ENGINEERING REPORT ON
THE DRILLING IN THE UPPER MICHIGAN
PRECAMBRIAN BASINS

GEOLOGICAL SURVEY DIVISION
MICHIGAN DEPARTMENT OF NATURAL RESOURCES
LANSING, MICHIGAN  48909

April 1979

ISSUED BY THE U.S. DEPARTMENT OF ENERGY
GRAND JUNCTION OFFICE
UNDER CONTRACT NO. EY-76-C-13-1664

metadc958311
ENGINEERING REPORT
ON THE DRILLING IN THE
UPPER MICHIGAN PRECAMBRIAN BASINS

James Trow

April 1979

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
BY
GEOLOGICAL SURVEY DIVISION
MICHIGAN DEPARTMENT OF NATURAL RESOURCES

UNDER CONTRACT NO. 77–074–X
## CONTENTS

<table>
<thead>
<tr>
<th>Heading</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>v</td>
</tr>
<tr>
<td>Summary</td>
<td>v</td>
</tr>
<tr>
<td>DL-1 Engineering Report</td>
<td>1</td>
</tr>
<tr>
<td>DL-3 Engineering Report</td>
<td>15</td>
</tr>
<tr>
<td>DL-4 Engineering Report</td>
<td>27</td>
</tr>
<tr>
<td>DL-5 Engineering Report</td>
<td>47</td>
</tr>
<tr>
<td>DL-6 Engineering Report</td>
<td>61</td>
</tr>
<tr>
<td>DL-7 Engineering Report</td>
<td>71</td>
</tr>
</tbody>
</table>
INTRODUCTION

This report, prepared by James Trow, Geological Survey Division, Michigan Department of Natural Resources, presents engineering details, individual borehole histories and brief preliminary geologic summaries of six (6) holes drilled in two areas of the Upper Michigan Peninsula. These two areas include five (5) holes drilled in the East Baraga Basin, Dead River Basin and Clark Creek Basin (all in Marquette County) and one (1) hole drilled on the northwest flank of the Amasa Oval in Iron County.

A more detailed geological report will be available in the near future through the Grand Junction Office Technical Library. Geophysical logs, on microfiche, for each borehole are included in this report.

SUMMARY

The Upper Michigan Precambrian Basins Project was conducted by the Michigan Department of Natural Resources, Geological Survey Division, under a subcontract from Bendix Field Engineering Corporation. This project was in support of the United States Department of Energy (DOE) National Uranium Resource Evaluation (NURE) program.

This project consisted of six (6) holes, ranging in depth from 697 feet (212.45 m) to 3,176 feet (968.04 m). A total of 9,896 feet (3,016.3 m) were drilled, of which 8,654 feet (2,637.74 m) were cored.

The project began in late September 1977 and continued into May 1978, with final site restoration and clean-up.
James Trow
Geologist-in-Charge
for
Geological Survey Division
Michigan Department of Natural Resources

1978
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>3</td>
</tr>
<tr>
<td>Location</td>
<td>3</td>
</tr>
<tr>
<td>Site Selection</td>
<td>3</td>
</tr>
<tr>
<td>Geology</td>
<td>3</td>
</tr>
<tr>
<td>Drilling and logging</td>
<td>5</td>
</tr>
<tr>
<td>Principal firms and agencies</td>
<td>5</td>
</tr>
<tr>
<td>Borehole data</td>
<td>6</td>
</tr>
<tr>
<td>Location</td>
<td>6</td>
</tr>
<tr>
<td>Elevation</td>
<td>6</td>
</tr>
<tr>
<td>Total depth</td>
<td>6</td>
</tr>
<tr>
<td>Dates</td>
<td>6</td>
</tr>
<tr>
<td>Casing</td>
<td>6</td>
</tr>
<tr>
<td>Bit sizes</td>
<td>6</td>
</tr>
<tr>
<td>Bits used</td>
<td>6</td>
</tr>
<tr>
<td>Inclination</td>
<td>7</td>
</tr>
<tr>
<td>Mud used</td>
<td>8</td>
</tr>
<tr>
<td>Borehole logs</td>
<td>8</td>
</tr>
<tr>
<td>Birdwell Division of S.S.C.</td>
<td>8</td>
</tr>
<tr>
<td>Bendix Field Engineering Corporation</td>
<td>8</td>
</tr>
<tr>
<td>Borehole history</td>
<td>8</td>
</tr>
<tr>
<td>Additional geologic data now available</td>
<td>13</td>
</tr>
</tbody>
</table>

## FIGURES

- Figure 1. Location map 4

## BOREHOLE LOGS

**Birdwell Division of S.S.C.**
- Gamma-ray log and neutron log In pocket
- Spontaneous-potential log and resistivity log In pocket
- Caliper log and bulk density log In pocket

**Bendix Field Engineering Corporation**
- Gamma-ray, spontaneous potential, & resistivity logs In pocket
- Gamma spectrometer (KUT) log In pocket
- Thermal neutron and epithermal neutron logs In pocket
- Caliper log In pocket
- Magnetic susceptibility log In pocket
This report presents engineering details, history, and a very brief preliminary geologic summary of DL-1 in the East Baraga Basin. More geologic information will follow in a final report on all holes of the project in which thin sections and chemical analyses will be reported. More detailed geological and geophysical information, including on-site well logs, is immediately available from Greg Wilson, Michigan Geological Survey Division of the D.N.R., Stevens T. Mason Building, Box 30028, Lansing, Michigan 48909, telephone (517)373-1256.

LOCATION (lat. 46°45'30"N., long. 87°50'28"W.)

Drill location 1 is on rolling forest land in the NW1/4SW1/4 section 5, T. 50 N., R. 28 W., Marquette County, Michigan, near a monument with an altitude of 1,152.90 feet, 795.42 feet east and 240.46 feet south of the west quarter corner of section 5. The site is reached by driving three miles on Marquette County Highway 510 generally southwest from its intersection with County Highway 550 (southeast from Big Bay), then three miles generally west-southwest on the Triple-A Road, then two miles west on another dirt road, and then one-tenth of one mile south on a trail which loops back east to rejoin the dirt road. See Figure 1.

SITE SELECTION

The site was selected on available state land by the Michigan Geological Survey because U.S. Geological Survey gravity surveys by John Klasner suggested that it is on the north (upthrown) side of a major fault zone with parallel east-west peridotite dikes, whereas DL-3 is on the south (downthrown) side. The gravity measurements implied that at DL-1 the Early Precambrian (age W) basement rocks should be at a depth of approximately 1,000 feet, and at a depth of approximately 3,000 feet at DL-3.

GEOLOGY

Pleistocene overburden of sand and boulders extends to a depth of 71 feet. From there to a terminal depth of 2,148 feet the Precambrian X Michigamme Formation consists principally of pyritic black and gray slate, argillite, and graywacke. Algal stromatolites occur at 1,992 and 2,039 feet. Ammonium molybdate tests on acidized core reveal that phosphate is not a significant constituent in the footage drilled. Scintillometer tests on the core and downhole geophysical logging show a maximum calculated 35 ppm uranium in black slate and gray argillite in the interval 86-90 feet, immediately below a depleted porous zone. A broad zone of radioactivity from 1,734-2,044 feet implies uranium content from 8-32 ppm.
Figure 1. Location map of DL-1, DL-3, DL-4, DL-5 and DL-7
Conspicuous slaty cleavage dipping from 37°-65° SW caused deviation of the hole from the intended vertical to a northeast plunge of 33-1/2° (56-1/2° from the vertical) at terminal depth. East-west vertical faults display dragged slaty cleavage (suggesting Precambrian Y age for the faulting) and dragged bedding which indicate that the north block is downthrown in all cases. With the exception of these locally dragged strata, the Michigamme Formation dips from 30°SE to 3°NW, with an average of 14°SE.

Correlation with marker horizons in DL-7, one and one-half miles to the east-northeast, suggests that Precambrian W basement rocks would have been encountered with 451 more feet of drilling at DL-1, at an inferred 2,599 feet, with a vertical depth of 2,049 feet, or 896 feet below sea level.

**DRILLING AND LOGGING**

HQWNL and NQWNL bits used in the intended vertical drilling were large enough to permit inclination tests at every 50 or 100 feet by means of a Sperry-Sun single-shot camera. Attempts on the part of the bits to penetrate the conspicuous slaty cleavage perpendicularly resulted in deviations of as much as 56-1/2° from the initial vertical at 2,148 feet. Wedging attempts did not solve this problem. Work on subsequent holes showed that such deviation could be minimized by (1) using core barrels 10 feet in length rather than more limber barrels 20 feet in length, (2) by letting the drill rods "float" in deep holes rather than forcing their advance hydraulically, (3) by changing bits frequently to assure sharpness, and (4) by using one gallon of Torque Trim per load of water. Inside-outside double-step bits were used for most of the drilling. DL-1 was abandoned at 2,148 feet because of excessive binding and string wear in the lower 40 feet resulting from sharp deviation, and because of decisions in Grand Junction. Core recovery was essentially 100%, except obviously where wedging was attempted.

Birdwell geophysical logging depths are in error by an overestimate of 14 feet at 2,148 feet, so that any given true depth can be calculated by multiplying the Birdwell depth by 0.9935.

**PRINCIPAL FIRMS AND AGENCIES**

**FUNDED BY:**
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado 81501

**CONTRACTOR:**
Bendix Field Engineering Corporation
Grand Junction Operations
Grand Junction, Colorado 81501

**SUBCONTRACTOR:**
Geological Survey Division
Michigan Department of Natural Resources
Stevens T. Mason Building, Box 30028
Lansing, Michigan 48909

5
DRILLING SUBCONTRACTOR:
Longyear Company
P. O. Box 186
Keewatin, Minnesota 55753

GEOPHYSICAL LOGGING SUBCONTRACTOR:
Birdwell Division of S.S.C.
P. O. Box 256
Mt. Pleasant, Michigan 48858

BOREHOLE DATA

LOCATION:
NW1/4SW1/4 section 5, T. 50 N., R. 28 W., Marquette County, Michigan; 795.42 feet east and 240.46 feet south of the west quarter corner of section 5.

ELEVATION:
Monument at 1,152.90 feet, essentially the same as the collar of the hole.

TOTAL DEPTH:
2,148 feet below monument (on curving course deviating from initial vertical by 56-1/2° at terminal depth) 647 feet below sea level.

DATES:
Well spudded; October 7, 1977. Rig released; December 12, 1977.

CASING:
Four inch surface casing set at 79 feet. NW casing set at 1,004 feet and later all removed except for 90 feet left between 914-1,004 feet, after breaking during pulling of casing.

BIT SIZE:
5-5/8 inch rock bit used from surface to 79 feet. HQWL bits used from 79-1,004 feet. All inside-outside double-step bits. NQWL bits used from 1,004-2,148 feet. All inside-outside double-step but no. 15.

BITS USED:

<table>
<thead>
<tr>
<th>No.</th>
<th>Size</th>
<th>Depth In</th>
<th>Depth Out</th>
<th>Total Feet</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5-5/8 in. rock bit</td>
<td>Surface</td>
<td>79</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>HQWL 75-48355</td>
<td>79</td>
<td>254</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>263</td>
<td>268</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>BX-HQ 75-49962</td>
<td>254</td>
<td>263</td>
<td>9</td>
<td>Wedging, tapered reamer</td>
</tr>
<tr>
<td>4</td>
<td>BX con. 75-50057</td>
<td>254</td>
<td>263</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Depth in Feet</td>
<td>Deviation from Vertical</td>
<td>Bearing</td>
<td>Remarks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>-------------------------</td>
<td>---------------</td>
<td>--------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>104</td>
<td>3/4°</td>
<td>S.65°W.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>154</td>
<td>3/4°</td>
<td>N.50°W.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>204</td>
<td>1-1/4°</td>
<td>Due N.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>254</td>
<td>3°</td>
<td>N.12°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>294</td>
<td>4-1/2°</td>
<td>N.5°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>304</td>
<td>5°</td>
<td>N.5°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>324</td>
<td>5-1/2°</td>
<td>N.5°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>344</td>
<td>5-3/4°</td>
<td>N.10°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>394</td>
<td>7°</td>
<td>N.12°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>444</td>
<td>8°</td>
<td>N.14°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>494</td>
<td>9-1/2°</td>
<td>N.15°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>544</td>
<td>11-1/2°</td>
<td>N.15°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>594</td>
<td>13-1/2°</td>
<td>N.17°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>644</td>
<td>14-1/4°</td>
<td>N.17°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>694</td>
<td>15-1/4°</td>
<td>N.18°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>744</td>
<td>17°</td>
<td>N.20°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>794</td>
<td>18-1/2°</td>
<td>N.19°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>894</td>
<td>21-1/2°</td>
<td>N.20°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1004</td>
<td>23-3/4°</td>
<td>N.20°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1104</td>
<td>26°</td>
<td>N.18°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1194</td>
<td>28-1/4°</td>
<td>N.21°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1294</td>
<td>31-3/4°</td>
<td>N.18°E.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
MUD USED: Eighteen 50-pound sacks of Quick Gel for a total of 900 pounds.

BOREHOLE LOGS

**BIRDWELL DIVISION OF S.S.C. (Microfiche copies of logs in pocket)**
- Gamma-Ray Log: 8 to 2,139 feet
- Neutron Log: 0 to 2,148 feet
- Spontaneous Potential and Resistivity Log: 55 to 2,148 feet
- Caliper Log: 45 to 2,148 feet
- Bulk Density Log: 91 to 1,976 feet

**BENDIX FIELD ENGINEERING CORPORATION (Microfiche copies of logs in pocket)**
- Gamma-Ray, Spontaneous-Potential, and Resistivity Logs: 20 to 1,920 feet
- Gamma Spectrometer (KUT) Log: 0 to 1,920 feet
- Neutron-Neutron Log: 0 to 1,920 feet
- Caliper Log: 0 to 1,612 feet
- Magnetic Susceptibility Log: 0 to 1,610 feet
- Floating debris in hole jammed at 1,920 feet, thereby preventing deeper penetration of sondes.

BOREHOLE HISTORY

1977
October 6  Truck rig 2201 started to move from DL-3 to DL-1, 6 hours.

October 7  Continued moving rig, 10 hours. Rigged up, 10 hours, and spudded into overburden vertically to penetrate 7 feet with 5-5/8 inch rock bit, 4 hours.

October 10 Drilled from 7-61 feet of bouldery overburden with 5-5/8 inch rock bit; used fifteen 50 pound bags of Quick Gel; pumped out sump, and mixed new batch of mud, 18 hours.

October 11 Drilled from 61-79 feet with 5-5/8 inch rock bit, striking ledge at 71 feet; set and cemented 80 feet of 4-inch casing; used sixteen 94 pound bags of Portland cement and three 50 pound bags of Quick Gel; drilled 79-134 feet of HQ core with HQWL bit.
75-48335 for 100% core recovery; wrong Sperry-Sun tool used at 104 feet, suggested that the hole departed from the vertical by 3/4°; 24 hours.

October 12 Drilled 134-164 feet with 100% recovery, experienced stuck tube, 9 hours. Sperry-Sun inclination test within casing at 79 feet showed 1/2° deviation from the vertical, test at 104 feet showed 3/4°, S.65°W, deviation, and test at 154 feet showed deviation of 3/4°, N.50°W.; 3 hours.

October 13 Drilled 164-214 feet with 100% recovery, 10 hours. Rig service required 1 hour. Inclination test at 204 feet showed deviation of 1-1/4°N.; 1 hour.

October 17 Drilled 214-254 feet with 100% recovery, 12 hours. Test at 254 feet showed deviation of 3-1/4°; 1 hour. However, this appeared to be a bad test so Longyear agreed to repeat one free of charge on the next day.

October 18 Repeated inclination test at 254 feet revealed deviation of 3°, N.12°E.; 1 hour. Wedging commenced, 2 hours. Bundles of all casing and HQ rods disassembled and hauled to drill sites, 9 hours.

October 19 Wedging required 21 hours. Wrong threads on the wedge necessitated three trips to machine shop; 3 hours. Wedging prevented coring from 254-263 feet. A tapered reamer from BX to HQ, 75-49962, was applied at 254 feet and used to 263 feet. A BX conventional bit 75-50058 was installed at 254 feet; another BX conventional bit 75-50057 was installed at 254 feet. HQ drilling from 263-268 feet yielded 100% core recovery. HQWL bit 75-48331 was installed at 268 feet.

October 20 HQ drilling from 268-304 feet yielded 100% recovery; 8 hours. Deviation at 294 feet had increased to 4-1/2°, N.5°E.; 1 hour. More wedging was attempted between 304-313 feet with a tapered HQ reamer and a tapered reamer barrel; 14 hours.

October 24 Wedging was completed; 2 hours. Drilling from 313-344 feet resulted in 100% recovery; 6 hours. Deviation at 324 feet was 5-1/2°, N.5°E.; deviation at 344 feet was 5-3/4°, N.10°E.; 2 hours. Full-hole tools were put on, 2 hours, and reaming with them proceeded for 3 hours, from 254-344 feet.

