5 (Fig. 1) were sampled in 1979 at several levels during pumping tests. The analytical results of these samples are summarized in Table 8. MP3 actually intersects the ore zone at depth and the samples from it gave the extremely high Rn , and He values shown in Table 8 and in Figure 2. In 1980 this hole was not available for sampling, instead five others became available, three with piezometers and two for draw-down tests.

The analytical results of samples from these five holes are summarized in Table 9. Exploration holes 302, 303 and 304 (Fig. 1) were converted to hydrological-environmental holes by sealing 3 piezometers in each hole. Marked changes in trace element concentrations between water samples from open holes and water samples from sealed holes were observed. Rn and O_2 were lower and virtually all trace elements, pH , and conductivity considerably higher in samples from the piezometers. He remained essentially the same, but instead of a flat profile it increased smoothly with depth in the closed holes. No doubt the results were distorted by the mode of sampling and the fact that the holes were sampled only two weeks after completion, but the drifts in element content confirmed earlier

observations that the groundwater in this area was relatively young and sinking. The lower Rn concentrations in older, slower moving and higher concentrations in more actively circulating waters requires an explanation. Weathering of soils and readsorption of Ra on surfaces of water channels close to the weathering process result in highly efficient Rn emanators. Moving waters bring this Rn into boreholes but stagnant water, or very slowly moving water, cannot because of the relatively short half life of Rn.

Some of the analytical results of samples, taken from two 0.5 m diameter test holes during draw-down tests, are shown in Figure 7. One of these large diameter holes (HY-1) was located near hole 303 and one (HY-2) near hole 68 (see Fig. 1). They clearly show changes in trace element content with time; water from HY-1 becomes more mineralized with time indicating that older water is moving into the pumping zone. The results from hole HY-2 suggest that after about three days of pumping essentially pure surface water was being drawn into the pumping zone.

Concern by drillers, and curiosity, prompted the sampling of wells used by drillers for drinking and cooking. The analytical results of the well water samples are listed in Table 10. All the determined element concentrations except perhaps Rn, were found to be well below the safe or recommended levels set by health authorities. Over the past 20 years various people and organizations have suggested safe Rn levels ranging from 500 pCi/L to 25,000 pCi/L. According to R.G. McGregor (personal communication, Health and Welfare Canada, Ottawa) present thinking tends towards a safe Rn level of 10,000 pCi/L in water used by people in homes.

Most of the element concentrations in well 1 samples at Midwest are higher than well 2 samples. Well 1 was about 30 m from South McMahon Lake and well 2

130 m, but it had been in use for a lot longer than well 2. So it is open for debate whether the distance from the ore zone or the amount of pumping was responsible for the lower levels in well 2.

At McClean well 1 was used by the camp and well 2 and 3 were being drilled for future use. Wells 1 and 2 are similar to each other; well 3 appears to tap a different, more radioactive, water system as indicated by higher Rn, Ra, and As levels. All three wells gave waters with a distinct repulsive odour which was not identified but which was, no doubt, the cause for the search of yet another well.

CONCLUSIONS

In general the trace element dispersion in groundwaters around the Midwest and McClean Deposits appears weak and limited in extent. However, the deposits generate extremely high concentrations of Rn and He in groundwaters that permeate the deposits and the fractures connected with the deposits. The spatial dispersion of these dissolved gases appears to be controlled by groundwater movement through fractures in the host sandstones. The simultaneous presence of both gases in anomalous concentrations in groundwater (Rn greater than 4000 pCi/L; He greater than 200 nL/L) of the Athabasca sandstone must be considered a favourable indicator of U mineralization. Anomalous He alone is more likely to be an indication of major deep seated fractures, and Rn alone indicates actively circulating groundwaters.

Arsenic was found to be more abundant and mobile than U in groundwater regimes. Therefore As could serve as an effective pathfinder for mineralization containing As minerals. Ni also appeared to be more mobile than U in groundwaters, however, the poor detection limit of the analytical technique makes such an observation tentative.

Conductivity in groundwaters appears to be also an indicator of mineralization, but does not indicate the type or grade of mineralization, or whether mineralization is due to minerals or just the result of aging aquifers.

This study suggests the presence of Rn, He, As, Ni and conductivity halos extending at least 1 km along fractures and less than 300 m in sandstone. Detailed, well controlled field tests are required for more refined estimates of the size of Rn and He halos around U ore deposits.

More sophisticated techniques such as pumping formation waters from different depth, filtering and acidification of freshly collected samples, and in situ analytical probes are needed to evaluate the ultimate effectiveness of groundwater geochemistry for prospecting in wilderness terrain. Limited control and treatment of the samples limits the conclusions of this study. However, the results provide typical element concentrations and ranges one might expect in sandstone U-Ni deposit environments. These are useful for environmental impact studies and for reference in unknown environments.

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REFERENCE

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TABLES

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FIGURES

Figure 1. Location of sampled boreholes in the Midwest Deposit area.

Figure 2. Element concentrations in groundwater across the Midwest Deposit along line 124N. Each point represents the average of logtransformed values (where indicated) of at least eight samples taken at equal intervals between surface and bottom (except for MP3 where only one sample, directly from the ore zone was taken).

- - samples taken in the summer of 79, two days after drilling.
- Δ - samples taken in the summer of 79, two weeks after drilling.
- - samples taken in the spring of 80, nine months after drilling.
- - samples taken in the spring of 80, nine months after drilling (unacidified).
- - detection limit of analytical technique.

Figure 3. Vertical groundwater element profiles from the Midwest Deposit area.

Figure 4. Location of sampled boreholes in the McClean Deposits area.

Figure 5. Element concentrations in groundwater collected in the summer of 1980 along the McClean North mineralized zone. Each point represents the average of logtransformed values (where indicated) of at least eight samples taken at equal intervals between surface and bottom.

- - acidified samples
- - unacidified samples
- - samples from depth >7 m <110 m only
- ⊙ - log (inches x % U_3O_8), 0.02% cutoff)
- - detection limit of analytical technique

Figure 6. Vertical groundwater element profiles from the McClean North mineralized zone. The U cps are 10 m visually integrated values of total gamma-ray logs.

Figure 7. Concentration of selected trace elements in groundwater near the Midwest U deposit as a function of time of pumping during draw-down tests. Holes HY-1 and HY-2 are located at the same place as holes 303 and 68, respectively (see Fig. 1).

Table 1. Units and detection limits and comparison of analytical results of 22 field duplicates of borehole water samples from the Midwest and McClean deposit areas.