October 25 Drilling from 344-444 feet yielded 100% recovery; 22 hours. Deviation at 394 feet was 7°, N.12°E.; deviation at 444 feet was 8°, N.14°E.; 2 hours.

October 26 Drilling from 444-544 feet resulted in 100% recovery; 22 hours. Deviation at 494 feet was 9-1/2°, N.15°E.; deviation at 544 feet was 11-1/2°, N.15°E.; 2 hours.
October 27  Drilled 544-624 feet with 100% recovery, 18 hours. Handling rods required 5 hours with bit HQWL 75-48339. Deviation at 594 feet (where the new bit was installed) was 13-1/2°, N.17°E.; 1 hour. Broken rock from 594-604 feet caused loss of all water return at 595 feet. Circulation returned within 10 feet. Oil change consumed 1 hour.

October 31 Drilled 624-744 feet with 100% recovery; 22 hours. Deviation at 644 feet was 14-1/4°, N.17°E.; deviation at 694 feet was 15-1/4°, N.18°E.; 2 hours.

November 1 Drilling from 744-854 feet yielded 100% recovery; 22 hours. Deviation at 744 feet was 17°, N.20°E.; deviation at 794 feet was 18-1/2°, N.19°E.; 2 hours.

November 2 Drilling from 854-954 feet yielded 100% recovery; 22 hours. At 934 feet bit 75-46936 was installed; 2 hours. Deviation at 894 feet was 21-1/2°, N.20°E.; 1 hour.

November 3 Drilling from 954-1,004 feet yielded 100% recovery; 10 hours. An oil change occupied 1 hour. Deviation at 1,004 feet was 23-3/4°, N.20°E.; 1 hour. Handling rods occupied 3 hours. Collaring hole and placing 1,005 feet of HW casing occupied 9 hours. NWCS bit 75-3024 was used from 1,004-1,005 feet; 1 hour.

November 7 To start NQ coring, NQWL bit 75-36167 was installed at 1,004 feet, involving handling rods for 4 hours. Drilling from 1,004-1,104 feet produced 100% recovery; 19 hours. Deviation at 1,104 feet was 26°, N.18°E.; 1 hour.

November 8 Drilling from 1,104-1,184 feet yielded 100% recovery; 15 hours. Hole was washed out with clean water. Handling rods consumed 7 hours, including installing bit NQWL 75-36169 at 1,134 feet. Repairs on hydraulic line occupied 2 hours.

November 9 Drilling from 1,184-1,299 feet yielded 100% recovery; 22 hours. Deviation at 1,194 feet was 28-1/4°, N.21°E.; deviation at 1,294 feet was 31-3/4°, N.18°E.; 2 hours.

November 10 Handling rods required 6 hours. Bit HQWL 75-36172 was applied at 1,299 feet. A lifter case became unscrewed, requiring another handling of the rods. An oil change required 1 hour. Drilling from 1,299-1,364 feet yielded 100% recovery; 12 hours.

November 14 Drilling from 1,364-1,484 feet yielded 100% recovery; 23 hours. Deviation at 1,394 feet was 35°, N.18°E.; 1 hour.

November 15 Drilling from 1,484-1,604 yielded 100% recovery; 22 hours. Deviation at 1,494 feet was reported by the driller to be 38-3/4°, N.19°E., and reported by Jack Avery to be 40°, N.18°E.; deviation at 1,594 feet was 42°, N.17°E.; 2 hours.
November 16  Drilling from 1,604-1,606 feet yielded 100% recovery; 2 hours. The bit was burned in the hole and separated at the bottom of the shank. Handling rods consumed 20 hours. The burned bit was left in hole and the chopping rod applied. The hole was then washed, after which NQWL bit 75-36166 was installed at 1,606 feet. No core was obtained between 1,606-1,608 feet, and no charge was assessed; 2 hours.

November 17 Drilled through burned bit. Drilled from 1,608-1,654 feet with 100% recovery; 12 hours. Handling rods consumed 11 hours as NQWL bit 75-36170 was installed at 1,614 feet. An oil change occupied 1 hour.

November 20 Drilling from 1,654-1,708 feet yielded 100% recovery; 11 hours. Deviation at 1,694 feet was 42-1/4°, N.17°E.; 1 hour.

November 21 Drilling from 1,708-1,824 feet yielded 100% recovery; 23 hours. Deviation at 1,794 feet was 42°, N.16°E.; 1 hour. Deviation test was scheduled for rerun at 1,800 feet next day, as it was suspect.

November 22 Repetition of deviation test at 1,800 feet showed 44°, N.15°E. deviation. Drilling from 1,824-1,924 feet recovered 100% core; 18 hours. Deviation at 1,894 feet was 47-3/4°, N.14°E.; 1 hour. Handling of rods consumed 5 hours during installation of HQWL bit 75-53411 at 1,914 feet. This standard flat-faced old fashioned bit was different from the inside-outside double-step bits used previously. I had requested this old fashioned bit six weeks earlier for a trial at DL-3 when the early drilling there departed radically from the vertical. At that time I considered the possibility that deviation might be encouraged by the steps on the bit encountering the northeast-dipping bedding tangentially, and that a flat-faced bit might not be so deflected. However, subsequent drilling at DL-1 produced an identical direction of deflection even though the bedding at DL-1 dipped southwestwardly; in contrast, the orientation of slaty cleavage was identical at both sites. Therefore, the deviation of the holes must have been encouraged by the tendency of the bit to penetrate slaty cleavage perpendicularly. Clearly, the bedding-control hypothesis was invalid, and there was no need to try a flat-faced bit. For some reason, it suddenly appeared, six weeks late, and was summarily installed.

November 28 At first, this flat-faced bit seemed to work as well as the inside-outside double-step bits, as drilling from 1,924-2,024 feet produced 100% recovery in 23 hours. Deviation at 2,004 feet was 50-3/4°, N.14°E.; 1 hour.

November 29 Drilling from 2,024-2,139 feet produced 100% recovery in 23 hours. Deviation at 2,104 feet was 55°, N.14°E.; 1 hour.
November 30  Drilling from 2,139-2,148 feet yielded 100% recovery; 3 hours.  
The deviation observed by the second (and last) shift on November 29 plus the observation of bedding parallel to the core caused Jack McCaslin of Bendix to drive to town to call Grand Junction, where Bendix authorities decided to stop the drilling, and called me in East Lansing about this. Unable to reach Jack Avery in the field, I agreed on the evidence available, as I had already terminated DL-3 drilling on the basis of too much core parallel to bedding. As it turned out, in DL-1 the parallelism of bedding to the core was only temporary in drag along a fault between 2,084-2,124 feet from November 29 drilling, but this bedding flattened at lower levels to yield 45° intersections.

At the drill rig, Jack Avery learned that severe binding was reducing R.P.M.'s during drilling to one-half the normal rate. When the rods were pulled, requiring 4 hours, it was observed that in the 40 feet of full-hole tools at the bottom of the string, threads were worn and cracked, one full-hole rod was cracked, and the bit was worn and cracked. This was a close one. Some rods were reinserted and withdrawn, 3 hours, for duplicate determinations of deviation by two Sperry-Sun cameras at the bottom of the hole. At 2,148 feet deviation was 56-1/2°, N.12°E., and 56-1/4°, N.14°E.; 2 hours. Rods were finally pulled; 2 hours. Inasmuch as we were only an estimated 400-500 feet from our target at the base of the Michigamme Formation, Michigan Geological Survey, Jack Avery and I were inclined to cement the hole back to 1,800 feet, and re-enter with inside-outside double step NQWL or NQ bits, lubricate with Torque Trim, and proceed slowly. Unfortunately, hole termination procedures were already being implemented, as 10 hours were spent in pulling casing.

December 1  During the pulling of casing, 90 feet of NW casing broke from the rest and remain in the hole between 914-1,004 feet, thereby denying us the prerogative of re-entering with NQ tools and avoiding a sharp pinch where new casing would meet the old. BQ or BX hole would be too small to allow passage of Bendix KUT geophysical probes, so we could not proceed with the smaller size. Birdwell geophysical surveys were run for 10 hours, and pulling of casing continued for 4 hours.

December 12  Rigging down consumed 6 hours, snow delays caused 5 hours to be lost, and demobilization occupied 3 hours.

Two statements summarize the drilling characteristics of the Michigamme Formation of the East Baraga Basin: (1) It is almost impossible to maintain a straight vertical hole in these rocks. (2) Almost perfect core recovery is routine.
If a straight vertical hole is desired, it is suggested alternatively that (1) core barrels 10 feet long should be used instead of the more limber barrels 20 feet long, the rods should be allowed to "float" in deep holes rather than advanced mechanically, bits should be changed frequently to assure sharpness, and Torque Trim should be used at the approximate rate of one gallon per load of water, or (2) hammer drilling should be used with geologic information obtained from rock chips and geophysical logs. If inclined holes are required, such holes can be oriented perpendicularly to slaty cleavage, inside-outside double-step bits plus careful drilling practices should produce relatively straight holes. Obviously, deviation problems would not be as serious in short holes as in long holes.

ADDITIONAL GEOLOGIC DATA NOW AVAILABLE

Jack W. Avery's one-site diamond drill logs, my geologic interpretation, including a cross section of gross structure, and my recommendations for further exploration are now available from Greg Wilson, Michigan Geological Survey Division of the D.N.R., Stevens T. Mason Building, Box 30028, Lansing, Michigan 48909; telephone (517)373-1256.
CONTENTS

Introduction .................................................. 17
Location ......................................................... 17
Site selection .................................................. 17
Geology .......................................................... 17
Drilling and logging ............................................ 19
Principal firms and agencies .................................. 19
Borehole data ................................................. 20
Location ......................................................... 20
Elevation ......................................................... 20
Total depth ...................................................... 20
Dates ............................................................ 20
Casing ............................................................ 20
Bit size .......................................................... 20
Bits used ......................................................... 20
Inclination ....................................................... 21
Mud used ......................................................... 22
Borehole logs ................................................... 22
Birdwell Division of S.S.C. ..................................... 22
Bendix Field Engineering Corporation ........................ 22
Borehole history ................................................ 22
Additional geologic data now available ..................... 26

FIGURES

Figure 1. Location map ....................................... 18

BOREHOLE LOGS

Birdwell Division of S.S.C.
  Gamma-ray log and neutron log .............................. In pocket
  Spontaneous-potential log & resistivity log ................ In pocket
  Bulk density log ........................................... In pocket
  Caliper log ................................................ In pocket

Bendix Field Engineering Corporation
  Gamma-ray log ............................................. In pocket
  Caliper log ................................................ In pocket

16
This report presents engineering details, history, and a very brief preliminary geologic summary of DL-3 in the East Baraga Basin. More geologic information will follow in a final report on all holes of the project in which thin sections and chemical analyses will be reported. Additional detailed geological information, including on-site well logs, is immediately available from Greg Wilson, Michigan Geological Survey Division of the D.N.R., Stevens T. Mason Building, Box 30028, Lansing, Michigan 48909, telephone (517)373-1256.

LOCATION (lat. 46°44'9"N., long. 87°54'17"W.)

Drill location 3 is on the flat, sandy Yellow Dog Plains in the NW1/4NW1/4 section 14, T. 50 N., R. 29 W., Marquette County, Michigan, generally north of swamps related to the Yellow Dog River, near a monument with an altitude of 1,449.47 feet, 801.39 feet east and 448.12 feet south of the northwest corner of section 14. This site is reached by driving three miles on Marquette County Highway 510 generally southwest from its intersection with Highway 550 (southeast from Big Bay), and then eleven miles southwest on the Triple-A Road to a trail which is followed 1.3 miles south. The latter trail passes through an old abandoned lumber camp. See Figure 1.

SITE SELECTION

The site was selected by the Michigan Geological Survey because U.S. Geological Survey gravity mapping by John Klasner suggested that in this immediate area the East Baraga (structural) Basin attains its maximum stratigraphic section of the Michigamme Formation, estimated by Klasner to be of the order of magnitude of 3,000 feet thick. As complete a stratigraphic section of the formation as possible was desired, hence this location was chosen in terms of availability of state land.

GEOLOGY

Pleistocene overburden of sand and a few boulders extends to a depth of 163 feet. From there to a terminal depth of 1,634 feet, the Precambrian X Michigamme Formation consists principally of carbon-rich black and gray straight-bedded to contorted slate with disseminated finely-grained pyrite, cubes of pyrite, discordant sheets of pyrite, and conformable thin siliceous pyritic laminae. Chalcopyrite occurs at 343 feet, 805 feet, and between 965-1,123 feet; pyrrhotite occurs sporadically between 965-1,168 feet and 1,235-1,634 feet. Birdwell bulk density logs show that the formation possesses a surprisingly high density, averaging 2.90 g/cm³, probably as a consequence of abundant sulfides. Ammonium molybdate tests on acidized core reveal that phosphate is not a significant constituent in the footage drilled. Radioactivity of the core measured by a scintillometer is less than two times background at all depths as measured by Jack W. Avery. Birdwell gamma-ray logs show the highest radioactivity between 910-1,010 feet.
Figure 1. Location map of DL-1, DL-3, DL-4, DL-5 and DL-7
Conspicuous slaty cleavage dipping from 40°-55°SW caused deviation of the hole from the initial vertical to a northeast plunge of 46° (44° from the vertical) at terminal depth, as the bit attempted to penetrate slaty cleavage perpendicularly. Bedding dips from 20°NE (right side up) to 60°SW (overturned) on this, the southwest side of the syncline. Minor faults in this hole are marked by brecciated zones or by white talcous gouge or black graphitic gouge. Such faults dip southwestward, apparently parallel to slaty cleavage. An east-west vertical Precambrian Y diabase dike four feet thick occurs between 1,545-1,551 feet.

This hole was terminated high in the Michigamme Formation in strata dipping much more steeply than expected from basin configuration. These steeper dips plus the deviation of the hole prevented us from attaining our stratigraphic objectives. Geometric projections (based upon the orientation of bedding in the hole and at available outcrops on the margin of the basin) suggest that the Precambrian W basement rocks may be more than 5,000 feet deep at this location. The high densities of the sulfide-rich Precambrian X rocks, plus the possibility of greenstones rather than granites in the underlying Precambrian W basement, may account for the underestimate of basement depth from gravity data, by the U.S. Geological Survey.

DRILLING AND LOGGING

HQWL and NQWL bits used in the intended vertical drilling were large enough to permit inclination tests at every 50 or 100 feet by means of a Sperry-Sun single-shot camera. Attempts on the part of the bits to penetrate the conspicuous slaty cleavage perpendicularly resulted in deviations. When first called for, wedges were not available, so segment A was terminated at a depth of 495 feet, the hole was cemented back to 150 feet, from which slightly straighter segment B was drilled. Wedging failed to correct developing deviation, so that within 40 feet of the terminal depth of 1,634 feet, the bore plunged 46°NE (44° from the vertical). Steepening dip of bedding with depth plus increasing deviation of the hole from the vertical caused near parallelism of the core with bedding, thereby calling for abandonment. Core recovery was essentially 100%, except where wedging was attempted.

Birdwell geophysical logging depths are in error by an overestimate of 10 feet at 1,634 feet, so that any given true depth can be calculated by multiplying the Birdwell depth by 0.9939. Birdwell logging was accomplished immediately before rigging down. By the time that Bendix logging of all holes was accomplished, this hole was so unstable that wise practice dictated that only the gamma-ray and caliper probes should be risked, and those only to a depth of 750 feet.

PRINCIPAL FIRMS AND AGENCIES

FUNDED BY:
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado 81501
CONTRACTOR:
Bendix Field Engineering Corporation
Grand Junction Operations
Grand Junction, Colorado 81501

SUBCONTRACTOR:
Geological Survey Division
Michigan Department of Natural Resources
Stevens T. Mason Building, Box 30028
Lansing, Michigan 48909

DRILLING SUBCONTRACTOR:
Longyear Company
P. O. Box 186
Keewatin, Minnesota 55753

GEOPHYSICAL LOGGING SUBCONTRACTOR:
Birdwell Division of S.S.C.
P. O. Box 256
Mt. Pleasant, Michigan 48858

BOREHOLE DATA

LOCATION:
NW1/4NW1/4 section 14, T. 50 N., R. 29 W., Marquette County, Michigan;
801.39 feet east and 448.12 feet south of the northwest corner of section
14.

ELEVATION:
Monument at 1,449.47 feet, essentially the same as the collar of the hole.

TOTAL DEPTH:
1,634 feet below monument (on curving course as much as 44° from vertical) 11 feet below sea level.

DATES:
Well spudded; September 27, 1977. Rig released; December 8, 1977.

CASING:
4 inch surface casing set at 177 feet. NW casing set at 895 feet and later all removed except for 105 feet left between 790 and 895 feet, after breaking during pulling of casing.

BIT SIZE:
3-5/8 inch rock bit used from surface to 177 feet. HQWL inside-outside double-step bits used from 177-895 feet. NQWL inside-outside double-step bits used from 895-1,634 feet.
## BITS USED:

<table>
<thead>
<tr>
<th>No.</th>
<th>Size</th>
<th>Depth In</th>
<th>Depth Out</th>
<th>Total Feet</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5-5/8 inch rock bit</td>
<td>Surface</td>
<td>177</td>
<td>177</td>
<td>Segment A</td>
</tr>
<tr>
<td>2</td>
<td>HQWL 75-33397</td>
<td>177</td>
<td>228</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>NQWL 75-36176</td>
<td>228</td>
<td>495</td>
<td>267</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>HQWL 75-48337</td>
<td>150</td>
<td>287</td>
<td>137</td>
<td>Segment B</td>
</tr>
<tr>
<td>5</td>
<td>HQWL 75-48830</td>
<td>287</td>
<td>385</td>
<td>258</td>
<td>Before reaming</td>
</tr>
<tr>
<td>6</td>
<td>HQWL 75-48334</td>
<td>305</td>
<td>545</td>
<td>80</td>
<td>After reaming</td>
</tr>
<tr>
<td>7</td>
<td>HQWL 75-46929</td>
<td>545</td>
<td>735</td>
<td>190</td>
<td>Reaming full</td>
</tr>
<tr>
<td>8</td>
<td>NQWL 75-48328</td>
<td>735</td>
<td>895</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>NWCS 75-52225</td>
<td>895</td>
<td>896</td>
<td>1</td>
<td>Setting NW</td>
</tr>
<tr>
<td>10</td>
<td>NQWL 75-36168</td>
<td>895</td>
<td>939</td>
<td>44</td>
<td>casing</td>
</tr>
<tr>
<td>11</td>
<td>NQWL 75-41892</td>
<td>939</td>
<td>995</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>NQWL 75-36175</td>
<td>995</td>
<td>1215</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>NQWL 75-36164</td>
<td>1215</td>
<td>1634</td>
<td>419</td>
<td></td>
</tr>
</tbody>
</table>

## INCLINATION (By Sperry-Sun single-shot camera):

<table>
<thead>
<tr>
<th>Depth in feet</th>
<th>Deviation from vertical</th>
<th>Bearing</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0°</td>
<td>N.11°E.</td>
<td>Segment A</td>
</tr>
<tr>
<td>200</td>
<td>1/4°</td>
<td>N.11°E.</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>3-3/4°</td>
<td>N.11°E.</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>9-3/4°</td>
<td>N.11°E.</td>
<td></td>
</tr>
<tr>
<td>495</td>
<td>16°</td>
<td>N.10°E.</td>
<td></td>
</tr>
<tr>
<td>205</td>
<td>1/2°</td>
<td>Due N.</td>
<td>Segment B</td>
</tr>
<tr>
<td>255</td>
<td>1-1/2°</td>
<td>Due N.</td>
<td></td>
</tr>
<tr>
<td>305</td>
<td>3-3/4°</td>
<td>N.5°E.</td>
<td>Wedging 305-314</td>
</tr>
<tr>
<td>319</td>
<td>4°</td>
<td>N.5°E.</td>
<td></td>
</tr>
<tr>
<td>345</td>
<td>6-3/4°</td>
<td>N.8°E.</td>
<td>Wedging 346-354</td>
</tr>
<tr>
<td>353</td>
<td>7°</td>
<td>N.10°E.</td>
<td></td>
</tr>
<tr>
<td>385</td>
<td>9°</td>
<td>N.8°E.</td>
<td></td>
</tr>
<tr>
<td>435</td>
<td>10-3/4°</td>
<td>N.5°E.</td>
<td></td>
</tr>
<tr>
<td>485</td>
<td>13°</td>
<td>N.8°E.</td>
<td></td>
</tr>
<tr>
<td>535</td>
<td>16°</td>
<td>N.6°E.</td>
<td></td>
</tr>
<tr>
<td>585</td>
<td>17-1/2°</td>
<td>N.7°E.</td>
<td></td>
</tr>
<tr>
<td>635</td>
<td>19-1/2°</td>
<td>N.3°E.</td>
<td></td>
</tr>
<tr>
<td>685</td>
<td>21-3/4°</td>
<td>N.10°E.</td>
<td></td>
</tr>
<tr>
<td>785</td>
<td>25°</td>
<td>N.8°E.</td>
<td></td>
</tr>
<tr>
<td>885</td>
<td>29-1/2°</td>
<td>N.6°E.</td>
<td></td>
</tr>
<tr>
<td>995</td>
<td>31-3/4°</td>
<td>N.16°E.</td>
<td></td>
</tr>
<tr>
<td>1095</td>
<td>33-1/4°</td>
<td>N.17°E.</td>
<td></td>
</tr>
<tr>
<td>1205</td>
<td>37°</td>
<td>N.6°E.</td>
<td></td>
</tr>
<tr>
<td>1295</td>
<td>38-1/4°</td>
<td>N.17°E.</td>
<td></td>
</tr>
<tr>
<td>1395</td>
<td>39-1/2°</td>
<td>N.17°E.</td>
<td></td>
</tr>
<tr>
<td>1495</td>
<td>42-1/2°</td>
<td>N.21°E.</td>
<td></td>
</tr>
<tr>
<td>1594</td>
<td>44°</td>
<td>N.18°E.</td>
<td></td>
</tr>
</tbody>
</table>
MUD USED: Twenty-eight 50 pound sacks of Quick Gel for a total of 1,400 pounds.

BOREHOLE LOGS

BIRDWELL DIVISION OF S.S.C. (Microfiche copies of logs in pocket)
Gamma-Ray Log: 1 to 1,626 feet
Neutron Log: 0 to 1,634 feet
Spontaneous Potential and Resistivity Log: 895 to 1,634 feet
Caliper Log: 645 to 1,634 feet
Bulk Density Log: 893 to 1,574 feet

BENDIX FIELD ENGINEERING CORPORATION (Microfiche copies of logs in pocket)
Gamma-Ray Log: 0 to 750 feet
Caliper Log: 0 to 750 feet

Attempts to remove stuck casing after Birdwell logging so deteriorated the hole that by the time Bendix engineers arrived for logging, hole condition did not warrant risking the above sondes to any greater depths, and did not warrant risking any of the other sondes.

BOREHOLE HISTORY

1977
September 13 Drilling subcontract signed by Longyear Company.
September 19 Mobilization of Longyear rig 2201 from Minnesota, 12 hours.
September 20 Mobilization of rig from Minnesota, 12 hours.
September 21 Mobilization of rig from Minnesota, 24 hours.
September 22 Mobilization of rig from Minnesota, 24 hours.
September 23 Drilling subcontract signed by Bendix Field Engineering Corp.
September 26 Rigging up at DL-3, 24 hours.
September 27 Fixed station pump, hauled water, and mixed mud. Ten 50 pound bags of Quick Gel used. Drilled 132 feet through sandy overburden with 5-5/8 inch rock bit; 25 hours.
September 28 Drilled from 132-177 feet with 5-5/8 inch rock bit, 132-163 feet in overburden, ledge encountered at 163 feet, 12 hours. Pumped out sump and mixed new batch of mud, washed out hole with clean mud. Used fifteen 50 pound sacks of Quick Gel. Hauled rods to site from main road. Hauled water to fill sumps; 12 hours.
October 3 Put in 179 feet of 4-inch casing and cemented it in hole, 10 hours. Put in HQ rods and washed hole; 2 hours. Ran Sperry-Sun inclination tests at 100 feet (0° deviation) and at 200 feet (1/4° deviation, N.11°E.) to test departure from vertical; 2 hours. Drilled 177-208 feet with bit HQWL 75-33397 to obtain 29 feet of core in 31 feet for a core recovery of 94%; 10 hours. Twenty-nine 94 pound bags of Portland cement and three 50 pound bags of Quick Gel were used. Four loads of water were hauled two miles.
October 4  Drilled 208-228 feet with HQ core recovery 100%. Put in 230 feet of NW casing, changed bit to NQWL 75-36176. Drilled 228-255 feet and obtained 27 feet of NQ core with 100% recovery; 12 hours. Drilled 255-335 feet obtaining 80 feet of NQ core for 100% recovery; 11 hours. Six loads of water hauled five miles. Inclination test at 300 feet revealed 3-3/4° deviation at N.11°E. from the vertical; 1 hour.

October 5  Drilled 335-495 feet with 100% core recovery; 21 hours. Took two inclination tests at 400 feet; both revealed 9-3/4° deviation from the vertical, N.11°E. Another test at 495 feet revealed 16° deviation from the vertical, N.10°E.; 3 hours. Both HQ and NQ bits used so far were double-step inside-outside types.

October 6  Wedges had not been available when requested earlier so the 16° deviation at 495 feet prompted telephone consultation between East Lansing, Grand Junction, Lansing, and Marquette concerning whether the hole should now be wedged (as the wedges were now available) or temporarily abandoned. After five hours the decision was made to move the rig to DL-1 and to reoccupy DL-3 with the second rig when it became available. In the meantime, wedging could be tried at DL-1 at lesser depths, if necessary. Accordingly, rods were pulled at DL-3, the hole was cemented back to 150 feet with seventeen 94 pound bags of Portland cement, and three loads of water were hauled three miles; 15 hours. Rigging down consumed 3 hours. The remaining 6 hours were spent in moving to DL-1.

October 12  Mobilization of second Longyear rig 2108 from Wisconsin; 12 hours.

October 13  Rigging up consumed 13 hours.

October 14  Waiting for truck, unloading rods, and hauling them into DL-3 occupied 10 hours.

October 17  More rigging up consumed another 12 hours. Washing out the hole and re-entering consumed another 8 hours. Drilling was attempted with bit HQL-48337 for 4 hours in cement.

October 18  Cement was drilled for 16 hours; engine trouble on the drill consumed 4 hours.

October 19  Cement was drilled from 150-195 feet requiring 7 hours. 100% core recovery was obtained in rock from 195-217 feet; 5 hours. An inclination test at 205 feet indicated a deviation of 1/2° from the vertical, due N.; 1 hour.

October 20  A slower advance was being attempted in order to drive a straighter hole. 100% core recovery was obtained from 217-247 feet; 11 hours.
October 24  Core drilling for 18 hours gave 100% recovery from 247-305 feet. Handling the rods and changing the bit to HQWL 75-48830 at 287 feet required 3 hours. Inclination tests at 255 feet (1-1/2° due N.) and 305 feet (3-3/4°, N.5°E.) consumed 2 hours. The beginning of wedging operations consumed 2 hours.

October 25  Wedging between 305-314 feet consumed 15 hours. An inclination test at 319 feet yielded 4°, N.5°E., showing that we had gained nothing in the wedging but had lost 17 hours and what could have been 9 feet of core at the wedge. Another inclination test at 345 feet yielded 6-3/4°, N.8°E., showing more deviation from the vertical. Such tests consumed 2 hours. Drilling for 7 hours between 314-345 feet yielded 100% core recovery.

October 26  Core drilling between 345 and 346 feet yielded 100% recovery. Another wedging was attempted between 346-334 feet, losing eight potential feet of core. A tapered reamer and reamer barrel were used. The wedging occupied 18 hours, half of which was paid for by Longyear. An inclination test at 353 feet yielded 7° deviation from the vertical, N.10°E., showing no gain on the inclination problems. The latter test occupied 1 hour. Continued drilling from 354-375 feet yielded 100% core recovery. Core drilling occupied 5 hours.

October 27  From 375-385 feet 100% core recovery occurred. In view of the failure of wedging to solve the deviation problems, alternatives were attempted. At 385 feet full-hole tools with bit 75-48334 were installed, inasmuch as the inclination test at 385 feet showed 9° deviation from the vertical, N.8°E. It was necessary to ream with full-hole tools from 305-385 feet. This changeover and reaming occupied 5 hours. Continued drilling to 435 feet resulted in core recovery of 100%. Core drilling consumed 15 hours, inclination tests consumed 2 hours. The deviation at 435 feet was 10-3/4°, N.5°E., still increasing. An oil change required 1 hour.

October 31  In 16 hours of coring, between 435-497 feet, 100% core recovery resulted. An inclination test at 485 feet showed 13°, N.8°E., deviation from the vertical; 1 hour. Fuel-line problems with the engine and resulting repairs occupied 7 hours. It was quite clear at this point that the main cause of the deviation of the hole was the slaty cleavage toward which the bit attempted to drill perpendicularly, as both DL-1 and DL-3 were deviating in the same direction and the orientation of slaty cleavage was the same at both sites, whereas the bedding dipped in opposite directions at the two sites. It appeared that no common deviation remedies such as wedging, holding back on bit pressure, slow penetration, stiffer strings of tools, etc. would solve our problem. Inasmuch as the slaty cleavage in the hole dipped from 40° to 55°SW, it was obvious that the hole would wander until it attained a deviation of 40° to 55° to the northeast (measured from the intended vertical course), perpendicular to cleavage. While in some instances it might be proper to aim such a hole perpendicularly to cleavage at the surface, to minimize deviation, in this instance such orientation would have been counterproductive, as resulting core would have been almost parallel to bedding right from the start.
November 1  Coring between 497-570 feet resulted in 100% recovery in 20 hours. Changing the bit to HQWL 75-46929 at 545 feet required 3 hours. An inclination test at 535 feet showed the deviation to be 16°, N.6°E., from the vertical; 1 hour.

November 2  Coring from 570-670 feet resulted in 100% recovery in 22 hours. Inclination tests at 585 feet (17-1/2°, N.7°E.) and at 635 feet (19-1/2°, N.3°E.) occupied 2 hours.

November 3  Coring from 670-765 feet yielded 100% recovery in 20 hours. At 735 feet bit HQWL 48328 was applied; 2 hours. An inclination test at 685 feet showed deviation of 21-3/4°, N.10°E.; 1 hour.

November 7  Coring from 765-875 feet resulted in 100% recovery in 23 hours. An inclination test at 785 feet showed deviation from the vertical of 25°, N.8°E.; 1 hour.

November 8  Coring from 875-895 feet occupied 6 hours and yielded 100% recovery. An inclination test at 885 feet yielded a deviation from the vertical of 29-1/2°, N.6°E. Here it was decided to step down to NQ core. Accordingly, rods were pulled requiring 7 hours and casing was started down to 895 feet; 10 hours. It was difficult to lower casing because of binding.

November 9  NW casing was set at 895 feet requiring 4 hours, after drilling 895-896 feet with NWCS 75-52225 bit requiring 1 hour. Coring from 895-965 feet obtained 100% recovery in 13 hours. However, two additional bit changes were involved; NQWL 75-36168 at 895 feet, and NQWL 75-41892 at 939 feet; 6 hours.

November 10 Coring from 965-995 feet yielded 100% recovery; 8 hours. A broken hydraulic hose resulted in 6 hours lost time.

November 14 NQWL 75-36175 bit was installed at 995 feet; 3 hours. Coring from 995-1,095 yielded 100% recovery; 19 hours. Inclination tests at 995 feet (31-3/4°, N.16°E.) and at 1,095 feet (33-1/4°, N.17°E.) occupied 2 hours.

November 15 Coring from 1,095-1,215 feet yielded 100% recovery; 21 hours. Handling rods required 2 hours. Inclination test at 1,205 feet yielded deviation from the vertical of 37°, N.6°E.; 1 hour.

November 16 Coring from 1,215-1,345 feet yielded 100% recovery; 23 hours. Bit NQWL 75-36164 was installed at 1,215 feet. An inclination test at 1,295 feet yielded 38-1/4°, N.17°E.; 1 hour.

November 17 Coring from 1,345-1,475 feet yielded 100% recovery; 23 hours. An inclination test at 1,395 feet yielded 39-1/2°, N.17°E.; 1 hour.

November 20 Coring from 1,475-1,535 feet yielded 100% recovery; 11 hours. An inclination test at 1,495 feet yielded deviation of 42-1/2°, N.21°E.; 1 hour.
November 28  Coring from 1,535-1,613 feet yielded 100% recovery; 23 hours. An inclination test at 1,594 feet yielded a deviation of 44°, N.18°E., 1 hour.

November 29  Coring from 1,613-1,634 feet yielded 100% recovery; 6 hours. Upon my recommendation, the hole was terminated because increasing deflection from the vertical, coupled with increasing dip of the strata obviously had resulted in coring the same sequence twice, and an expectation of a continuation of the hole coring it, parallel to bedding, for the third time. Withdrawing rods consumed 4 hours. Pulling casing consumed 8 hours.

November 30  Geophysical probing of the hole by Birdwell occupied 10 hours: self potential, resistivity, gamma-ray, neutron, caliper, and bulk density logs were obtained. The bulk density probe was unable to reach the bottom 60 feet of the hole because of tightness. Pulling casing occupied 4 hours.

December 6  Pulling casing occupied 14 hours, of which 3 hours were spent hammering casing, before and after lowering casing cutter and cutting casing at 800 feet. It was necessary to run water line to wash hole.

December 7  Pulling of casing retrieved 790 feet of NW casing; 105 feet of this casing remained in the hole; 11 hours. Rigging down occupied 5 hours.

December 8  Rigging down occupied 3 hours; demobilization occupied 3 hours.

Two statements summarize the drilling characteristics of the Michigamme Formation of the East Baraga Basin: (1) It is almost impossible to maintain a straight hole in these rocks; (2) Almost perfect core recovery is routine.