| Variables | Units | Detection limit | Value recorded when below d.l. | $\bar{X}A_1$ | $\bar{X}A_2$ | S.D. ₁ | S.D. ₂ | *Precision, % |
|------------------|-------|-----------------|--------------------------------|--------------|--------------|-------------------|-------------------|---------------|
| Ra | pCi/L | 0.5 | 0.2 | 16.4 | 17.3 | 61.5 | 64.8 | 42 |
| Rn | pCi/L | 2 | 1 | 5970 | 5965 | 3830 | 3800 | 13 |
| He | nL/L | 10 | 5 | 4730 | 4810 | 17930 | 18280 | 11 |
| D.O. | ppm | 0.2 | 0.1 | 5.5 | 5.5 | 2.5 | 2.5 | 10 |
| COND | µm/cm | 5 | 2 | 77 | 78 | 146 | 147 | 5 |
| pH | | 2 | 1 | 6.00 | 6.03 | 0.48 | 0.49 | 2 |
| Eh | mv | 10 | 5 | 317 | 319 | 126 | 128 | 13 |
| HCO ₃ | ppm | 1 | 0.5 | 17 | 18 | 13 | 13 | 17 |
| ALKA | ppm | 1 | 0.5 | 14 | 15 | 10 | 11 | 17 |
| F | ppb | 20 | 10 | 78 | 79 | 44 | 46 | 9 |
| SO ₄ | ppm | 5 | 2 | 7.3 | 6.6 | 8.1 | 6.4 | 156 |
| Cl | ppm | 1.0 | 0.5 | 12.7 | 12.4 | 38.6 | 36.5 | 26 |
| U (A)* | ppb | 0.2 | 0.1 | 15.1 | 15.5 | 60.8 | 66.3 | 62 |
| Na (A) | ppm | 0.1 | 0.05 | 4.2 | 4.5 | 7.9 | 8.8 | 31 |
| K (A) | ppm | 0.1 | 0.05 | 4.5 | 4.5 | 10.8 | 10.9 | 13 |
| Ca (A) | ppm | 0.5 | 0.2 | 4.6 | 4.5 | 5.6 | 5.4 | 10 |
| Mg (A) | ppm | 0.5 | 0.2 | 1.7 | 1.7 | 3.2 | 3.0 | 12 |
| Mn (A) | ppb | 10 | 5 | 232 | 230 | 348 | 345 | 12 |
| Fe (A) | ppb | 20 | 10 | 6230 | 5200 | 10400 | 6080 | 153 |
| Zn (A) | ppb | 5 | 2 | 137 | 150 | 139 | 160 | 71 |
| Cu (A) | ppb | 1 | 0.5 | 30 | 47 | 46 | 81 | 227 |
| Pb (A) | ppb | 2 | 1 | 6.8 | 6.4 | 6.2 | 5.8 | 62 |
| Ni (A) | ppb | 2 | 1 | 5.1 | 5.7 | 7.8 | 8.8 | 52 |
| Co (A) | ppb | 2 | 1 | 1.9 | 2.0 | 2.2 | 2.3 | 30 |
| As (A) | ppb | 0.5 | 0.2 | 13.0 | 19.7 | 29.9 | 49.9 | 263 |

*(A) = acidified samples

*Precision = $2(S)/\bar{X}p$ 100

$$(S)^2 = \frac{1}{2n} \sum_{i=1}^n (X_{1i} - X_{2i})^2$$

(S) = standard deviation

$\bar{X}p$ = pooled mean of duplicates

Subscripts 1 and 2 refer to 1st and 2nd duplicate, respectively

n = no. of duplicates

Table 2. Typical concentrations of characteristic ore and other elements in borehole waters from a fence of holes across the Midwest Deposit along line 124N.

| | West of ore zone | | Ore zone* | East of ore zone |
|-------------------------------|------------------|---------|-----------|------------------|
| | Valley | Drumlin | | |
| pH | 6.7 | 6.6 | 6.5 | 5.5 |
| Conductivity (μ mhos/Cu) | 80 | 30 | 150 | 30 |
| He (nL/L) | 300 | 60 | 187000 | 60 |
| Rn (pCi/L) | 2000 | 8000 | 113000000 | 4000 |
| O ₂ | 2 | 8 | 1.5 | 7 |
| U (ppb) | bd** | bd | 6 | bd |
| Ni (ppb) | bd | bd | 10 | bd |
| As (ppb) | bd | bd | 100 | bd |

* One sample from 188 m level after considerable pumping of sealed hole

** bd = below detection

Table 3. Analytical results of 1979 water samples from 17 exploration boreholes from the Midwest Deposits area.

| | \bar{X}_A | S.D. | Max. | Min. | \bar{X}_G |
|------------------|-------------|------|-------|------|-------------|
| N | 145 | | 178 | 120 | |
| SADE* | 113 | 64 | 244 | 0 | 87 |
| SIDE* | 217 | 55 | 575 | 116 | 214 |
| TEMP* | 5.2 | 0.9 | 8 | 3 | 5.1 |
| COLOR* | 0.7 | 0.5 | 2 | 0 | 1.0 |
| SUSMAT* | 1.0 | 0.4 | 4 | 0 | 1.0 |
| Ra | 5.5 | 17.8 | 170 | 0.5 | 1.6 |
| Rn | 5000 | 5554 | 42130 | 8 | 3310 |
| He | 85 | 110 | 1162 | 32 | 63 |
| D.O. | 6.3 | 2.9 | 10.6 | 0.1 | 5.1 |
| COND | 80 | 249 | 2820 | 13 | 38 |
| pH | 6.3 | 1.3 | 12.2 | 4.8 | 6.2 |
| Eh | 286 | 133 | 447 | -122 | 246 |
| HCO ₃ | 18 | 15 | 78 | 1 | 13 |
| F | 86 | 72 | 420 | 27 | 66 |
| SO ₄ | 4.2 | 14.5 | 120 | 2 | 1.3 |
| Cl | 1.4 | 1.9 | 8.5 | 0.5 | 0.9 |
| U | 1.7 | 6.1 | 55 | 0.1 | 0.3 |
| Na | 4.4 | 7.9 | 53.5 | 0.9 | 2.6 |
| K | 2.7 | 5.4 | 37.4 | 0.3 | 1.2 |
| Ca | 4.1 | 6.6 | 56.5 | 0.9 | 2.8 |
| Mg | 1.0 | 1.4 | 12.5 | 0.1 | 0.7 |
| Mn | 122 | 153 | 631 | 5 | 54 |
| Fe | 1680 | 6410 | 57260 | 10 | 191 |
| Zn | 47 | 60 | 372 | 2 | 22 |
| Cu | 3.6 | 4.5 | 28.0 | 0.5 | 2.3 |
| Pb | 2.7 | 4.3 | 44.0 | 1.0 | 2.2 |
| Ni | 2.0 | 2.1 | 13.0 | 1.0 | 1.5 |
| Co | 1.4 | 1.9 | 19.0 | 1.0 | 1.1 |
| As | 0.8 | 1.2 | 10.4 | 0.2 | 0.5 |

* SADE = sample depth

SIDE = site depth

TEMP = temperature, °C

COLOR = relative intensity of color; 0 = clear; 1 = white; 2 = yellow; 3 = brown

SUSMAT = suspended matter relative scale; 0 = none; 1 = trace; 2 = 0.2 mm,
3 = 1 mm; 4 = 2 mm

Table 4. Analytical results of 1980 water samples from 14 exploration boreholes from the Midwest Deposit area.