It should be noted on page 26 that segment B (drilled with HQWL tools to a depth of 895 feet) deviated less rapidly in the first 495 feet than segment A (drilled with NQWL tools from 228-495 feet). This suggests that in these rocks larger and stiffer strings of tools deviate less. Experience in later holes showed that deviation could be minimized by using core barrels 10 feet long rather than the more limber barrels 20 feet long, by allowing the rods to "float" in deep holes rather than by advancing them mechanically, by changing bits more frequently to assure sharpness, and by using Torque Trim at the approximate rate of one gallon per load of water. If core is not required, down-hole hammering probably would produce straighter vertical holes than diamond drilling.

ADDITIONAL GEOLOGICAL DATA NOW AVAILABLE

Jack W. Avery's on-site diamond drill logs, my geologic interpretation including a cross section of gross structure, and my recommendations for further exploration are now available from Greg Wilson, Michigan Geological Survey Division of the D.N.R., Stevens T. Mason Building, Box 30028, Lansing, Michigan 48909; telephone (517)373-1256.
ENGINEERING REPORT
DIAMOND-DRILLING FOR GEOLOGIC INFORMATION
IN THE MIDDLE PRECAMBRIAN BASINS
IN THE WESTERN PORTION OF NORTHERN MICHIGAN

James Trow
Geologist-in-Charge
for
Geological Survey Division
Michigan Department of Natural Resources

1978

PREPARED FOR
U.S. DEPARTMENT OF ENERGY
AND
BENDIX FIELD ENGINEERING CORPORATION
GRAND JUNCTION OFFICE
PROJECT NO. 20-77-2132
CONTENTS

Introduction .................................................. 29
Location ....................................................... 29
Site selection ................................................. 29
Geology ........................................................ 29
Drilling and logging ......................................... 31
Principal firms and agencies ............................... 32
Borehole data ................................................. 32
Location ........................................................ 32
Elevation ....................................................... 32
Total depth .................................................... 32
Dates ............................................................ 33
Casing ............................................................ 33
Bit size ........................................................ 33
Bits used ....................................................... 33
Inclination ..................................................... 34
Mud used ....................................................... 35
Special lubricants ............................................ 35
Borehole logs ................................................ 35
Birdwell Division of S.S.C. .................................. 35
Bendix Field Engineering Corporation .................... 35
Borehole history .............................................. 36
Additional geologic data now available .................. 45

FIGURES

Figure 1. Location map ....................................... 30

BOREHOLE LOGS

Birdwell Division of S.S.C.
Gamma-ray and neutron log .................................. In pocket
Spontaneous-potential & resistivity logs .................. In pocket
Caliper and bulk density logs ................................ In pocket
Elastic properties log ...................................... In pocket

Bendix Field Engineering Corporation
Gamma-ray, spontaneous-potential, & resistivity logs .... In pocket
Gamma spectrometer (KUT) log ............................ In pocket
Neutron-neutron logs ....................................... In pocket
Caliper & magnetic susceptibility logs ................... In pocket
INTRODUCTION

This report presents engineering details, history, and a very brief preliminary geologic summary of DL-4 in the Dead River Basin. More geologic information will follow in a final report on all holes of the project, in which thin sections and chemical analyses will be reported. More detailed geological information, including on-site well logs and ammonium molybdate phosphate determinations, is immediately available from Greg Wilson, Michigan Geological Survey Division of the D.N.R., Stevens T. Mason Building, Box 30028, Lansing, Michigan 48909.

LOCATION (lat. 46°35′32″N., long. 87°46′15″W.)

Drill location 4 is on rolling forested land in the NW1/4NE1/4 section 2, T. 48 N., R. 28 W., Marquette County, Michigan, on the northeast side of County Highway 573, 70 feet northwest of a bench mark of 1,469 feet altitude. The monument at 1,469.94 feet altitude is 157.49 feet east and 505.92 feet south of the northern quarter corner of section 2. The site is reached by driving approximately twelve miles generally northwest on County Highway 573 from its intersection with U.S. 41 in Ishpeming. See Figure 1.

SITE SELECTION

Originally, the Michigan Geological Survey selected a site several hundred feet to the southeast of the above mentioned location, because of John Klasner's gravity survey for the U.S. Geological Survey. This stratigraphic map suggested that a maximum section of Precambrian X strata would be encountered at the original site. However, a ground magnetometer survey by Jack W. Avery and I showed that the original selection was too close to an east-west negative magnetic anomaly thought to be caused by a Precambrian Y diabase dike. Accordingly, we moved the site several hundred feet northwest along the road, to avoid any risk of coring solely a vertical diabase dike.

GEOLOGY

Pleistocene overburden is mainly sandy to a depth of 45 feet, and mainly bouldery from 45-76 feet, at which ledge was struck. From there to 2,966 feet Precambrian X Michigamme light gray to black argillite and slate alternate with graded-bedded "salt and pepper" graywacke with ripped up black slate clasts. Chlorite and clastic pink feldspars become more abundant at depths more than 1,670 feet; biotite becomes a noticeable constituent at depths greater than 1,916 feet. Algal stromatolites occur at 2,761, 2,769, 2,774, 2,856, 2,861, and 2,907 feet. Slaty cleavage, though not as abundant as at DL-1, DL-3, and DL-7, appears to have the same orientation at DL-4, from 35°-65°SW. The shallowest conglomerate in this hole occurs in this unit at a depth of 2,832 feet. From 2,966-3,019 feet, Precambrian X Michigamme strata appear to contain significant carbonate in argillites, graywackes, and conglomerates.
Figure 1. Location map of DL-1, DL-3, DL-4, DL-5 and DL-7
Cherty carbonate occurs at 2,971-2,973 feet and at 2,994-3,019 feet. Cores of 2 inch thick conglomerates at 3,008 and 3,011 feet display 2-1/2 and 4-1/4 times background radioactivity, according to scintillometer measurements by Jack W. Avery. From 3,019-3,119 feet Precambrian X Michigamme reddish-gray graywackes grade into orthoquartzite. The basal beds contain some very well-rounded quartz grains resembling pearls of tapioca; these are thought to be derived from quartz phenocrysts in Precambrian W porphyritic rhyolites. Bedding of the above-mentioned Precambrian X strata generally dips between 5°-40°NE. These strata unconformably overlie chloritized metaregolith developed on Precambrian W granite and gneiss which extend from 3,119 feet to the terminal depth of 3,176 feet.

Ammonium molybdate tests on acidized core by William T. Swenor show that phosphate occurs sporadically only below the depth of 2,810 feet.

Pyrite appears at almost all levels; chalcopyrite and sphalerite occur at several levels within the range 1,388-1,411 feet; chalcopyrite and pyrrhotite occur within the zone 1,402-1,506 feet; chalcopyrite alone occurs in a fault zone between 1,685-1,706 feet and at 2,832 feet in conglomerate; pyrrhotite occurs with pyrite between 1,402-1,506 feet; pyrrhotite occurs mainly alone in Precambrian W gneiss at 3,127 feet.

Some of the mineralization discussed above is related to southwest dipping normal faults which appear to be essentially parallel to slaty cleavage between 1,069-1,084, 1,274-1,276, 1,394-1,402, 1,540-1,545, and 1,685-1,706 feet as well as at 2,098 feet.

Precambrian Y unmetamorphosed diabase and gabbro dikes dipping 55°-60°SW, parallel to slaty cleavage, occur from 2,286-2,358 feet and from 2,825-2,827 feet.

**DRILLING AND LOGGING**

HQWL and NQWL tools used in the intended vertical drilling were large enough to permit inclination tests at every 50 or 100 feet by means of a Sperry-Sun single-shot camera. Slaty cleavage was less abundant here than at DL-1, DL-3, and DL-7 and so the drilling proceeded with less deviation from the vertical; the maximum deviation measured was 12° at 3,126 feet. Also contributing to the straightness of the hole were (1) using core barrels 10 feet long rather than more limber barrels 20 feet long, (2) allowing the drill rods to "float" rather than forcing them mechanically, (3) changing bits frequently enough to assure sharpness, (4) using approximately one gallon of Torque Trim per load of water, and (5) greasing the rods to minimize friction and vibration. Core recovery was essentially 100%, except where wedging was attempted and in fractured zones.

The greatest problem encountered in this hole started with the improper insertion of a wedge at 1,356-1,365 feet to correct a deviation of 3-1/2°, as revealed by an inclination of 6-1/2° at 1,390 feet. In cementing back from 1,411 feet to a level above the wedge, for rewedging purposes, too much cement was poured and the rods were not pulled high enough, resulting in cementing the rods in the hole from 1,033-1,244 feet.
Longyear corrected the problem at its own expense by wedging at 978-987 feet to yield sequence B of core, which overlaps the original sequence between 987-1,411 feet.

Birdwell geophysical logging depths are in error by an underestimate of only 2 feet at 3,176 feet, so that any true depth can be calculated by multiplying the Birdwell depth by 1.0006.

**PRINCIPAL FIRMS AND AGENCIES**

**FUNDED BY:**
- U.S. Department of Energy
  - Grand Junction Office
  - Grand Junction, Colorado 81501

**CONTRACTOR:**
- Bendix Field Engineering Corporation
  - Grand Junction Operations
  - Grand Junction, Colorado 81501

**SUBCONTRACTOR:**
- Geological Survey Division
  - Michigan Department of Natural Resources
  - Stevens T. Mason Building, Box 30028
  - Lansing, Michigan 48909

**DRILLING SUBCONTRACTOR:**
- Longyear Company
  - P. O. Box 186
  - Keewatin, Minnesota 55753

**GEOPHYSICAL LOGGING SUBCONTRACTOR:**
- Birdwell Division of S.S.C.
  - P. O. Box 256
  - Mt. Pleasant, Michigan 48858

**BOREHOLE DATA**

**LOCATION:**
- NW1/4NE1/4 section 2, T. 48 N., R. 28 W., Marquette County, Michigan; 157.49 feet east and 505.92 feet south of the north quarter corner of section 2.

**ELEVATION:**
- Monument at 1,469.94 feet essentially the same as collar of hole.

**TOTAL DEPTH:**
- 3,176 feet below monument (on relatively straight spiral course deviating from initial vertical by a maximum of 12° within 50 feet of terminal depth) 1,702 feet below sea level.
DATES:

CASING:
4-inch casing was set at 84 feet. NW casing was set at 1,469 feet.
1,005 feet removed; 1,004-1,469 feet in hole.

BIT SIZE:
5-5/8 inch rock bit used from surface to 84 feet. HQWL bits used from 84-1,469 feet. NQWL bits used from 1,469-3,176 feet.

<table>
<thead>
<tr>
<th>No.</th>
<th>Size</th>
<th>Depth In</th>
<th>Depth Out</th>
<th>Total Feet</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5-5/8 in. rock bit</td>
<td>Surface</td>
<td>84</td>
<td>132</td>
<td>False ledge-boulders at 48 feet; moved rig 2 feet and redrilled</td>
</tr>
<tr>
<td>2</td>
<td>HQWL 75-46940</td>
<td>23</td>
<td>86</td>
<td>65</td>
<td>Drilled cement in casing; see Borehole History</td>
</tr>
<tr>
<td>3</td>
<td>HQWL 75-48329</td>
<td>86</td>
<td>230</td>
<td>144</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>HQWL 75-62259</td>
<td>230</td>
<td>608</td>
<td>378</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>HQWL 75-62266</td>
<td>608</td>
<td>955</td>
<td>347</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>HQWL 75-63859</td>
<td>995</td>
<td>1056</td>
<td>101</td>
<td>Wedging 1056-1065</td>
</tr>
<tr>
<td>7</td>
<td>HQWL 75-62270</td>
<td>1065</td>
<td>1356</td>
<td>291</td>
<td>Wedging 1356-1365</td>
</tr>
<tr>
<td>8</td>
<td>HQWL 75-62269</td>
<td>1365</td>
<td>1411</td>
<td>46</td>
<td>Lost in hole when cemented</td>
</tr>
<tr>
<td>9</td>
<td>HQWL ?</td>
<td>987</td>
<td>1021</td>
<td>34</td>
<td>Wedging 978-987 started segment B</td>
</tr>
<tr>
<td>10</td>
<td>HQWL 75-63861</td>
<td>1021</td>
<td>1276</td>
<td>255</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>HQWL 85-00766</td>
<td>1276</td>
<td>1469</td>
<td>193</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>NQWL ?</td>
<td>1469</td>
<td>1701</td>
<td>232</td>
<td>Hole reduced</td>
</tr>
<tr>
<td>13</td>
<td>NQWL 75-36173</td>
<td>1701</td>
<td>2008</td>
<td>307</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>NQWL 75-58256</td>
<td>2008</td>
<td>2294</td>
<td>286</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>NQWL 75-35671</td>
<td>2294</td>
<td>2376</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>NQWL 75-58262</td>
<td>2376</td>
<td>2726</td>
<td>350</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>NQWL 75-58265</td>
<td>2726</td>
<td>2949</td>
<td>223</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>NQWL 75-58255</td>
<td>2949</td>
<td>2998</td>
<td>49</td>
<td>Some chert, here down</td>
</tr>
<tr>
<td>19</td>
<td>NQWL 75-41891</td>
<td>2998</td>
<td>3071</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>NQWL 75-58264</td>
<td>3071</td>
<td>3103</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>NQWL 75-58263</td>
<td>3103</td>
<td>3136</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>NQWL 75-58258</td>
<td>3136</td>
<td>3159</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>NQWL 75-58204</td>
<td>3159</td>
<td>3176</td>
<td>17</td>
<td>To terminal depth, in granite &amp; gneiss</td>
</tr>
</tbody>
</table>

For more details, see "Borehole History".
**INCLINATION (By Sperry-Sun single-shot camera):**

<table>
<thead>
<tr>
<th>Depth in Feet</th>
<th>Deviation from Vertical</th>
<th>Bearing</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>106</td>
<td>1/4°</td>
<td>N.40°W.</td>
<td></td>
</tr>
<tr>
<td>224</td>
<td>1/2°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>306</td>
<td>1/4°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>356</td>
<td>3/4°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>406</td>
<td>0°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>506</td>
<td>3/4°</td>
<td>N.45°E.</td>
<td></td>
</tr>
<tr>
<td>556</td>
<td>1/4°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>606</td>
<td>3/4°</td>
<td>N.50°E.</td>
<td></td>
</tr>
<tr>
<td>656</td>
<td>3/4°</td>
<td>N.50°E.</td>
<td></td>
</tr>
<tr>
<td>706</td>
<td>3/4°</td>
<td>N.45°E.</td>
<td></td>
</tr>
<tr>
<td>756</td>
<td>7/8°</td>
<td>Due E.</td>
<td></td>
</tr>
<tr>
<td>806</td>
<td>3/4°</td>
<td>N.45°E.</td>
<td></td>
</tr>
<tr>
<td>856</td>
<td>1°</td>
<td>N.70°E.</td>
<td></td>
</tr>
<tr>
<td>906</td>
<td>1-3/4°</td>
<td>N.80°E.</td>
<td></td>
</tr>
<tr>
<td>956</td>
<td>1-3/4°</td>
<td>N.80°E.</td>
<td></td>
</tr>
<tr>
<td>1006</td>
<td>1-3/4°</td>
<td>N.80°E.</td>
<td></td>
</tr>
<tr>
<td>1056</td>
<td>2-1/2°</td>
<td>Due E.</td>
<td>Wedging 1056-1065</td>
</tr>
<tr>
<td>1076</td>
<td>2-1-1/8°</td>
<td>N.70°E.</td>
<td></td>
</tr>
<tr>
<td>1104</td>
<td>2-3/4°</td>
<td>N.60°E.</td>
<td></td>
</tr>
<tr>
<td>1156</td>
<td>3°</td>
<td>N.75°E.</td>
<td></td>
</tr>
<tr>
<td>1206</td>
<td>3°</td>
<td>N.85°E.</td>
<td></td>
</tr>
<tr>
<td>1256</td>
<td>3°</td>
<td>Due E.</td>
<td></td>
</tr>
<tr>
<td>1306</td>
<td>3-1/4°</td>
<td>S.80°E.</td>
<td></td>
</tr>
<tr>
<td>1356</td>
<td>3-1/2°</td>
<td>S.75°E.</td>
<td>Wedging 1356-1365</td>
</tr>
<tr>
<td>1376</td>
<td>6°</td>
<td>N.70°E.</td>
<td></td>
</tr>
<tr>
<td>1390</td>
<td>6-1/2°</td>
<td>N.70°E.</td>
<td></td>
</tr>
<tr>
<td>991</td>
<td>3/4°</td>
<td>N.55°E.</td>
<td></td>
</tr>
<tr>
<td>1021</td>
<td>1/4°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1076</td>
<td>1/3°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1126</td>
<td>1/2°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1176</td>
<td>1°</td>
<td>N.75°E.</td>
<td></td>
</tr>
<tr>
<td>1226</td>
<td>1-1/4°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1276</td>
<td>1-3/4°</td>
<td>N.60°E.</td>
<td></td>
</tr>
<tr>
<td>1326</td>
<td>1-3/4°</td>
<td>N.75°E.</td>
<td></td>
</tr>
<tr>
<td>1376</td>
<td>2°</td>
<td>Due E.</td>
<td></td>
</tr>
<tr>
<td>1426</td>
<td>1-3/4°</td>
<td>N.80°E.</td>
<td></td>
</tr>
<tr>
<td>1476</td>
<td>2-1/4°</td>
<td>N.80°E.</td>
<td></td>
</tr>
<tr>
<td>1526</td>
<td>2°</td>
<td>Due E.</td>
<td></td>
</tr>
<tr>
<td>1576</td>
<td>2-1-1/4°</td>
<td>N.80°E.</td>
<td></td>
</tr>
<tr>
<td>1626</td>
<td>2°</td>
<td>N.85°E.</td>
<td></td>
</tr>
<tr>
<td>1676</td>
<td>2°</td>
<td>N.80°E.</td>
<td></td>
</tr>
<tr>
<td>1726</td>
<td>2°</td>
<td>N.80°E.</td>
<td></td>
</tr>
<tr>
<td>1776</td>
<td>2°</td>
<td>N.80°E.</td>
<td></td>
</tr>
<tr>
<td>1826</td>
<td>2°</td>
<td>N.85°E.</td>
<td></td>
</tr>
<tr>
<td>1876</td>
<td>2°</td>
<td>N.75°E.</td>
<td></td>
</tr>
<tr>
<td>1926</td>
<td>2°</td>
<td>N.75°E.</td>
<td></td>
</tr>
</tbody>
</table>
1976  2-1/4°  S.85°E.
2026  2°    S.80°E.
2076  2-1/4°  S.80°E.
2126  2°    S.70°E.
2176  2°    S.65°E.
2226  2°    S.60°E.
2276  2°    S.40°E.
2326  2-1/2°  S.50°E.
2376  2-1/4°  S.55°E.
2426  2-1/2°  S.45°E.
2476  2-3/4°  S.30°E.
2526  3°    S.20°E.
2576  3-1/2°  S.15°E.
2626  3-3/4°  S. 5°E.
2676  4-1/4°  S. 5°W.
2726  5-1/2°  S.10°W.
2776  5-3/4°  S. 5°W.
2826  6-1/2°  S.15°W.
2876  7-1/2°  S.25°W.
2926  9°    S.25°W.
2976  10°    S.20°W.
3026  10-3/4°  S.30°W.
3076  11-3/4°  S.30°W.
3126  12°    S.30°W.  T.D. 3176

MUD USED: Twenty-four 50 pound sacks of Quick Gel for a total of 1,200 pounds.