| | \bar{X}_A | S.D. | Max. | Min. | \bar{X}_G |
|------------------|-------------|-------|-------|------|-------------|
| N | 188 | | 189 | 188 | |
| SADE | 113 | 64 | 246 | 6 | 90 |
| SIDE | 221 | 32 | 251 | 91 | 219 |
| TEMP | 4.7 | 0.87 | 8 | 4 | 4.6 |
| COLOR | 0.4 | 0.68 | 3 | 0 | 0 |
| SUSMAT | 0.8 | 0.7 | 5 | 0 | 0 |
| Ra | 2.4 | 3.7 | 26 | 0.5 | 1.2 |
| Rn | 7813 | 6026 | 45600 | 71 | 5754 |
| He | 140 | 121 | 1027 | 50 | 110 |
| D.O. | 5.5 | 2.1 | 9.2 | 2.0 | 5.0 |
| COND | 66 | 136 | 1430 | 10 | 35 |
| pH | 6.3 | .9 | 11.5 | 5.1 | 6.2 |
| Eh | 334 | 119 | 513 | 120 | 309 |
| HCO ₃ | 19 | 15 | 65 | 0.5 | 13 |
| ALKA | 19 | 26 | 306 | 0.5 | 13 |
| F | 105 | 89 | 717 | 43 | 87 |
| SO ₄ | 6.3 | 10.8 | 86 | 2 | 3.4 |
| Cl | 6.2 | 26.9 | 220 | 0.5 | 0.5 |
| U | 0.5 | 1.4 | 11.4 | 0.1 | 0.2 |
| U (A)* | 1.9 | 5.4 | 49.4 | 0.1 | 0.4 |
| Na | 7.1 | 20.4 | 155 | 1.0 | 2.4 |
| K | 1.0 | 2.0 | 17.0 | 0.2 | 0.6 |
| Ca | 4.4 | 10.7 | 139 | 1.2 | 2.9 |
| Mg | 0.98 | 0.86 | 3.82 | 0.18 | 0.69 |
| Mn (A) | 134 | 168 | 565 | 5 | 45.7 |
| Fe (A) | 7500 | 11800 | 73200 | 10 | 2090 |
| Zn (A) | 180 | 253 | 2585 | 29 | 120 |
| Cu (A) | 22.9 | 52.7 | 509 | 3 | 11.0 |
| Pb (A) | 9.1 | 16.4 | 113 | 1 | 4.7 |
| Ni (A) | 3.7 | 10.3 | 140 | 1 | 2.3 |
| Co (A) | 1.1 | 0.3 | 4.0 | 1 | 1 |
| As (A) | 12.5 | 49.5 | 472 | 0.2 | 2.1 |

*(A) = acidified samples

Table 5. Analytical results of 1980 water samples from 7 exploration boreholes from the McClean Deposit.

| | \bar{X}_A | S.D. | Max. | Min. | \bar{X}_G |
|------------------|-------------|-------|--------|------|-------------|
| N | 67 | | 67 | 44 | |
| SADE | 69 | 54 | 180 | 2 | 41 |
| SIDE | 190 | 3 | 200 | 188 | 190 |
| TEMP | 4.3 | 0.8 | 7 | 3 | 4.3 |
| COLOR | 1.1 | 0.5 | 2 | 0 | 1.1 |
| SUSMAT | 1.3 | 1.2 | 8 | 1 | 1.2 |
| Ra | 193 | 783 | 6350 | 0.5 | 25.7 |
| Rn | 21970 | 81190 | 644830 | 37 | 4677 |
| He | 41600 | 49680 | 187950 | 66 | 13180 |
| D.O. | 2.6 | 0.8 | 3.9 | 0.7 | 2.4 |
| COND | 355 | 269 | 1000 | 48 | 251 |
| pH | 5.7 | 0.5 | 6.4 | 4.7 | 5.8 |
| Eh | 183 | 64 | 300 | 81 | 170 |
| HCO ₃ | 20 | 11 | 57 | 1 | 17 |
| ALKA | 16 | 9 | 47 | 1 | 14 |
| F | 115 | 68 | 475 | 46 | 100 |
| SO ₄ | 6.9 | 7.9 | 33.0 | 2.0 | 4.4 |
| Cl | 83.6 | 73.7 | 250 | 2.8 | 47.9 |
| U | 29.1 | 60.2 | 312 | 0.1 | 3.1 |
| U (A)* | 189 | 927 | 7287 | 0.1 | 4.4 |
| Na | 21.4 | 19.7 | 80.8 | 2.3 | 13.2 |
| K | 24.1 | 25.4 | 147 | 0.5 | 14.1 |
| Ca | 19.6 | 24.9 | 135 | 1.4 | 11.2 |
| Mg | 9.6 | 10.1 | 53.0 | 0.6 | 5.0 |
| Mn (A) | 715 | 1106 | 8880 | 67 | 417 |
| Fe (A) | 19240 | 51500 | 406000 | 2180 | 10230 |
| Zn (A) | 407 | 649 | 4070 | 53 | 240 |
| Cu (A) | 34.4 | 65.8 | 430 | 4.0 | 16.2 |
| Pb (A) | 41 | 80 | 515 | 1 | 18 |
| Ni (A) | 106 | 497 | 3928 | 1 | 14 |
| Co (A) | 6.8 | 19.4 | 126 | 1 | 2.7 |
| As (A) | 600 | 4043 | 33000 | 0.6 | 10.0 |

*(A) = acidified samples

Table 6. Analytical results of 1980 water samples from 4 exploration boreholes from east of the McClean Deposit on the winter Road.

| | \bar{X}_A | S.D. | Max. | Min. | \bar{X}_G |
|------------------|-------------|------|-------|------|-------------|
| N | 13 | | 13 | 13 | |
| SADE | 65 | 35 | 129 | 30 | 56 |
| SIDE | Unknown | | | | |
| TEMP | 4.9 | 0.4 | 5 | 4 | 4.8 |
| COLOR | 0.1 | 0.3 | 1 | 0 | 0.0 |
| SUSMAT | 0.9 | 0.3 | 1 | 0 | 1 |
| Ra | 2.2 | 1.6 | 4.8 | 0.5 | 1.6 |
| Rn | 9085 | 4970 | 16630 | 1210 | 7410 |
| He | 106 | 36 | 180 | 75 | 100 |
| D.O. | 7.7 | 1.7 | 8.8 | 2.4 | 7.4 |
| COND | 16 | 9 | 40 | 8 | 14 |
| pH | 5.9 | 0.2 | 6.1 | 5.5 | 5.9 |
| Eh | 385 | 32 | 425 | 309 | 380 |
| HCO ₃ | 11 | 5 | 20 | 6 | 10 |
| ALKA | 9 | 4 | 16 | 5 | 8 |
| F | 72 | 14 | 109 | 54 | 71 |
| SO ₄ | 2.6 | 2.2 | 10.0 | 2.0 | 2.2 |
| Cl | 0.5 | 0 | 0.5 | 0.5 | 0.5 |
| U | 0.1 | 0.1 | 0.5 | 0.1 | 0.2 |
| U (A)* | 0.8 | 0.5 | 2.0 | 0.1 | 0.6 |
| Na (A) | 1.4 | 0.5 | 3.0 | 1.0 | 1.3 |
| K (A) | 0.5 | 0.5 | 2.1 | 0.2 | 0.4 |
| Ca (A) | 1.9 | 0.6 | 3.0 | 1.2 | 1.8 |
| Mg (A) | 0.5 | 0.4 | 1.7 | 0.2 | 0.4 |
| Mn (A) | 54 | 52 | 167 | 5 | 32 |
| Fe (A) | 1780 | 2100 | 5590 | 50 | 570 |
| Zn (A) | 34 | 13 | 69 | 19 | 32 |
| Cu (A) | 41 | 93 | 350 | 5 | 16 |
| Pb (A) | 6.7 | 6.0 | 20 | 1 | 4.4 |
| Ni (A) | 6.7 | 15.0 | 56 | 1 | 2.6 |
| Co (A) | 1.3 | 0.6 | 3.0 | 1 | 1.2 |
| As (A) | 1.9 | 1.4 | 4.1 | 0.5 | 1.4 |

*(A) = acidified samples

Table 7. Arithmetic means of dissolved gases in borehole water samples.

| Gases | Midwest | | McClean |
|-------------------------------|--------------------------|----------------------------|--------------------------|
| | Exploration boreholes | Hydrological- boreholes | Exploration boreholes |
| No. of samples | 69 | 11 | 7 |
| TDG (mL/L) | - | 31.5 | 38 |
| He (nL/L) | 95 | 86 | 9390 |
| Ar (μ L/L) | 570 | 453 | 594 |
| H ₂ S (μ L/L) | - | <10 | 10 |
| H ₂ (mL/L) | 0.9 | <0.02 | 0.09 |
| CH ₄ (mL/L) | <0.02 | <0.02 | 0.64 |
| N ₂ (mL/L) | 29.3 | 18.8 | 24.9 |
| O ₂ (mL/L) | 7.0 | 6.6 | 1.1 |
| CO ₂ (mL/L) | - | 1.6 | 2.5 |

*TDG = total dissolved gas

Table 8. Analytical results of 1979 water samples from 3 hydrological boreholes from the Midwest Deposit area.

| | \bar{X}_A | S.D. | Max. | Min. | \bar{X}_G |
|------------------|-------------|----------|-----------|------|-------------|
| N | 12 | | 12 | 10 | |
| SADE | 119 | 77 | 230 | 6 | 81 |
| SIDE | 224 | 20 | 256 | 204 | 224 |
| TEMP | 8.5 | 0.7 | 9 | 8 | 6.9 |
| COLOR | 0 | 0 | 0 | 0 | 0 |
| SUSMAT | 0.1 | 0.3 | 1 | 0 | 0 |
| Ra | 50.2 | 148 | 518 | 0.5 | 8.3 |
| Rn | 9432540 | 32615000 | 113000000 | 4560 | 30900 |
| He | 15910 | 53880 | 187000 | 43 | 288 |
| D.O. | 2.7 | 2.3 | 9.3 | 1.1 | 2.2 |
| COND | 63 | 35 | 150 | 23 | 55 |
| pH | 6.2 | 0.3 | 6.9 | 5.7 | 6.2 |
| Eh | 290 | 124 | 535 | 100 | 263 |
| HCO ₃ | 32 | 26 | 102 | 11 | 26 |
| F | 185 | 100 | 420 | 55 | 162 |
| SO ₄ | 1 | 0 | 1 | 1 | 1 |
| Cl | 4.1 | 4.4 | 13.2 | 0.5 | 2.0 |
| U | 1.3 | 1.6 | 5.6 | 0.1 | 0.7 |
| Na | 2.8 | 1.3 | 5.9 | 1.3 | 2.5 |
| K | 1.3 | 1.8 | 6.8 | 0.2 | 0.9 |
| Ca | 5.8 | 3.7 | 16 | 2.0 | 5.0 |
| Mg | 2.2 | 2.0 | 8.0 | 0.4 | 1.6 |
| Mn | 442 | 290 | 866 | 10 | 163 |
| Fe | 77 | 149 | 530 | 20 | 33 |
| Zn | 97 | 149 | 510 | 6 | 39 |
| Cu | 12 | 23 | 78 | 1 | 3.6 |
| Pb | 1 | 0 | 1 | 1 | 1 |
| Ni | 7.2 | 7.0 | 26 | 1 | 5.0 |
| Co | 4.4 | 7.2 | 27 | 1 | 2.6 |
| As | 10.2 | 33.6 | 117 | 0.2 | 0.6 |

Table 9. Analytical results of 1980 water samples from 5 hydrological boreholes from the Midwest Deposit area.

| | \bar{X}_A | S.D. | Max. | Min. | \bar{X}_G |
|------------------|-------------|-------|-------|------|-------------|
| N | 26 | | 27 | 11 | |
| SADE | 112 | 57 | 186 | 9 | 89 |
| SIDE | 193 | 39 | 214 | 10 | 178 |
| TEMP | 4.4 | 0.6 | 5 | 3 | 4.4 |
| COLOR | 0.4 | 0.6 | 2 | 0 | 0.0 |
| SUSMAT | 0.7 | 0.9 | 2 | 0 | 0 |
| Ra | 2.6 | 4.6 | 23.4 | 0.5 | 1.3 |
| Rn | 7048 | 3680 | 13360 | 1382 | 5890 |
| He | 177 | 124 | 433 | 52 | 141 |
| D.O. | 5.6 | 3.2 | 10.2 | 1.1 | 4.6 |
| COND | 55 | 93 | 495 | 8 | 35 |
| pH | 6.1 | 0.7 | 9.1 | 5.2 | 6.0 |
| Eh | 369 | 125 | 501 | 89 | 339 |
| HCO ₃ | 27 | 32 | 171 | 6 | 20 |
| ALKA | 25 | 37 | 198 | 5 | 17 |
| F | 77 | 13 | 101 | 51 | 76 |
| SO ₄ | 9.8 | 19.8 | 100 | 2 | 4.2 |
| Cl | 0.8 | 1.0 | 5.0 | 0.5 | 0.5 |
| U | 0.9 | 2.6 | 13.5 | 0.1 | 0.3 |
| U (A) | 3.2 | 9.2 | 46.8 | 0.1 | 0.6 |
| Na | 15.2 | 63.9 | 328 | 0.9 | 2.6 |
| K | 1.4 | 1.8 | 9.7 | 0.2 | 1.0 |
| Ca | 10.7 | 29.4 | 153 | 0.9 | 3.9 |
| Mg | 2.7 | 6.8 | 35.5 | 0.2 | 1.1 |
| Mn (A)* | 457 | 906 | 4507 | 14 | 145 |
| Fe (A) | 5160 | 11020 | 52800 | 250 | 1100 |
| Zn (A) | 492 | 508 | 2355 | 56 | 309 |
| Cu (A) | 41 | 61 | 257 | 4 | 18 |
| Pb (A) | 21 | 28 | 106 | 2 | 10 |
| Ni (A) | 10.7 | 12.3 | 46 | 1 | 6.0 |
| Co (A) | 3.8 | 5.4 | 20.0 | 1 | 2 |
| As (A) | 3.1 | 3.3 | 12.8 | 0.4 | 2.1 |