SPECIAL LUBRICANTS:
182 gallons of Torque Trim. Rods copiously greased below 1,500 feet to minimize friction and vibration at greater depths.

BOREHOLE LOGS

BIRDWELL DIVISION OF S.S.C. (Microfiche copies of logs in pocket)
Gamma-Ray Log: 49 to 3,171 feet
Neutron Log: 49 to 3,175 feet
Spontaneous-Potential and Resistivity Logs: 1,468 to 3,176 feet
Caliper Log: 1,343 to 3,174 feet
Bulk Density Log: 1,389 to 3,174 feet
Elastic Properties Log: 1,470 to 3,172 feet

BENDIX FIELD ENGINEERING CORPORATION (Microfiche copies of logs in pocket)
Gamma-Ray Log: 20 to 2,710 feet
Gamma Spectrometer (KUT) Log: 0 to 2,710 feet
Neutron-Neutron Log: 0 to 2,710 feet
Spontaneous-Potential and Resistivity Logs: 1,000 to 2,711 feet
Caliper Log: 0 to 2,710 feet
Magnetic Susceptibility Log: 0 to 2,710 feet
A mud plug at 2,711 feet prevented deeper penetration by Bendix sondes.
BOREHOLE HISTORY

1977

December 5  Moved 44 skid rig 440 to site, 12 hours.

December 7  Mobilization required 3 hours, rigging up required 9 hours.

December 8  Moving rods from DL-1 and DL-3 required 16 hours. Caterpillar was required for 7 hours.

December 12  Caterpillar was required for 5 hours.

December 13  Snow delay occupied 4 hours, rigging up consumed 7 hours, and drilling overburden from 0-10 feet with a 5-5/8" rock bit consumed 3 hours. Ten 50 pound bags of Quick Gel were used, and two loads of water were hauled. Caterpillar required 6 hours.

December 14  Drilling overburden from 10-47 feet consumed 12 hours. Five 50 pound bags of Quick Gel were used and one load of water was hauled.

December 15  On the assumption that ledge had been struck, 48 feet of 4" surface casing were placed in the hole; 5 hours. Seven 94 pound bags of Fondu and three 50 pound bags of Quick Gel were used. Handling rods required 4 hours, including installation of HQWL bit 75-46940.

December 19  When it was clear that large boulders of black slate instead of ledge occurred in the hole, the rig was moved 2 feet, and drilling of overburden from 0-63 feet with a 5-5/8" rock bit consumed 24 hours. Four 50 pound bags of Quick Gel were used, and two loads of water were hauled.

December 20  Drilling overburden to presumed ledge at 76 feet, and continuing for sure into ledge at 84 feet (63-84 feet) required 7 hours with the 5-5/8" rock bit. Placing 85 feet of 4 inch surface casing required 3 hours. Preparing and setting required 9 hours. Nineteen 94 pound bags of Fondu were used. Washing the hole required 2 hours. HQWL bit 75-46940 was installed at 84 feet, and core drilling yielded 100% from 84-86 feet; 1 hour. One load of water was hauled.

December 21  The discovery that 63 feet of solid cement filled the hole called for drilling cement; 19 hours. Handling rods required 2 hours as HQWL bit 75-48329 was applied at 86 feet. Core drilling from 86-96 feet yielded 100% recovery; 3 hours.

December 22  Core drilling from 96-116 feet yielded 100% recovery; 10 hours. An inclination test at 106 feet showed deviation from the vertical of 1/4°. Caterpillar for plowing roads consumed 6 hours. Malfunction of Sperry-Sun camera for the inclination test required the camera be brought from the other site.
1978

January 3 Cleaning snow from rig, starting, and core drilling from 116-130 feet with 100% recovery consumed 12 hours. Four loads of water were hauled. Replacement of master clutch assembly consumed 12 hours.

January 4 Drilling from 130-140 feet yielded 100% recovery; 7 hours. Shaft sheared on hydraulic pump, and so was replaced. This item plus trouble with station pump occupied 17 hours.

January 5 Drilling from 140-230 feet yielded 100% recovery; 20 hours. Sperry-Sun camera twice failed to obtain inclination reading, 4 hours.

January 9 Attempts to reach snowbound drill rig consumed 10 hours.

January 10 Continued snow delays cost 3 hours. Handling rods to install HQWL bit 75-62259 occupied 9 hours. Inclination test at 224 feet (1/2°) required 40 minutes. Equipment repairs consumed 18 hours.

January 11 Drilling from 230-288 feet yielded 100% recovery; 15 hours. Handling rods required 2 hours. Hauling twelve loads of water consumed 2 hours. Twenty-one gallons of Torque Trim were used. Repairs on station pump consumed 5 hours.

January 12 Drilling from 288-348 feet yielded 100% recovery; 22 hours. Servicing drill occupied 1 hour, and an inclination test at 306 feet (1/4°) required 45 minutes. Seven loads of water were hauled, and three gallons of Torque Trim were used.

January 16 Drilling from 348-408 feet yielded 100% recovery; 19-1/4 hours. Handling rods required 3 hours. Two inclination tests at 356 feet (3/4°) and at 406 feet (0°) required 1-1/2 hours. Ten loads of water were hauled and 5 gallons of Torque Trim were used.

January 17 Drilling from 408-508 feet yielded 100% recovery; 22 hours. Inclination tests at 406 feet (1/2°) and 506 feet (3/4°) required 1-3/4 hours. Eleven loads of water were hauled and ten gallons of Torque Trim were used.

January 18 Drilling from 508-608 feet yielded 100% recovery; 22 hours. Inclination tests at 556 feet (1/4°) and at 606 feet (3/4°) required 2 hours. Six loads of water were hauled and four gallons of Torque Trim were used.

January 19 Drilling from 608-696 feet yielded 100% recovery; 21 hours. Handling rods required 2 hours as HQWL bit 75-62266 was applied at 608 feet. An inclination test at 656 feet (3/4°) required 1 hour. Six loads of water were hauled and four gallons of Torque Trim were used.
January 20  Drilling from 696-716 feet yielded 100% recovery; 4 hours. An inclination test at 706 feet (3/4°) required 1 hour. Three loads of water were hauled and one gallon of Torque Trim was used. Servicing drill required 2 hours and draining for weekend required 1 hour.

January 23  A Caterpillar was used for 15 hours in filling old sumps and in digging a new one. Lining the new sump with plastic to prevent seepage and repairing a broken engine required 12 hours. Second shift drilled from 716-756 feet with 100% recovery; 11 hours. An inclination test at 756 feet (7/8°) occupied 1 hour. Five loads of water were hauled, and five gallons of Torque Trim were used.

January 24  Drilling from 756-850 feet yielded 100% recovery; 23 hours. An inclination test at 806 feet (3/4°) consumed 1 hour. Initially the sump was empty, so ten loads of water were hauled. Eight gallons of Torque Trim were used.

January 25  Drilling from 850-925 feet yielded 100% recovery; 22 hours. Inclination tests at 856 feet (1°) and 906 feet (1-3/4°) required 2 hours. Three loads of water were hauled and six gallons of Torque Trim were used.

January 26  Drilling from 925-946 feet yielded 100% recovery; 7 hours. Handling stuck rods required 4 hours. Servicing drill required 1 hour. The worsening storm caused a loss of 10 hours on the second shift.

January 30  Starting after several days absence required 8 hours. Drilling from 946-976 feet yielded 100% recovery; 10 hours. Handling rods required 5 hours, including installation of bit 75-63859 at 955 feet. An inclination test at 955 feet (1-3/4°) consumed 1 hour. Five loads of water were hauled and five gallons of Torque Trim were used. Transmission had to be filled with oil.

January 31  Drilling from 976-1,056 feet yielded 100% recovery; 22 hours. Inclination tests at 1,006 feet (1-3/4°) and 1,056 feet (2-1/2°) required 2 hours. Six loads of water were hauled and three gallons of Torque Trim were used.

February 1  Wedging occupied 15 hours and taking apart hydraulic system occupied 9 hours.

February 6  Continuing hydraulic equipment repairs consumed 8 hours. Wedging consumed 12 hours (Longyear's expense) and 4 hours were spent in travel time to and from Marquette for machining.

February 7  Wedging occupied 21 hours (Longyear's expense) and drilling from 1,056-1,069 feet yielded 69% recovery (because of wedging); 3 hours. Four loads of water were hauled and four gallons of Torque Trim were used.
February 8  Drilling from 1,069-1,111 feet yielded 100% recovery; 16 hours. Handling rods required 5 hours. Inclination tests at 1,076 feet (2-1/8") and 1,104 feet (2-3/4") required 2 hours. Equipment repair required 1 hour. Four loads of water were hauled and four gallons of Torque Trim were used.

February 9  Drilling from 1,111-1,182 feet yielded 100% recovery; 23 hours. An inclination test at 1,156 feet (3") consumed 1 hour. Three loads of water were hauled and three gallons of Torque Trim were used.

February 10 Drilling from 1,182-1,260 feet yielded 100% recovery; 22 hours. Inclination tests at 1,206 feet (3") and 1,256 feet (3") required 2 hours. Four loads of water were hauled and four gallons of Torque Trim were used.

February 11 Drilling from 1,260-1,314 feet yielded 100% recovery; 14 hours. An inclination test at 1,306 feet (3-1/4") required 1 hour. Servicing the entire rig consumed 1 hour. Draining to prevent freezing during the coming weekend consumed 1 hour.

February 13 Starting required 3 hours. Drilling from 1,314-1,356 feet yielded 100% recovery; 18 hours. Determining inclination at 1,356 feet (3-1/2") required 1 hour. Under the weather conditions existing hauling two loads of water required 2 hours. Two gallons of Torque Trim were used.

February 14 Repairs occupied 8 hours and wedging occupied 16 hours. Plugged bit would not let water flow.

February 15 Wedging occupied 18 hours. Equipment repair required 3 hours, as drill motor was not operating properly. Two loads of water were hauled. The BX plug HQWL was reamed from 1,356-1,365 feet with no core recovery.

February 16 Wedging occupied 4 hours. Drilling from 1,365-1,406 feet yielded 100% recovery; 16 hours. Wire line broke. Handling rods required 3 hours. An inclination test at 1390 feet (6-1/2") indicated that the wedge must have been inserted backwards and that the hole now deviated almost twice as much as before wedging. Three loads of water were hauled and three gallons of Torque Trim were used.

February 17 Drilling from 1,406-1,411 feet yielded 100% recovery; 2 hours. The decision was approved to cement back to 1,356 feet, above the bad wedge. Further inclination checks occupied 6 hours. Handling rods required 1 hour. Hauling water required 1 hour. Preparing and cementing hole consumed 14 hours. Six 94 pound bags of Portland cement were used.

February 20– March 9 It was discovered that the rods apparently had not been pulled high enough during the cementing and the rods were cemented in the hole from 1,244 up to 1,033 feet. It was agreed that Longyear would at its own expense remedy the situation and that we should start paying again when drilling reached 1,411 feet. All the events of
Longyear's corrective efforts will not be chronicled here, except to state that they included washing, chopping, cutting, drilling, fishing, hammering, and pulling. Unfortunately such attempts failed, so that on March 10 wedging between 978-987 feet was successful in initiating the drilling of sequence B, with overlap of footage from 987-1,411 feet. The 1,411 feet depth was reached on March 20, one month after the discovery of the cemented rods. Inasmuch as core was obtained after March 10, that segment will be recorded here.

March 10
Wedging at the interval 978-987 feet occupied 14 hours. Drilling from 987-1,011 feet with 100% recovery consumed 8 hours. An inclination test at 991 feet (3/4°) required 1 hour. Draining to prevent freezing during the weekend occupied 1 hour.

March 13
Drilling from 1,011-1,068 feet yielded 100% recovery; 18 hours. Handling rods required 3 hours to install HQWL bit 75-63861 at 1,021 feet. An inclination test at 1,021 feet (1/4°) required 1 hour. Two loads of water were hauled, and two gallons of Torque Trim were used.

March 14
Drilling from 1,068-1,152 feet yielded 100% recovery; 22 hours. Core lifters lost their grip, but all core was recovered later. Inclination tests at 1,076 feet (1/3°) and 1,126 feet (1/2°) consumed 2 hours. Two loads of water were hauled and two gallons of Torque Trim were used.

March 15
Drilling from 1,152-1,260 feet yielded 100% recovery; 15 hours. An inclination test at 1,176 feet (1°) required 1 hour. Draining to prevent freezing consumed 1 hour. Two loads of water were hauled.

March 16
Drilling from 1,206-1,276 feet yielded 100% recovery; 21 hours. Handling rods required 2 hours. Inclination tests at 1,226 feet (1-1/4°) and 1,276 feet (1-3/4°) consumed 2 hours. Two loads of water were hauled and two gallons of Torque Trim were used.

March 17
Drilling from 1,276-1,326 feet yielded 100% recovery; 13 hours. Handling rods required 7 hours, including installing HQWL bit 85-00766 at 1,276 feet. Water delay lost 3 hours. Fixing wire line consumed 1 hour.

March 18
Drilling from 1,326-1,384 feet yielded 100% recovery; 17 hours. Inclination tests at 1,326 feet (1-3/4°) and 1,376 feet (2°) occupied 2 hours. Servicing drill consumed 2 hours and draining to prevent freezing occupied 1 hour. Two loads of water were hauled and two gallons of Torque Trim were used.

March 20
Starting consumed 1 hour. Drilling from 1,384-1,413 feet yielded 100% recovery; 11 hours. An attempt to adjust the diesel engine so that it would run at low speed required 4 hours. Two loads of water were hauled. Footage charge to client resumed at 1,411 feet.
March 21  Drilling from 1,413-1,464 feet yielded 100% recovery; 15 hours. An inclination test at 1,426 feet (1-3/4°) required 1 hour. Two loads of water were hauled; 1 hour. Installing new fuel pump on drill engine and fixing water swivel required 7 hours.

March 22  Drilling from 1,464-1,469 feet yielded 100% recovery; 2 hours. Decision was made to reduce hole diameter and to use NQWL bit. Unfortunately, actual bit number is not on record. Handling rods required 6 hours. Repairing lights consumed 1 hour. Starting to place NW casing required 11 hours.

March 23  Finished placing 1,470 feet of NW casing; 2 hours. Handling rods required 6 hours. Later handling rods required 4 hours when flat rod was discovered at 1,270 feet. Drilling from 1,469-1,506 feet yielded 100% recovery; 11 hours. An inclination test at 1,476 feet (2-1/4°) required 1 hour.

March 24  Drilling from 1,506-1,540 feet yielded 100% recovery; 12 hours. Handling and greasing rods required 11 hours. An inclination test at 1,526 feet (2°) required 1 hour.