*(A) = acidified samples

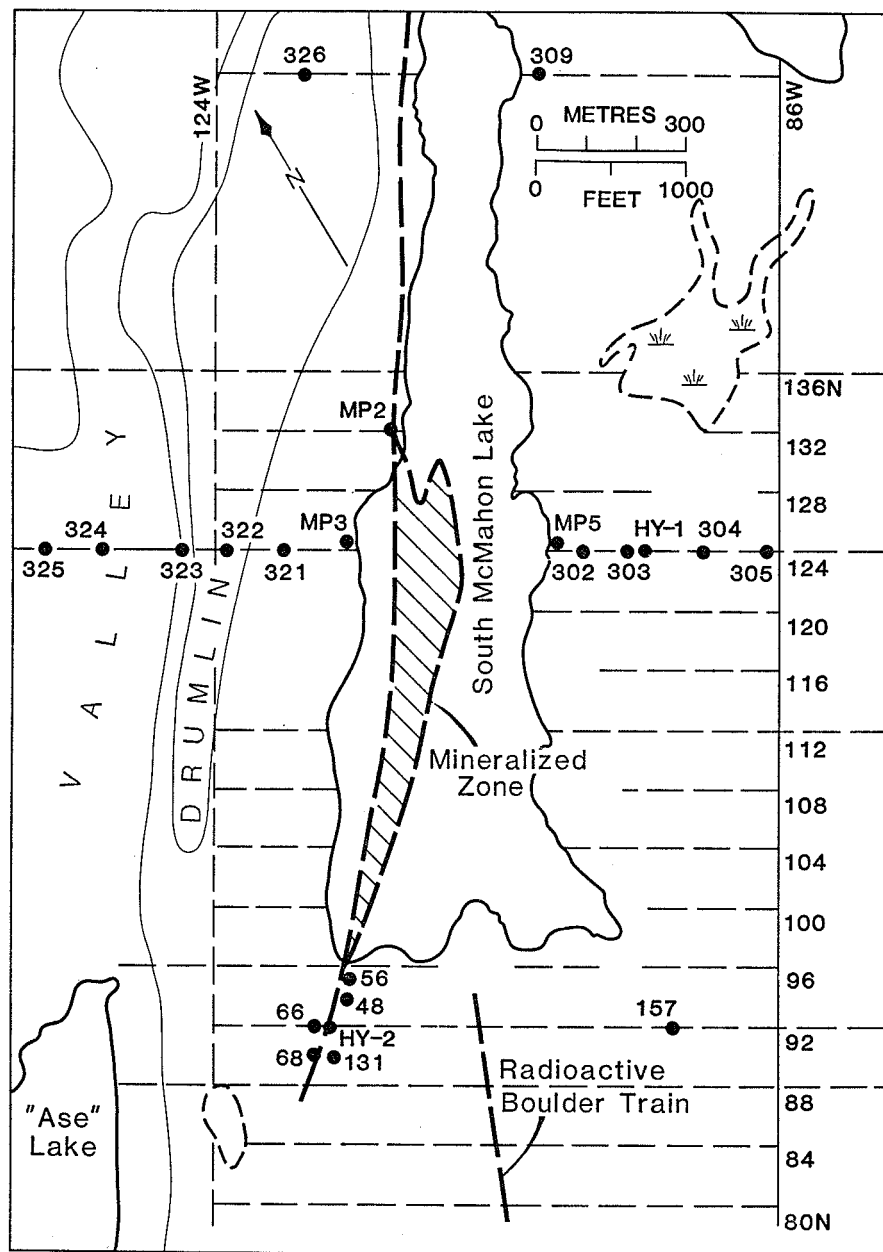
Table 10. Arithmetic means of the Midwest and McClean drilling camp well waters.

| Area | Midwest | | | McClean | | | |
|------------------|-----------|----------|----------|-----------|----------|----------|----------|
| Well # | Well 1 | Well 2 | | Well 1 | Well 2 | Well 3 | |
| Sampling time | March '79 | July '79 | July '80 | March '80 | July '80 | July '80 | Aug. '80 |
| No. of samples | 5 | 5 | 4 | 2 | 2 | 2 | 4 |
| SADE | 11 | 10 | 10 | 7 | 7 | 10 | 10 |
| SIDE | 14 | 100 | 100 | 169 | 169 | 30 | 55 |
| TEMP | 8 | 9 | 6 | 10 | 6 | 6 | 6 |
| SUSMAT | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| He | 123 | 45 | 48 | 58 | 96 | 110 | 680 |
| Rn | 14200 | 5350 | 4600 | 1330 | 2600 | 2730 | 6390 |
| D.O. | 3.9 | 6.1 | 8.6 | 10.0 | 4.2 | 8.0 | 3.8 |
| COND | 33 | 29 | 20 | 15 | 83 | 30 | 64 |
| pH | 5.8 | 5.5 | 5.8 | 5.8 | 6.6 | 6.5 | 5.6 |
| Eh | 410 | 360 | 430 | 420 | 160 | 270 | 390 |
| U (A3)* | 0.2 | - | - | 0.2 | - | - | - |
| U (FL)* | 0.2 | 0.2 | 0.2 | 0.9 | 0.2 | 0.2 | 0.2 |
| F | 50 | 29 | 49 | 31 | 51 | 57 | 52 |
| SO ₄ | 4.4 | 2.6 | 17.3 | 3.5 | 18.5 | 8.0 | 2.0 |
| Cl | 4.6 | 2.8 | 2.3 | 1.0 | 6.4 | 1.6 | 10.8 |
| HCO ₃ | 13 | 3 | 8 | 8 | 45 | 17 | 11 |
| Na | 3.0 | 2.6 | 2.1 | 1.6 | 4.4 | 1.9 | 5.0 |
| K | 0.3 | 0.4 | 0.3 | 0.4 | 0.6 | 0.4 | 5.2 |
| Ca | 2.5 | 1.9 | 1.9 | 1.5 | 10.0 | 3.8 | 3.5 |
| Mg | 0.7 | 0.4 | 0.3 | 0.3 | 1.9 | 0.6 | 0.9 |
| Mn | 102 | 37 | - | 10 | - | - | - |
| Fe | 28 | 191 | - | 25 | - | - | - |
| Ra | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 5 |
| Zn (A)* | 10 | 11 | 26 | 6 | 190 | 21 | 91 |
| Cu (A) | 5 | 1 | 126 | 6 | 18 | 6 | 85 |
| Pb (A) | 2 | 2 | 5 | 2 | 5 | 3 | 3 |
| Ni (A) | 2 | 4 | 2 | 2 | 9 | 2 | 9 |
| Co (A) | - | 2 | 10 | 2 | 80 | 10 | 55 |
| As (A) | 2 | .5 | .5 | .5 | 1 | .5 | 7 |
| U (A) | 0.2 | - | 0.2 | - | 0.2 | 0.2 | 0.5 |
| Mn (A) | 178 | - | 13 | - | 1197 | 92 | 299 |
| Fe (A) | 41 | - | 170 | - | 1260 | 90 | 2400 |

U(A3) = U determined by laser induced fluorometry

U(FL) = U determined by standard fluorometry

*(A) = acidified samples



GSC

FIG 1.

NEW

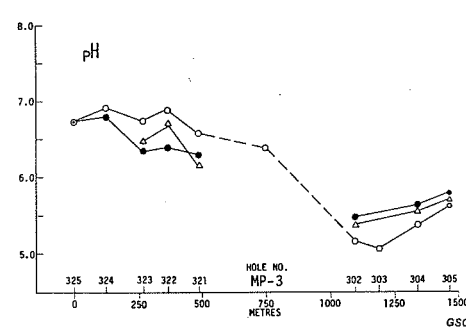
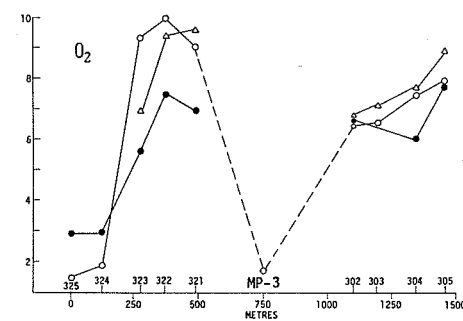
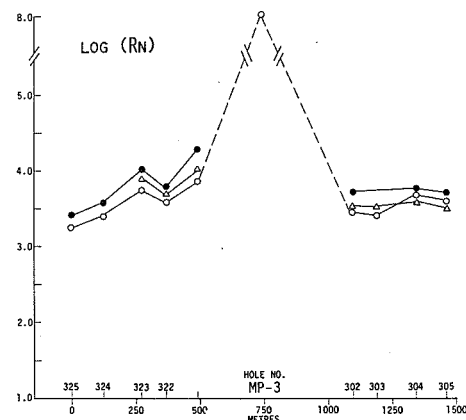
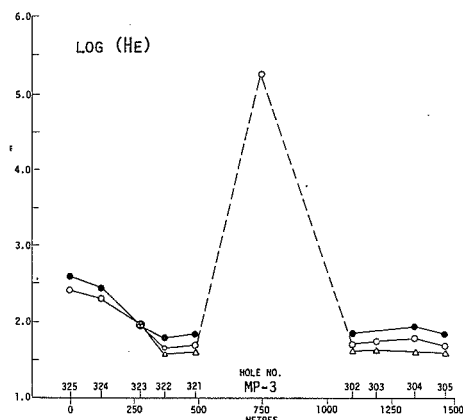
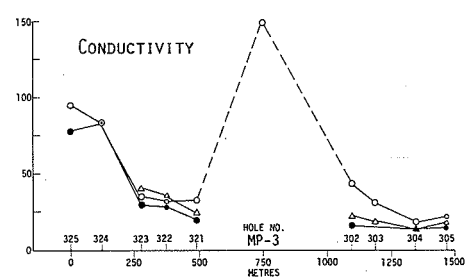
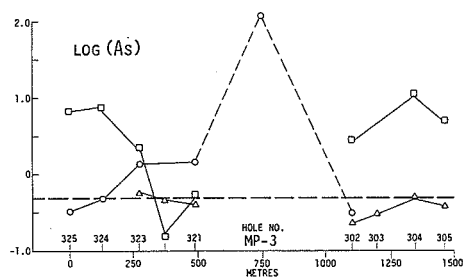
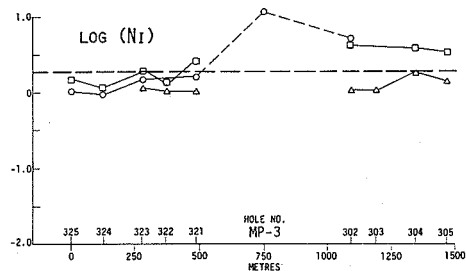
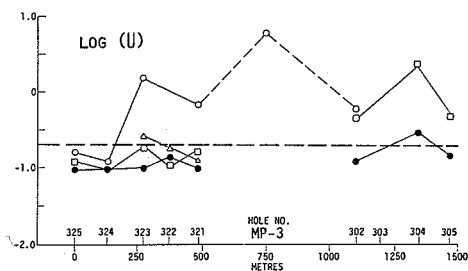
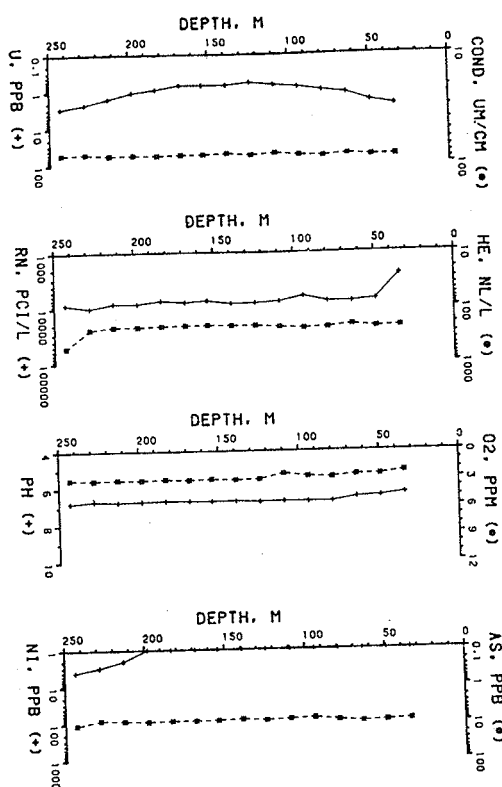
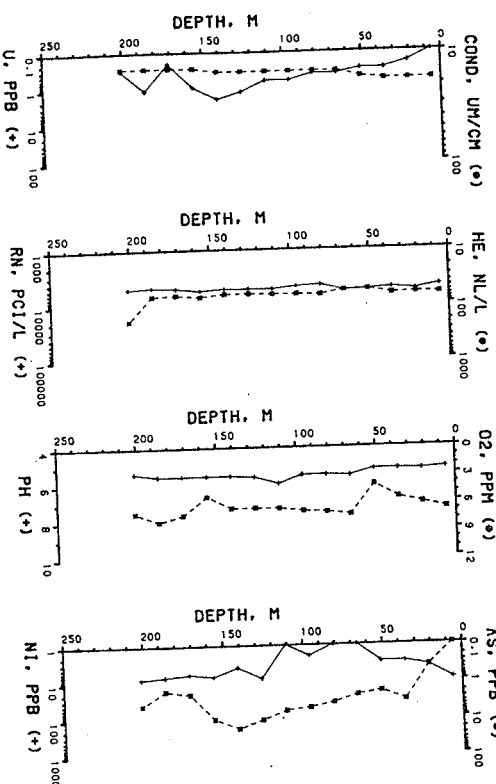


FIG. 2.

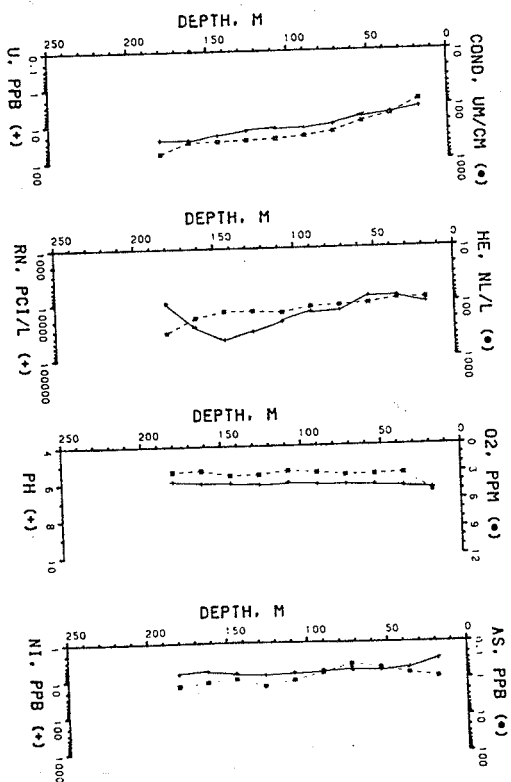
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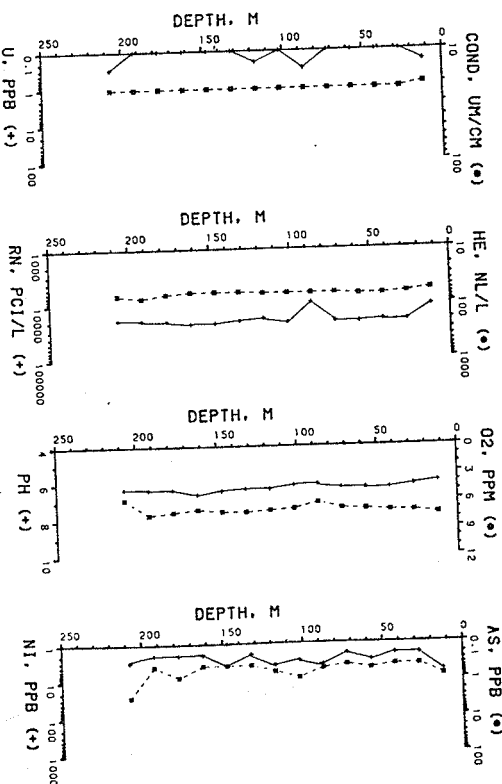
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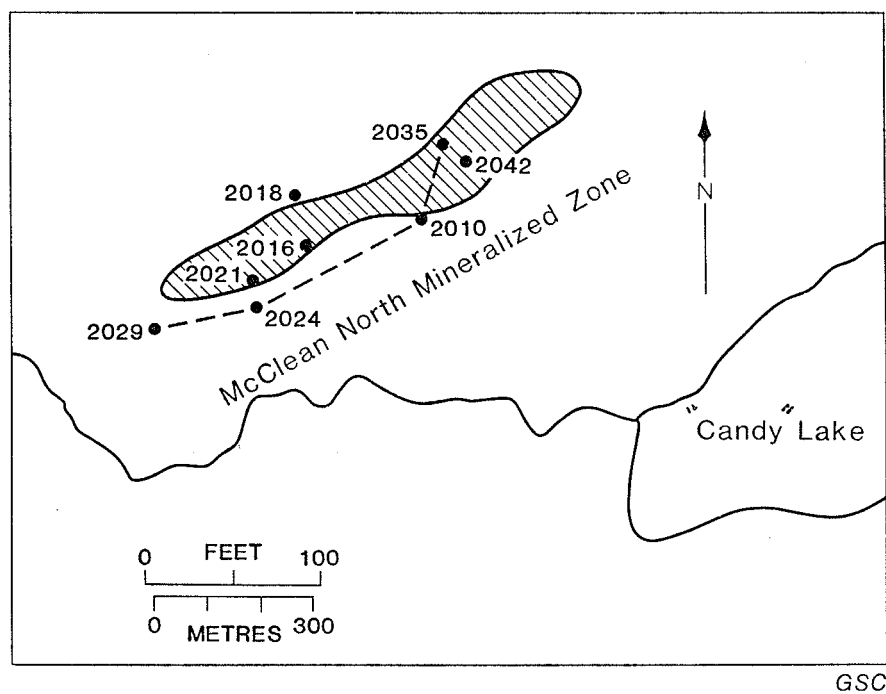