March 25  Drilling from 1,540-1,541 feet yielded 100% recovery; 1 hour. Servicing drill consumed 1 hour. Draining to prevent freezing occupied 1 hour.

March 27  Starting consumed 1 hour. Drilling from 1,541-1,586 feet yielded 100% recovery; 13 hours. Greasing rods occupied 7 hours. Repairing equipment occupied 2 hours. An inclination test at 1,576 feet (2-1/4°) took 1 hour.

March 28  Drilling from 1,586-1,646 feet yielded 100% recovery; 19 hours. An inclination test at 1,626 feet (2°) consumed 1 hour. Pump repairs consumed 4 hours.

March 29  Drilling from 1,646-1,701 feet yielded 89% recovery in badly sheared rock; 17 hours. Handling rods required 6 hours for changing the bit, again unfortunately not specified as to serial number. Determining inclination at 1,676 feet (2°) took 1 hour. Two loads of water were hauled.

March 30  Drilling from 1,701-1,744 feet yielded 100% recovery; 18 hours. A bit change required 5 hours of handling rods as NQWL bit 75-36173 was applied. An inclination test at 1,726 feet (2-1/3°) occupied 1 hour.

March 31  Drilling from 1,744-1,819 feet yielded 100% recovery; 23 hours. An inclination test at 1,776 feet (2°) required 1 hour.

April 1  Drilling from 1,819-1,860 feet yielded 100% recovery; 13 hours. An inclination test at 1,826 feet (2°) took 1 hour. Servicing the drill and draining to prevent freezing occupied 2 hours.
April 3 Drilling from 1,860-1,916 feet yielded 100% recovery; 16 hours. An inclination test at 1,876 feet (2°) required 1 hour. Repairing wire line took 3 hours. Pump repairs required 4 hours. Four loads of water were hauled.

April 4 Drilling from 1,916-1,986 feet yielded 100% recovery; 20 hours. Inclination tests at 1,926 feet (2°) and 1,976 feet (2-1/4°) took 2 hours. Hauling four loads of water took 2 hours.

April 5 Drilling from 1,986-2,041 feet yielded 100% recovery; 17 hours. Handling rods to change to NQWL bit 75-58256 at 2,008 feet required 6 hours. An inclination test at 2,026 feet (2°) required 1 hour.

April 6 Drilling from 2,041-2,114 feet yielded 100% recovery; 20 hours. An inclination test at 2,076 feet (2-1/4°) required 1 hour. Repairs required 3 hours. Three loads of water were hauled.

April 7 Drilling from 2,114-2,179 feet yielded 100% recovery; 22 hours. Inclination tests at 2,126 feet (2°) and 2,176 feet (2°) required 2 hours.

April 8 A burned bearing required taking off the head to change and grease the shaft bearing. Servicing the drill required 3 hours. Hauling one load of water required 1 hour. Draining prevented freezing.

April 10 Starting required 1 hour. Drilling from 2,179-2,232 feet yielded 100% recovery; 16 hours. An inclination test at 2,226 feet (2°) required 1 hour. Repairing pinions and shaft bearing required 4 hours. Hauling two loads of water took 2 hours.

April 11 Drilling from 2,232-2,294 feet yielded 100% recovery; 18 hours. Handling rods required 4 hours to install NQWL bit 75-35671 at 2,294 feet. An inclination test at 2,276 feet (2°) required 1 hour. Hauling two loads of water required 2 hours. Ten gallons of Torque Trim were used.

April 12 Drilling from 2,294-2,354 feet yielded 100% recovery; 19 hours. Handling rods required 4 hours. An inclination test did not work properly, 1 hour. Three loads of water were hauled and six gallons of Torque Trim were used.

April 13 Drilling from 2,354-2,386 feet yielded 100% recovery; 12 hours. Handling rods required 9 hours. NQWL bit 75-58262 was installed at 2,376 feet. Inclination tests at 2,326 feet (2-1/2°) and 2,376 feet (2-1/4°) required 2 hours. Four loads of water were hauled.

April 14 Drilling from 2,386-2,472 feet yielded 100% recovery; 26 hours. An inclination test at 2,426 feet (2-1/2°) took 1 hour. An oil change took 1 hour. Five loads of water were hauled. Draining prevented freezing.
April 17  Starting occupied 2 hours. Drilling from 2,472-2,536 feet yielded
100% recovery; 20 hours. Inclination tests at 2,476 feet (2-3/4°)
and 2,526 feet (3°) took 2 hours. Six loads of water were hauled
and four gallons of Torque Trim were used.

April 18  Drilling from 2,536-2,616 feet yielded 100% recovery; 22 hours. An
inclination test at 2,576 feet (3-1/2°) and another aborted attempt
took 2 hours. Two loads of water were hauled.

April 19  Drilling from 2,616-2,683 feet yielded 100% recovery; 21 hours.
Inclination tests at 2,626 feet (3-3/4°) and 2,676 feet (4-1/4°)
took 2 hours. Equipment repairs consumed 1 hour. Three loads of
water were hauled. Also fixed wire line.

April 20  Drilling from 2,683-2,726 feet yielded 100% recovery; 13 hours.
Handling rods required 6 hours. Had to braze nut on end of
hoisting cable, 2 hours. Draining to prevent freezing occupied 1
hour. Three loads of water were hauled and five gallons of Torque
Trim were used.

April 21  Drilling from 2,726-2,776 feet yielded 100% recovery; 17 hours.
Handling rods required 5 hours to install NQWL bit 75-58265 at
2,726 feet. Inclination tests at 2,726 feet (5-1/2°) and 2,776
feet (5-3/4°) took 2 hours. Three loads of water were hauled.

April 22  Drilling from 2,776-2,806 feet yielded 100% recovery; 10 hours.
The chain on the wire line drum came off and cracked the case of
the transmission, requiring 1 hour of repairs. Three loads of
water were hauled.

April 23  Continuing repairs required 4 hours, plus trip to Pembine,
Wisconsin, to get new transmission.

April 24  Replacing transmission took 12 hours. Drilling from 2,806-2,829
feet yielded 100% recovery; 10 hours. An inclination test at 2,826
feet (6-1/2°) took 1 hour.

April 25  Drilling from 2,829-2,900 feet yielded 100% recovery; 22 hours. An
inclination test at 2,876 feet (7-1/2°) took 1-1/2 hours. Wire
line broke. Three loads of water were hauled.

April 26  Drilling from 2,900-2,949 feet yielded 100% recovery; 15 hours.
Handling rods required 7 hours to install NQWL bit 78-58255 at
2,949 feet. An inclination test at 2,926 feet (9°) took 1-1/2
hours. Four loads of water were hauled, and five gallons of Torque
Trim were used.

April 27  Drilling from 2,949-2,998 feet yielded 100% recovery; 15 hours.
Handling rods required 2 hours. An inclination test at 2,976 feet
(10°) required 1-1/2 hours. Five loads of water were hauled.
April 28  Handling rods to change to NQWL bit 75-41891 at 2,998 feet required 10 hours. Drilling from 2,998-3,002 feet yielded 100% recovery; 1 hour. Equipment repair required 12 hours when bolts broke off hydraulic chuck. Replacements were obtained at Crandon, Wisconsin. Draining for weekend consumed 2 hours. One load of water was hauled and two gallons of Torque Trim were used.

May 1  Starting and changing oil required 2 hours. Drilling from 3,002-3,036 feet yielded 100% recovery; 12 hours. An inclination test at 3,026 feet (10-3/4°) required 1 hour and 40 minutes. Five loads of water were hauled and five gallons of Torque Trim were used.

May 2  Drilling from 3,036-3,081 feet yielded 100% recovery; 15 hours. Handling rods required 9 hours to change to NQWL bit 75-58264 at 3,071 feet. Four loads of water were hauled and five gallons of Torque Trim were used.

May 3  Drilling from 2,081-3,103 feet yielded 100% recovery; 14 hours. An inclination test at 3,076 feet (11-3/4°) took 1-3/4 hours. Tightness of the hole required 4 hours of attention with an extra five gallons of Torque Trim in addition to the three gallons normally used. Four loads of water were hauled.

May 4  Handling rods required 10 hours to install NQWL bit 75-58263 at 3,103 feet. Drilling from 3,103-3,136 feet yielded 100% recovery; 9 hours. An inclination test at 3,126 feet (12°) occupied 1-3/4 hours. Spent 3 hours in cutting a larger hole in top of boom to accommodate traveling block with double line. Seven loads of water were hauled.

May 5  Handling rods required 16 hours for installing NQWL bit 75-58258 at 3,136 feet and NQWL bit 75-58204 at 3,159 feet. Drilling from 3,136-3,159 feet yielded 100% recovery; 8 hours. Four loads of water were hauled.

May 6  Drilling from 3,159-3,176 feet (terminal depth) yielded 100% recovery; 7 hours. Wire line broke at 3,166 feet requiring that rods be pulled; 17 hours. Five loads of water were hauled and 29 gallons of Torque Trim were used.

May 7  Completed pulling rods in 4 hours. Casing was cut and pulled for 9 hours.

May 8  Pulled more casing and broke it at the surface into segments 20 feet long; 12 hours.

May 9  Pulling and cutting casing occupied 2 hours. Hauled one load of water. Stood by during Birdwell geophysical logging of hole; 14 hours.
May 10  Pulling more casing occupied 24 hours. Some 465 feet of NW casing were left in the hole, from 1,004-1,469 feet, but 1,005 feet were safely removed.

May 11  Rigging down occupied 6 hours.

Considering the great depth of this hole, it was relatively straight. Core recovery was 100% with the exception of footage where wedges were installed and footage where particularly fractured and faulted ground was penetrated. The straightness of the hole correlates with less conspicuous slaty cleavage than at DL-1, DL-3, and DL-7, with the use of stiffer core barrels 10 feet in length rather than 20 feet in length, with allowing the rods to "float" at greater depths without application of additional pressure, with the use of approximately one gallon of Torque Trim per load of water, and with greasing rods at deeper levels. Frequent changing of dull bits is also thought to have maintained a straighter hole. The use of HQWL tools to a depth of 1,469 feet probably contributed to the hole's relative straightness.

ADDITIONAL GEOLOGIC DATA NOW AVAILABLE

On-site diamond drill logs by Jack W. Avery and David W. Snider, my geologic interpretation including a cross section of gross structure, and my recommendations for further exploration are now available from Greg Wilson, Michigan Geological Survey Division of the D.N.R., Stevens T. Mason Building, Box 30028, Lansing, Michigan 48909; telephone (517)373-1256.
DIAMOND-DRILLING FOR GEOLOGIC INFORMATION
IN THE MIDDLE PRECAMBRIAN BASINS
IN THE WESTERN PORTION OF NORTHERN MICHIGAN

James Trow
Geologist-in-Charge
for
Geological Survey Division
Michigan Department of Natural Resources

1978

PREPARED FOR
U.S. DEPARTMENT OF ENERGY
AND
BENDIX FIELD ENGINEERING CORPORATION
GRAND JUNCTION OFFICE
PROJECT NO. 20-77-2132
CONTENTS

Introduction ................................................. Page 49
Location ...................................................... 49
Site selection ................................................ 49
Geology ......................................................... 49
Drilling and logging ......................................... 51
Principal firms and agencies ................................. 51
Borehole data .................................................. 52
Location ......................................................... 52
Elevation ......................................................... 52
Total depth .................................................... 52
Dates .......................................................... 52
Casing .......................................................... 53
Bit size ........................................................ 53
Bits used ....................................................... 53
Inclination ...................................................... 53
Mud used ......................................................... 53
Special lubricant .............................................. 53
Borehole logs ................................................. 53
Birdwell Division of S.S.C .................................... 53
Bendix Field Engineering Corporation ..................... 53
Borehole history .............................................. 53
Additional geologic data now available ..................... 59

FIGURES

Figure 1. Location map .................................... 50

BOREHOLE LOGS

Birdwell Division of S.S.C.
Gamma-ray and neutron log ................................ In pocket
Spontaneous-potential and resistivity log ............... In pocket
Caliper and bulk density log ............................... In pocket

Bendix Field Engineering Corporation
Gamma-ray, spontaneous-potential, and resistivity log In pocket
Gamma spectrometer (KUT) log ............................ In pocket
Neutron-neutron log ........................................ In pocket
Caliper and magnetic susceptibility log ................. In pocket
INTRODUCTION

This report presents engineering details, history, and a very brief preliminary geologic summary of DL-5 in the Clark Creek Basin. More geologic information will follow in a final report on all holes of the project, in which thin sections and chemical analyses will be reported. More detailed geological and geophysical information, including on-site well logs, is immediately available from Greg Wilson, Michigan Geological Survey Division of the D.N.R., Stevens T. Mason Building, Box 30028, Lansing, Michigan 48909, telephone (517)373-1256.

LOCATION (lat. 46°45’30"N., long. 87°50’28"W.)

Drill location 5 is on a partly forested sandy plain in the NW1/4SE1/4 section 16, T. 49 N., R. 27 W., Marquette County, Michigan, in an area north of the Dead River Basin, at a point approximately 300 feet north of a monument at an altitude of 1,429.83 feet, approximately 415 feet east and 367 feet south of the center of the section. This site is reached by driving northwest from U.S. Highway 41 on County Highway 510 for approximately thirteen miles, and then on a dirt road one mile generally west, to turn south onto a trail at the drill site. See Figure 1.

SITE SELECTION

The site was selected by the Michigan Geological Survey because of the intersection of two gravity anomalies thought to correspond to the intersection of two grabens, and hence the location of a maximum stratigraphic section, according to gravity maps by John Klasner of the U.S. Geological Survey. It was considered that the fullest sequence of Precambrian X metasediments could be sampled here, rather than at any other location in the Clark Creek Basin.

GEOLOGY

Pleistocene drift extends to a depth of at least 320 feet. Precambrian X Michigamme Formation below this consists of (a) green, slightly oxidized, non-pyritic argillite and graywacke from 339-475 feet, (b) light to dark gray pyritic argillite from 475-660 feet, (c) light gray to white chert and carbonate with algal stromatolites alternate with argillite from 660-702 feet, (d) green volcanic agglomerate from 702-714 feet has a basal conglomerate above a disconformity, (e) light gray graywacke and argillite extend from 714-750 feet, (f) gray to green argillite (upper portion chloritic) extends from 750-866 feet, (g) gray argillite alternates with graywacke and quartzite from 866-884 feet, (h) gray massive quartzite extends from 884-996 feet, and (i) gray-green quartzite grades downward into a phosphatic black pebble conglomerate in the interval 996-997 feet. These Precambrian X strata possess rare slaty cleavage which dips from 20°-40°SW, almost parallel to the bedding which dips from 15°-45°SW. A profound unconformity occurs at 997 feet, at the base of the above sequence.
Figure 1. Location map of DL-1, DL-3, DL-4, DL-5 and DL-7
Precambrian W sheared light green porphyritic metarhyolite tuff with 72-77 ppm uranium occurs at 997-1,059 feet. Green metabasalt with massive sulfides including pyrrhotite at 1,059-1,148 feet contains significant traces of gold (20-50 ppb) and copper (130-2,010 ppm) in strata-bound configuration. These Precambrian W strata appear to dip 50°NE.

Chalcopyrite also occurs in the Precambrian X conglomerate between 713-714 feet, and in a thin conformable breccia zone at 792 feet.

A precambrian Y diabase dike from 523-602 feet apparently dips from 45°-60°SW.

DRILLING AND LOGGING

HQWL bits used in the vertical drilling were large enough to permit inclination tests at every 50 or 100 feet by means of a Sperry-Sun single-shot camera. These tests showed that the maximum deviation of the hole from the vertical was 3°. Core recovery was almost 100%.

According to the drillers, the depth of the hole is 1,148 feet, and this figure almost corresponds to the Birdwell depth of 1,149 obtained during geophysical logging. To obtain true depth, multiply Birdwell depth by the factor 0.9991.

PRINCIPAL FIRMS AND AGENCIES

FUNDED BY:
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado 81501

CONTRACTOR:
Bendix Field Engineering Corporation
Grand Junction Operations
Grand Junction, Colorado 81501

SUBCONTRACTOR:
Geological Survey Division
Michigan Department of Natural Resources
Stevens T. Mason Building, Box 30028
Lansing, Michigan 48909

DRILLING SUBCONTRACTOR:
Longyear Company
P. O. Box 186
Keewatin, Minnesota 55753

GEOPHYSICAL LOGGING SUBCONTRACTOR:
Birdwell Division of S.S.C.
P. O. Box 256
Mt. Pleasant, Michigan 48858
LOCATION:
NW1/4SE1/4 section 16, T. 49 N., R. 27 W., Marquette County, Michigan; 415 feet east and 67 feet south of the center of section 16.

ELEVATION:
Monument at 1,429.83 feet essentially the same as the collar of the hole.

TOTAL DEPTH:
1,148 feet below monument (on almost straight course with maximum deviation of 3° from the vertical in deepest 60 feet), 282 feet above sea level.

DATES:

CASING:
4-inch surface casing set at 339 feet.