FIG. 4.

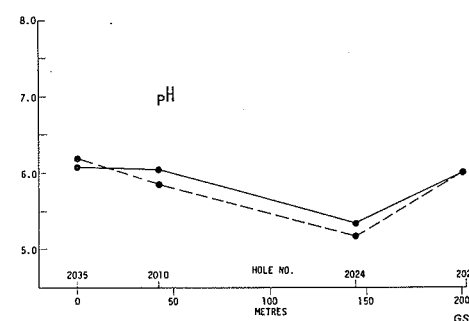
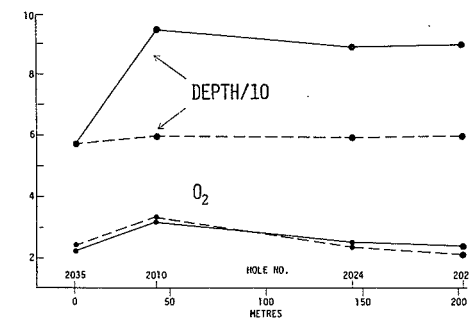
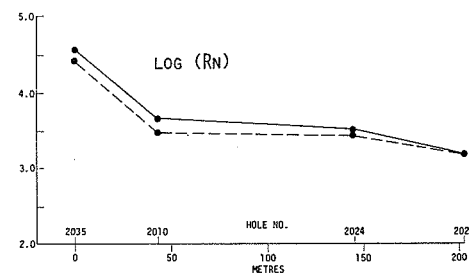
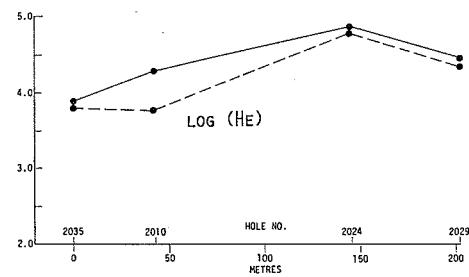
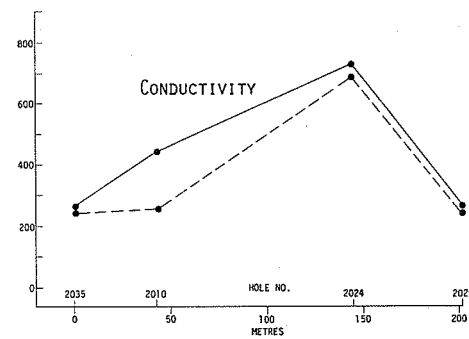
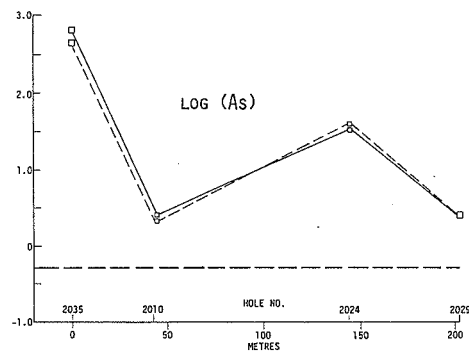
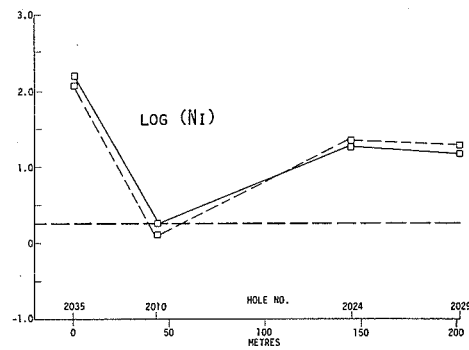
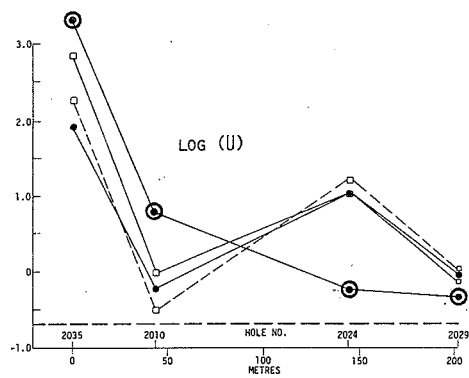
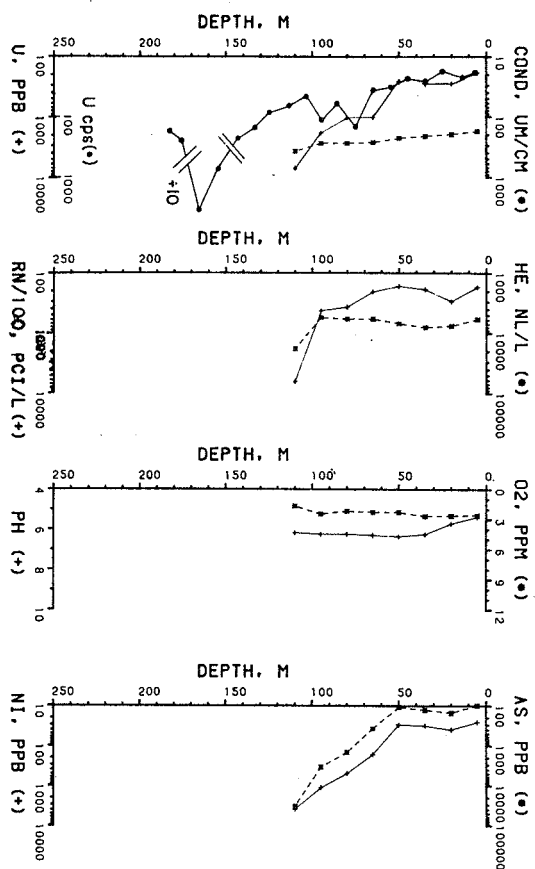
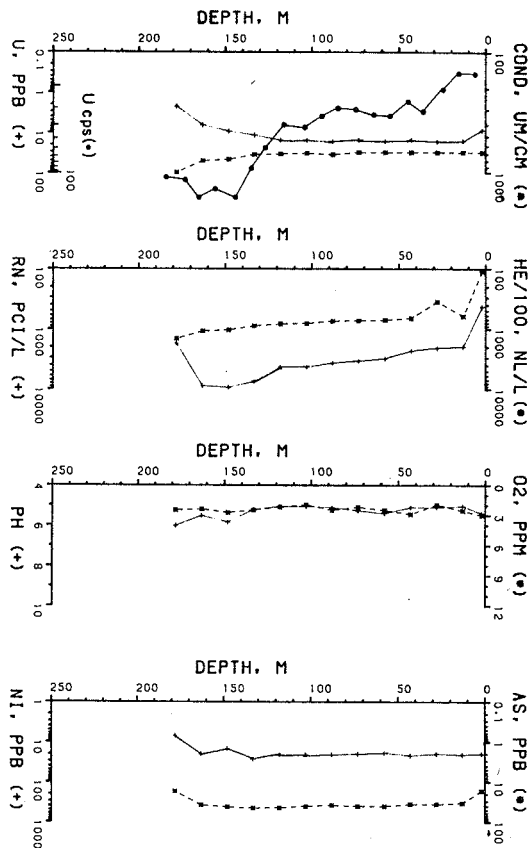


FIG. 5.

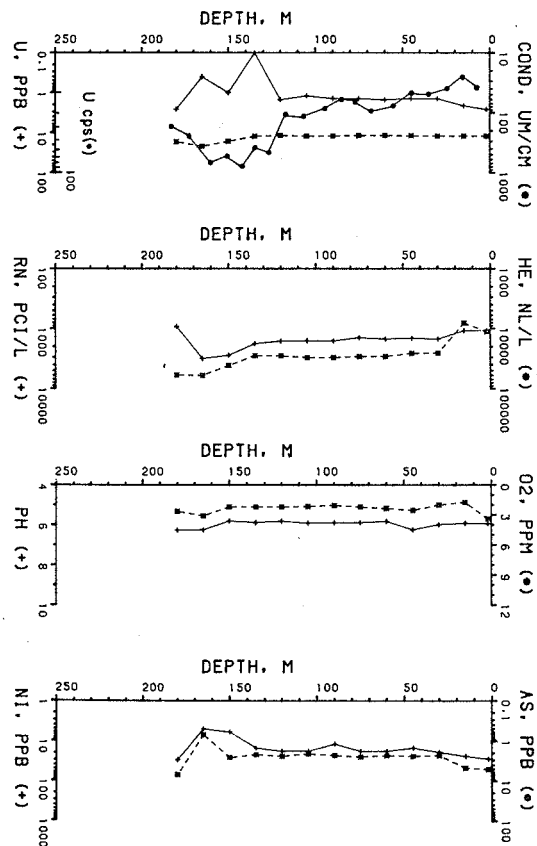
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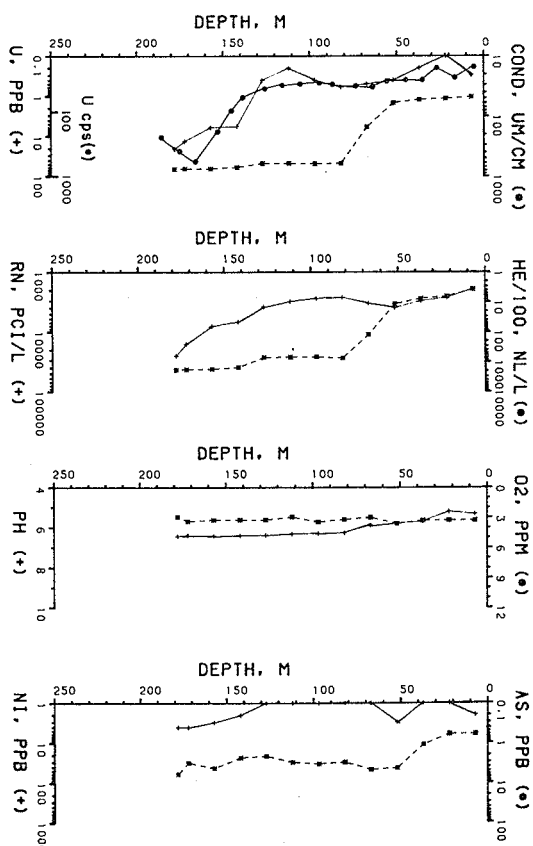
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DRILL HOLE NO. 2029, McCLEAN DEPOSITS 1980



DRILL HOLE NO. 2010, McCLEAN DEPOSITS 1980



5-2-302

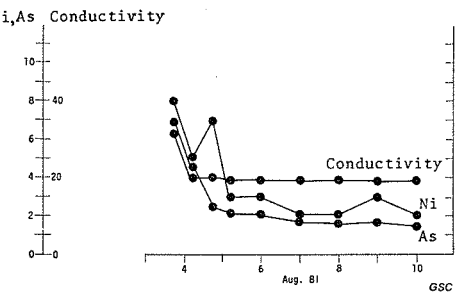
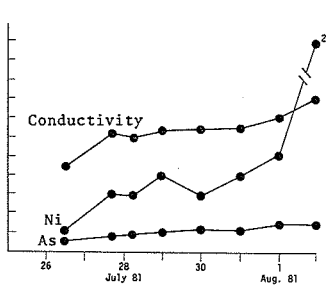
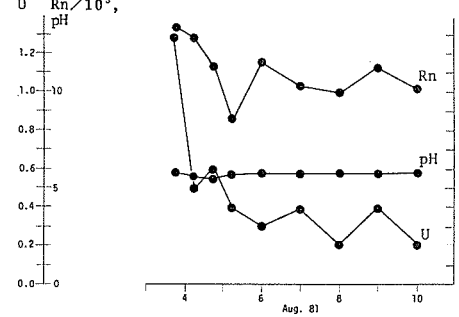
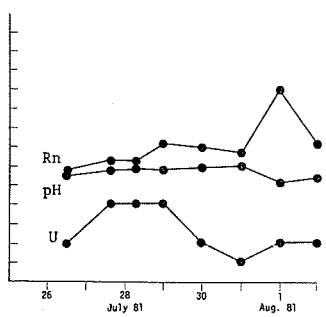
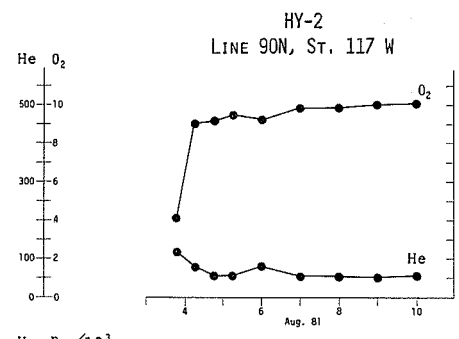
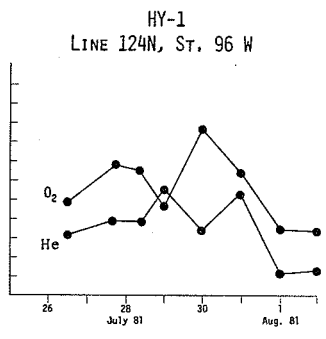


FIG. 7.