BIT SIZE:
5-5/8 inch rock bits used from surface to 339 feet. HQWL bits used from 339-1,148 feet (terminal depth).

BITS USED:

<table>
<thead>
<tr>
<th>No.</th>
<th>Size</th>
<th>Depth In</th>
<th>Depth Out</th>
<th>Total Feet</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5-5/8 inch rock bit Surface</td>
<td></td>
<td>273</td>
<td>273</td>
<td>Sandy overburden</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bouldery overburden</td>
</tr>
<tr>
<td>2</td>
<td>Four 5-5/8 inch rock</td>
<td>273</td>
<td></td>
<td></td>
<td>Bouldery overburden</td>
</tr>
<tr>
<td>3</td>
<td>bits chewed through</td>
<td></td>
<td></td>
<td></td>
<td>Bouldery overburden</td>
</tr>
<tr>
<td>4</td>
<td>lower bouldery overburden</td>
<td></td>
<td></td>
<td></td>
<td>Bouldery overburden</td>
</tr>
<tr>
<td>5</td>
<td>burden from 273-339 feet.</td>
<td></td>
<td>339</td>
<td></td>
<td>Bouldery overburden</td>
</tr>
<tr>
<td></td>
<td>Changed at unspecified depths.</td>
<td>339</td>
<td>346</td>
<td>66/4</td>
<td>After initial drilling, cement filled casing</td>
</tr>
<tr>
<td></td>
<td>HQWL 75-46933</td>
<td>179</td>
<td>366</td>
<td>195</td>
<td>to 179 foot level.</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bit burned, crown left in hole.</td>
</tr>
<tr>
<td>7</td>
<td>HQWL 75-62267</td>
<td>366</td>
<td>386</td>
<td>20</td>
<td>Quartzite</td>
</tr>
<tr>
<td>8</td>
<td>HQWL 75-63856</td>
<td>386</td>
<td>536</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>HQWL 75-62260</td>
<td>536</td>
<td>661</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>HQWL 75-62265</td>
<td>661</td>
<td>823</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>HQWL 75-63860</td>
<td>823</td>
<td>913</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>HQWL 75-63857</td>
<td>913</td>
<td>939</td>
<td>26</td>
<td></td>
</tr>
</tbody>
</table>
INCLINATION (By Sperry-Sun single-shot camera):

<table>
<thead>
<tr>
<th>Depth in Feet</th>
<th>Deviation from Vertical</th>
<th>Bearing</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>366</td>
<td>1/16°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>416</td>
<td>3/4°</td>
<td></td>
<td>Due N.</td>
</tr>
<tr>
<td>466</td>
<td>3/4°</td>
<td></td>
<td>N.10°E.</td>
</tr>
<tr>
<td>516</td>
<td>1/2°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>596</td>
<td>0°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>646</td>
<td>1/32°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>746</td>
<td>1°</td>
<td></td>
<td>Due S.</td>
</tr>
<tr>
<td>796</td>
<td>3/4°</td>
<td></td>
<td>Due S.</td>
</tr>
<tr>
<td>846</td>
<td>1°</td>
<td></td>
<td>Due S.</td>
</tr>
<tr>
<td>896</td>
<td>1-1/2°</td>
<td></td>
<td>S.25°E.</td>
</tr>
<tr>
<td>946</td>
<td>1°</td>
<td></td>
<td>Due S.</td>
</tr>
<tr>
<td>996</td>
<td>1-1/2°</td>
<td></td>
<td>Due S.</td>
</tr>
<tr>
<td>1086</td>
<td>3°</td>
<td></td>
<td>S.15°W.</td>
</tr>
<tr>
<td>1148</td>
<td>3°</td>
<td></td>
<td>S.10°W.</td>
</tr>
</tbody>
</table>

MUD USED: Forty-three 50 pound sacks of Quick Gel for a total of 2150 pounds.

SPECIAL LUBRICANT: 191 gallons of Torque Trim were used.

BOREHOLE LOGS

BIRDWELL DIVISION OF S.S.C. (Microfiche copies of logs in pocket)
Gamma-Ray and Neutron Log: 0 to 1,148 feet
Spontaneous-Potential and Resistivity Log: 270 to 1,148 feet
Caliper and Bulk Density Log: 240 to 1,146 feet.

BENDIX FIELD ENGINEERING CORPORATION (Microfiche copies of logs in pocket)
Gamma-Ray, Spontaneous-Potential, & Resistivity Log: 0 to 1,148 feet.
Gamma Spectrometer (KUT) Log: 0 to 1,145 feet.
Neutron-Neutron Log: 0 to 1,144 feet.
Caliper and Magnetic Susceptibility Log: 0 to 1,148 feet

BOREHOLE HISTORY

1977
December 1 Moved 44 skid K-2 rig to site; 5 hours. Repairs to water truck required 5 hours.

December 5 Rigging up required 12 hours.
December 6  Continued rigging up required 12 hours. Two loads of water were hauled and five 50 pound bags of Quick Gel were mixed.

December 7  Snow storm caused total of 14 hours delay. Plowing by Caterpillar required 8 hours.

December 8  Snow delay consumed 10 hours.

December 13  Moved the rest of the rods from DL-1 and DL-3; 8 hours. Snow delay consumed 8 hours. Hauled one load of water. Trouble with station pump consumed 4 hours.

December 14  Drilled 69 feet of overburden with 5-5/8 inch rock bit; 28 hours. Hauled three loads of water and used fourteen 50 pound bags of Quick Gel.

December 15  Drilled from 69-203 feet of overburden; 28 hours. Hauled two loads of water and used seven 50 pounds bags of Quick Gel. Caterpillar required for 3 hours to clear access road.

December 19  Drilled from 203-298 feet of overburden; 22 hours. Hauled one load of water and used two 50 pounds bags of Quick Gel. Pulling rods to change to diamond drilling bit required 2 hours.

December 20  Suspected ledge was only large boulders so drilling of overburden with rock bit continued from 298-323 feet; 18 hours. Handling rods for bit changes required 6 hours. One load of water was hauled and four 50 pound bags of Quick Gel were used.

December 21  Drilled with rock bit from 323-339 feet; 16 hours. One load of water was hauled and six 50 pound bags of Quick Gel were used. Lowering 4 inch surface casing occupied 4 hours.

December 22  Completed placing total of 340 feet of 4 inch casing; 4 hours. Forty-five 94 pound bags of Portland cement and five 50 pound bags of Quick Gel were used. One load of water was hauled. Washing out hole with clean mud occupied 6 hours. Handling rods, including installation of HQWL bit 75-46933 occupied 6 hours. Core drilling from 339-346 feet yielded 100% core recovery; 2 hours. The mobile 44 truck rig 2108 was returned to Crandon, Wisconsin, 6 hours.

1978

January 3  Re-entering hole occupied 22 hours. Eight loads of water were hauled. Washing hole required 2 hours. Plowing roads with Caterpillar required 6 hours.

January 4  Inasmuch as cement filled casing from 179 feet to the bottom, 20 hours were spent in drilling cement. Three loads of water were hauled. Station pump repairs consumed 4 hours.

January 5  Drilling cement occupied 12 hours. Four loads of water were hauled.
January 9  A snow storm caused 10 hours' delay in futile attempts to reach drill site.

January 10  Snow delay caused 4 hours' loss. Caterpillar plowing required 4 hours. Start-up difficulties consumed 5 hours. Drilling cement occupied 3 hours. Two loads of water were hauled. A stuck water truck and other weather-related difficulties consumed 12 hours.

January 11  Drilling cement required 5 hours. Handling rods consumed 5 hours. Drilling ledge from 346-366 feet yielded 100% core recovery; 8 hours. Changing bits to HQWL 75-62267 at 366 feet consumed 3 hours. An inclination test at 366 feet (1/16° deviation from the vertical) consumed 3/4 hour. Hauling nine loads of water consumed 2 hours. To reduce friction in hole ten gallons of Torque Trim were used.

January 12  Drilling from 366-376 feet yielded 100% recovery; 6 hours. Handling rods required 6 hours in an attempt to remove burned bit. Servicing drill occupied 3 hours. Fishing attempt required 3 hours. Delays consumed 1 hour. Crown of bit was left in hole. Six loads of water were hauled and fifteen gallons of Torque Trim were used.

January 16  Start-up consumed 2 hours. Handling rods consumed 3 hours. Drilling out burned bit crown consumed 5 hours. Hauling water consumed 2 hours. Plowing by Caterpillar consumed 11 hours.

January 17  Caterpillar plowing consumed 6 hours. Start-up consumed 1 hour. Drilling through burned bit consumed 3 hours. Handling rods consumed 4 hours. Drilling from 376-378 feet yielded 100% recovery; 2 hours. Hauling five loads of water consumed 2 hours. Five gallons of Torque Trim were used.

January 18  Starting occupied 2 hours. Drilling from 378-386 feet yielded 100% recovery; 3 hours. Handling rods to change to HQWL 75-63856 bit consumed 6 hours. Hauling six loads of water consumed 1 hour. Five gallons of Torque Trim were used.

January 19  Start-up required 2 hours. Drilling from 386-387 feet yielded 100% recovery; 1 hour. Handling rods required 3 hours and repair of pump and feed valve required 6 hours. Two loads of water were hauled.

January 23  Start-up required 2 hours and pump repairs required 6 hours. A stuck drill bit required 2 hours and hauling eight loads of water consumed 3 hours. Drilling from 387-403 feet yielded 100% recovery; 8 hours. Handling rods required 3 hours.

January 24  Digging another sump required 2 hours. Pump repairs required 2 hours as a pump liner was changed. Drilling from 403-456 feet yielded 100% recovery; 18 hours. Surveying the hole at 416 feet (3/4° deviation from the vertical) occupied 1/2 hour.
Caterpillar plowing to open roads between two rigs occupied 6 hours. Six loads of water were hauled and four gallons of Torque Trim were used.

January 25 Changing the transmission in the drill required 16 hours and installing new engine in station pump required 4 hours. Drilling from 456-466 feet yielded 100% recovery; 3 hours. An inclination measurement at 466 feet (3/4° deviation from the vertical) occupied 50 minutes. Three loads of water were hauled.

January 26 Cleaning drill site and equipment of snow occupied 8 hours. Equipment repair required 4 hours. Snow delays consumed 2 hours as the last six miles of road were blocked.

January 30 Start-up required 2 hours. Drilling from 466-496 feet yielded 100% recovery; 12 hours. Servicing rig consumed 1 hour. Pump problem and going for another pump required 7 hours. Drill repair consumed 2 hours. Four loads of water were hauled and the water truck was stuck for 1 hour. Four gallons of Torque Trim were used.

January 31 Drilling from 496-536 feet yielded 100% recovery in 16 hours. Handling rods required 3 hours as bit HQW 75-62260 was applied at 536 feet. An inclination test at 516 feet yielded 3/4° deviation from the vertical; 1 hour. Ten loads of water were hauled and the water truck was stuck for 2 hours. A fuel filter change required 1 hour and repairing the water swivel required 1 hour. Eighteen gallons of Torque Trim were used.

February 1 Drilling from 536-600 feet yielded 100% recovery; 20 hours. Three hours were consumed in two attempts for inclination tests, but malfunction of the Sperry-Sun camera precluded determining the deviation of the hole. Repairs to the station pump required 1 hour. Eight loads of water were hauled and eight gallons of Torque Trim were used.

February 2 Drilling from 600-646 feet yielded 100% recovery; 18 hours. Two more futile attempts were made to determine inclination, but again the camera was not operating properly; 4 hours. Camera was obtained from other rig. Deviation at 600 feet was 1/16° and deviation at 646 feet was 1/32°. Changing supply pump occupied 2 hours. Six loads of water were hauled and six gallons of Torque Trim were used.

February 6 Start-up occupied 3 hours. Pump difficulties occupied 9 hours. Drilling from 646-661 feet yielded 100% recovery; 10 hours. Handling rods required 2 hours. Caterpillar plowing consumed 8 hours. Ten loads of water were hauled and ten gallons of Torque Trim were used.

February 7 Drilling from 661-687 feet yielded 100% recovery; 16 hours. Handling rods required 2 hours in applying HQW L bit 75-62265 at
February 8  Drilling from 687-746 feet yielded 100% recovery; 18 hours. Handling rods required 4 hours. Water delays involved 1 hour. Repairing lights consumed 1 hour. Ten loads of water were hauled and fifteen gallons of Torque Trim were used.

February 9  Drilling from 746-750 feet yielded 100% recovery; 2 hours. Replacing transmission occupied 18 hours; waiting for its delivery consumed 3 hours. An abortive attempt to determine hole inclination occupied 1 hour. Two loads of water were hauled and two gallons of Torque Trim were used.

February 10 Drilling from 750-813 feet yielded 95% recovery; 20 hours. Inclination tests at 746 feet (1° from vertical) and 796 feet (3/4° from vertical) required 2 hours. Pump repairs consumed 1 hour. Nine loads of water were hauled and five gallons of Torque Trim were used.

February 11 Drilling from 813-823 feet yielded 100% recovery; 6 hours. Handling rods required 4 hours. Servicing drill consumed 2 hours. Water delay consumed 2 hours. Draining consumed 1 hour. Three loads of water were hauled and six gallons of Torque Trim were used.

February 13 Start-up required 3 hours. Drilling from 823-856 feet yielded 100% recovery; 10 hours. Handling rods consumed 3 hours to change to HQWL bit 75-63860 at 823 feet. An inclination test at 846 feet showed 1° deviation from the vertical; 1 hour. Pump repairs consumed 2 hours. Repairs to wire-line drum bearing required 3 hours. Water delays consumed 2 hours. Six loads of water were hauled and six gallons of Torque Trim were used.

February 14 Start-up required 1 hour. Drilling from 856-910 feet yielded 100% recovery; 16 hours. An inclination test at 896 feet showed 1-1/2° deviation from the vertical; 1 hour. Repairs required 6 hours. Ten loads of water were hauled and ten gallons of Torque Trim were used.

February 15 Drilling from 910-932 feet yielded 100% recovery; 9 hours. Handling rods required 4 hours to install HQWL bit 75-63857 at 913 feet. A stuck tube required 1 hour. Pump repairs required another 6 hours. Five loads of water were hauled and five gallons of Torque Trim were used.

February 16 Drilling from 932-946 feet yielded 100% recovery; 12 hours. Handling rods required 5 hours to install HQWL bit 75-63855 at 939 feet. An inclination test at 946 feet showed 1° deviation from the vertical; 1 hour. Water delays consumed 4 hours. Repairing jaws of chuck consumed 2 hours. Seven loads of water were hauled and seven gallons of Torque Trim were used.
February 17  Drilling from 946-986 feet yielded 100% recovery; 15 hours. Handling rods required 4 hours to install HQWL bit 75-63854 at 976 feet. Servicing hoses required 4 hours. Nine loads of water were hauled and nine gallons of Torque Trim were used.

February 18 Drilling from 986-1,006 feet yielded 100% recovery; 12 hours. Handling rods required 5 hours to install HQWL bit 85-00965 at 996 feet. An inclination test at 996 feet determined that deviation was 1-1/2° from the vertical; 1 hour. Water delays cost 6 hours. Servicing drill consumed 2 hours. Sation pump would not work even though primed.

February 20 Start-up required 2 hours. Drilling from 1,006-1,035 feet yielded 100% recovery; 11 hours. Handling rods for installing HQWL bit 85-00963 at 1,035 feet occupied 5 hours. Water delays consumed 3 hours. Broken front wheel bearing and wheel coming off water truck consumed 3 hours. Eleven loads of water were hauled and eight gallons of Torque Trim were used.

February 21 Drilling from 1,035-1,088 feet yielded 100% recovery; 12 hours. Fuel pump repair on water truck consumed 9 hours. Hauling nine loads of water consumed 3 hours. Nine gallons of Torque Trim were used.

February 22 Drilling from 1,088-1,145 feet yielded 100% recovery; 12 hours. Handling rods to install HQWL bit 85-00967 at 1,096 feet consumed 4 hours. An inclination test at 1,086 feet showed that the hole deviated 3° from the vertical (S.15°W.). Truck repairs consumed 5 hours. Hauling fourteen loads of water consumed 2 hours. Twelve gallons of Torque Trim were used. Caterpillar was required for 4 hours.

February 23 Drilling from 1,145-1,148 feet with 100% recovery completed hole in 2 hours. Handling rods consumed 8 hours. Hole surveying required 6 hours. Inclination at 1,148 feet was 3° from the vertical; 1 hour. Washing hole consumed 5 hours. Repairing hydraulic chuck consumed 2 hours. Five loads of water were hauled.

February 24 Birdwell geophysical logs were run; 11 hours. Rods and casing were broken on ground; 9 hours. Caterpillar was used 4 hours to fill sumps.

February 25 Rigging down consumed 20 hours including chopping of ice to free drill rig. Moving rig consumed 4 hours.

Drilling at DL-5 resulted in a much straighter hole than at DL-1, DL-3, and DL-7. Several factors are considered to be helpful; Slaty cleavage was not as conspicuous in the Michigamme Formation at DL-5; HQWL tools were used all the way to the terminal depth; stiffer core barrels ten feet long were used instead of more limber core barrels twenty feet long; approximately one gallon of Torque Trim per load of water was used for all drilling in ledge; rods were allowed to "float" at greater depths, rather than being advanced under additional pressure.
Core recovery was 100% except for 95% in brecciated zones in 750-813 footage.

ADDITIONAL GEOLOGIC DATA NOW AVAILABLE

Jack W. Avery's on-site drill logs, my geologic interpretation, including a cross section of gross structure, and my recommendations for further exploration are now available from Greg Wilson, Michigan Geological Survey Division of the D.N.R., Stevens T. Mason Building, Box 30028, Lansing, Michigan 48909; telephone (517)373-1256.
DIAMOND-DRILLING FOR GEOLOGIC INFORMATION
IN THE MIDDLE PRECAMBRIAN BASINS
IN THE WESTERN PORTION OF NORTHERN MICHIGAN

James Trow
Geologist-in-Charge
for
Geological Survey Division
Michigan Department of Natural Resources

1978

PREPARED FOR
U.S. DEPARTMENT OF ENERGY
AND
BENDIX FIELD ENGINEERING CORPORATION
GRAND JUNCTION OFFICE
PROJECT NO. 20-77-2132
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>63</td>
</tr>
<tr>
<td>Location</td>
<td>63</td>
</tr>
<tr>
<td>Site selection</td>
<td>63</td>
</tr>
<tr>
<td>Geology</td>
<td>63</td>
</tr>
<tr>
<td>Drilling and logging</td>
<td>65</td>
</tr>
<tr>
<td>Principal firms and agencies</td>
<td>65</td>
</tr>
<tr>
<td>Borehole data</td>
<td>66</td>
</tr>
<tr>
<td>Location</td>
<td>66</td>
</tr>
<tr>
<td>Elevation</td>
<td>66</td>
</tr>
<tr>
<td>Total depth</td>
<td>66</td>
</tr>
<tr>
<td>Dates</td>
<td>66</td>
</tr>
<tr>
<td>Casing</td>
<td>66</td>
</tr>
<tr>
<td>Bit size</td>
<td>66</td>
</tr>
<tr>
<td>Bits used</td>
<td>66</td>
</tr>
<tr>
<td>Inclination</td>
<td>67</td>
</tr>
<tr>
<td>Mud used</td>
<td>67</td>
</tr>
<tr>
<td>Borehole logs</td>
<td>67</td>
</tr>
<tr>
<td>Birdwell Division of S.S.C</td>
<td>67</td>
</tr>
<tr>
<td>Bendix Field Engineering Corporation</td>
<td>67</td>
</tr>
<tr>
<td>Borehole history</td>
<td>67</td>
</tr>
<tr>
<td>Additional geologic data now available</td>
<td>70</td>
</tr>
</tbody>
</table>

## FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1. Location map</td>
<td>64</td>
</tr>
</tbody>
</table>

## BOREHOLE LOGS

**Birdwell Division of S.S.C.**
- Gamma-ray, caliper, & bulk density logs
- Resistivity log

**Bendix Field Engineering Corporation**
- Gamma-ray, spontaneous-potential, and resistivity logs
- Gamma spectrometer (KUT) log
- Caliper and magnetic susceptibility logs
INTRODUCTION

This report presents engineering details, history, and a very brief preliminary geologic summary of DL-6 on the northwest flank of the Amasa Oval, in Iron County. More geologic information will follow in a final report on all holes of the project, in which thin sections and chemical analyses will be reported. More detailed geological information, including on-site well logs, is immediately available from Greg Wilson, Michigan Geological Survey Division of the D.N.R., Stevens T. Mason Building, Box 30028, Lansing, Michigan 48909, telephone (517)373-1236.

LOCATION (lat. 46°45'30"N., long. 87°50'28"W.)

Drill location 6 is on wooded, hilly land in the NE1/4NE1/4 section 30, T. 46 N., R. 33 W., Iron County, Michigan, 150 feet northwest from a monument at 1,595.14 feet altitude, 573.1 feet S. 62°27'30"W., from the northeast corner of section 30. This site is reached by driving 12-1/2 miles north from Amasa on U.S. 141, then one-half mile northwest on old (abandoned) U.S. 141. The drill site is on a trail running west, uphill, from the old road. See Figure 1.

SITE SELECTION

This site was selected by the Michigan Geological Survey because U.S. Geological Survey aeromagnetic map GP-609 suggests possible east-trending anticlines and synclines in this area. DL-6 was selected near such a magnetic trough, interpreted as a syncline, so that drilling down to the Precambrian X Hemlock Volcanics would yield as complete a section as possible of Precambrian X Michigamme Formation on available state land in the area.

GEOLOGY

Pleistocene sandy to bouldery overburden extends to a depth of 236 feet. Below this level, the Michigamme Formation is highly fractured and presumably is very near to faults. The Michigamme Formation consists of massive dark gray and graphitic argillite and slate at 253-421 feet, 445-630 feet, 658-801 feet, 903-965 feet, and 1,020-1,093 feet alternating with red oxidized cherty and slaty phosphatic iron-formation with pyrite at 421-445 feet, 630-658 feet, 801-903 feet, and 965-1,020 feet. The latter iron-formation contains red hematitic and blue martitic variants.

Ammonium molybdate tests on acidized core by William T. Swenor show that the argillites and slates are non-phosphatic whereas the iron-formations are phosphatic. Scintillometer tests by Jack W. Avery show that the core of the graphitic slate is the most radioactive rock encountered, with as much as 1-1/2 times background, whereas iron-formation is the least radioactive rock, with less than background count.
Figure 1. Location map of DL-6
Chalcopyrite occurs in the slate and argillite between 266-376 feet, in iron-formation between 965-977 feet, and especially in one graphitic zone in iron-formation (848-853 feet) with 3.56% organic carbon and 971 ppm of copper, both chemically determined.

Bedding apparently dips from 55°-90°S.

**DRILLING AND LOGGING**

HQWL and NQWL bits used in the vertical drilling were large enough to permit inclination tests at 50 or 100 foot intervals by means of a Sperry-Sun single-shot camera, which indicated that the maximum deviation of 4-1/2° from the vertical occurred at the terminal depth of 1,093 feet. The highly fractured nature of the ground caused loss of fluids and necessitated setting NW casing at 442 feet, beyond which NQWL bits were used. The hole was abandoned at 1,093 feet because of increasing deviation, binding of rods, and reduction in core recovery, which was 100% down to 702 feet and averaged 96% throughout the entire hole. However, core recovery was only 31% in the last 16 feet drilled, and only 14% in the last 7 feet drilled.

Caving and bridging in the hole interfered with geophysical logging by both Birdwell and Bendix. The maximum depth attained by any probe was 918 feet. The condition of the hole did not warrant risking the loss of irreplaceable sondes. For example, the Bendix KUT probe became stuck at 440 feet, and required over 1,000 pounds of vertical tension by Bendix engineers to be freed. Such hole conditions justified the decision not to risk the neutron-neutron probe in this hole.

**PRINCIPAL FIRMS AND AGENCIES**

**FUNDED BY:**
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado  81501

**CONTRACTOR:**
Bendix Field Engineering Corporation
Grand Junction Operations
Grand Junction, Colorado  81501

**SUBCONTRACTOR:**
Geological Survey Division
Michigan Department of Natural Resources
Stevens T. Mason Building, Box 30028
Lansing, Michigan  48909

**DRILLING SUBCONTRACTOR:**
Longyear Company
P. O. Box 186
Keewatin, Minnesota  55753

**GEOPHYSICAL LOGGING SUBCONTRACTOR:**
Birdwell Division of S.S.C.
P. O. Box 256
Mt. Pleasant, Michigan  48858
LOCATION:
NE1/4NE1/4 section 30, T. 46 N., R. 33 W., Iron County, Michigan; 150 feet northwest from monument 573.1 feet S.62° 27'30"W. from the northeast corner of section 30.

ELEVATION:
Monument at 1,595.14 feet altitude. Collar of hole is approximately 1,590 feet altitude.

TOTAL DEPTH:
1,093 feet, to approximately 497 feet above sea level.

DATES:

CASING:
4-inch surface casing set at 253 feet. NW casing set at 442 feet and all removed later.

BIT SIZE:
5-5/8 inch rock bit used from surface to 233 feet, and 236 to 253 feet. HQWL bits used from 233 to 236 feet, and from 253 to 442 feet. NQWL bits used from 442 to 1,093 feet, terminal depth.

BITS USED:

<table>
<thead>
<tr>
<th>No.</th>
<th>Size</th>
<th>Depth In</th>
<th>Depth Out</th>
<th>Total Feet</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5-5/8-inch surface</td>
<td>233</td>
<td>250</td>
<td></td>
<td>See Borehole</td>
</tr>
<tr>
<td></td>
<td>rock bit</td>
<td>236</td>
<td>253</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>HQWL 75-62232</td>
<td>233</td>
<td>236</td>
<td>9</td>
<td>History</td>
</tr>
<tr>
<td></td>
<td></td>
<td>253</td>
<td>259</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>HQWL 85-00968</td>
<td>259</td>
<td>442</td>
<td>183</td>
<td>Reaming to reopen for casing</td>
</tr>
<tr>
<td>4</td>
<td>NWCS unspecified</td>
<td>331</td>
<td>442</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>NQWL 75-62231</td>
<td>442</td>
<td>888+</td>
<td>446+</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Drillers' daily sheets imply that three more bits were applied at unspecified depths. Serial numbers are lacking.</td>
<td>888 + 1,093</td>
<td>205/3</td>
<td>Average</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>442</td>
<td>888+</td>
<td>446+</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>442</td>
<td>888+</td>
<td>446+</td>
<td></td>
</tr>
</tbody>
</table>
INCLINATION:

<table>
<thead>
<tr>
<th>Depth in feet</th>
<th>Deviation from vertical</th>
<th>Bearing</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>266</td>
<td>1-1/4°</td>
<td>N.60°W.</td>
<td></td>
</tr>
<tr>
<td>316</td>
<td>2°</td>
<td>N.65°W.</td>
<td></td>
</tr>
<tr>
<td>366</td>
<td>1-3/4°</td>
<td>N.65°W.</td>
<td></td>
</tr>
<tr>
<td>416</td>
<td>1°</td>
<td>N.35°W.</td>
<td></td>
</tr>
<tr>
<td>496</td>
<td>1°</td>
<td>N.25°W.</td>
<td></td>
</tr>
<tr>
<td>546</td>
<td>1°</td>
<td>N.20°W.</td>
<td></td>
</tr>
<tr>
<td>596</td>
<td>1-1/4°</td>
<td>N.25°W.</td>
<td></td>
</tr>
<tr>
<td>646</td>
<td>1°</td>
<td>N.60°W.</td>
<td></td>
</tr>
<tr>
<td>696</td>
<td>1-1/2°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>746</td>
<td>1°</td>
<td>N.5°W.</td>
<td></td>
</tr>
<tr>
<td>796</td>
<td>0°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>846</td>
<td>1-1/2°</td>
<td>S.85°E.</td>
<td></td>
</tr>
<tr>
<td>888</td>
<td>1-1/4°</td>
<td>Due N.</td>
<td></td>
</tr>
<tr>
<td>943</td>
<td>1°</td>
<td>S.80°E.</td>
<td></td>
</tr>
<tr>
<td>996</td>
<td>2°</td>
<td>S.70°W.</td>
<td></td>
</tr>
<tr>
<td>1046</td>
<td>3°</td>
<td>S.55°W.</td>
<td></td>
</tr>
<tr>
<td>1093</td>
<td>4-1/2°</td>
<td>N.55°E.</td>
<td>7-1/2° from last.</td>
</tr>
</tbody>
</table>

MUD USED:
Twenty-six 50 pound sacks of Quick Gel for a total of 1,300 pounds.
Thirty-four 50 pound sacks of bentonite for a total of 1,700 pounds.

BOREHOLE LOGS

Birdwell Division of S.S.C. (Microfiche copies of logs in pocket)
- Gamma-Ray Log: 100 to 916 feet
- Resistivity Log: 452 to 918 feet
- Caliper Log: 480 to 917 feet
- Bulk Density Log: 443 to 916 feet

Bendix Field Engineering Corporation (Microfiche copies of logs in pocket)
- Gamma-Ray Log: 5 to 900 feet
- Spontaneous-Potential and Resistivity Logs: 255 to 900 feet
- Gamma Spectrometer (KUT) Log: 5 to 900 feet
- Caliper Log: 5 to 900 feet
- Magnetic Susceptibility Log: 5 to 900 feet

BOREHOLE HISTORY

1978
February 27 Moving 44 skid rig K-2 from Marquette County to DL-6 took 32 hours. Caterpillar was required at drill site for 5 hours.

February 28 Further moving required 28 hours. Rigging up required 4 hours. A Caterpillar was used for 3 hours.
March 1  More moving occupied 8 hours. Rigging up consumed 12 hours.

March 2  Drilled overburden with 5-5/8 inch rock bit from 0-25 feet; 13 hours. Mixed mud for 4 hours, using eight 50 pound bags of Quick Gel.

March 3  Drilled overburden from 25-169 feet; 23 hours. Drained lines to prevent freezing during weekend; 1 hour.

March 6  Starting occupied 2 hours. Drilled overburden from 169-233 feet, when ledge apparently was struck; 19 hours. Mixed mud for 3 hours using two 50 pound sacks of bentonite.

March 7  Placing casing required 6 hours. Installing HQWL bit 75-62232 at 233 feet and core drilling to 236 feet with 50% recovery required 2 hours. Pulling casing required 4 hours and cleaning out hole 2 hours. Hauling water consumed 2 hours.

March 8  Freeing water truck occupied 8 hours. Continued pulling of casing occupied 3 hours. Cleaned sump; 2 hours. Mixed mud with ten 50 pound sacks of Quick Gel; 4 hours. Repairs to hydraulic chuck required 2 hours. Drilled shattered and fractured ledge unsuitable for setting casing with 5-5/8 inch rock bit from 236-243 feet; 4 hours. Reaming occupied 1 hour.

March 9  Drilled with rock bit from 243-253 feet; 5 hours. Four 50 pound bags of Quick Gel were used. Placing 4 inch surface casing to a depth of 253 feet occupied 8 hours; twenty-five 94 pound sacks of Fondu were used. Preparing and grouting hole required 1 hour; setting of cement required 6 hours. HQWL bit 75-62232 was again used from 253-259 feet. Handling rods required 1 hour as HQWL bit 85-00968 was applied at 259 feet. Core drilling from 253-266 feet yielded 100% recovery; 2-1/2 hours. A Sperry-Sun single-shot inclination test at 266 feet (1-1/4°) took 30 minutes. Hauled eight loads of water to fill sumps while cement was setting.

March 10 Core drilling from 266-331 feet yielded 100% recovery; 19 hours. An inclination test at 316 feet (2°) consumed 30 minutes. Rods were handled to install full-hole tools; 3 hours. Alternator belt broke, causing loss of electric lights.

March 11 Core drilling from 331-374 feet yielded 100% recovery; 14 hours. Handling rods required 3 hours. An inclination test at 366 feet (1-3/4°) took 1 hour. Servicing rig occupied 2 hours. Broken ground slowed drilling by requiring short runs.

March 13 Starting occupied 1-1/2 hours. Core drilling from 374-442 feet yielded 100% recovery; 18 hours. Handling rods required 2 hours to install HQWL bit 75-62231 at 442 feet. An inclination test at 416 feet (1°) took 30 minutes. Dead batteries plagued drill and pump operations; two alternator belts were replaced.
March 14  Stuck rods (in fractured ground) required 16 hours of effort to free. Cementing operations consumed 6 hours, and seven 94 pound bags of Fondu were used.

March 15  All 24 hours were involved in cleaning, grouting, and cementing operations.

March 16  Chopping and drilling cement from 246-314 feet required 24 hours. Eight 50 pound bags of bentonite were used.

March 17  A stuck tube required much handling of rods and washing of hole; 17 hours. Mixing mud required 7 hours; fifteen 50 pound bags of bentonite were used.

March 18  Cleaning hole required 6 hours. Placing casing to 331 feet and drilling occupied 14 hours. Servicing drill consumed 1 hour. Four loads of water were hauled. Draining to prevent freezing during the weekend took 1 hour.

March 20  Reaming with NWCS bit to reopen the hole from 331-442 feet and allow 443 feet of NW casing in the hole required 10 hours. Handling rods required 6 hours. Seven loads of water were hauled; mixing mud with four 50 pound bags of bentonite required 2 hours. Core drilling from 442-459 feet yielded 100% recovery of NQ core; 6 hours.

March 21  Core drilling from 459-592 feet yielded 100% recovery; 22 hours. Inclination tests at 496 feet (1°) and 546 feet (1°) required 2 hours. Four loads of water were hauled.

March 22  Core drilling from 592-713 feet yielded 96% recovery; 18 hours. Handling rods required 3 hours. Inclination tests at 596 feet (1-1/4°) and 646 feet (1°), as well as at 696 feet (1-1/2°) required 3 hours. Four loads of water were hauled.

March 23  Core drilling from 713-764 feet yielded 100% recovery; 12 hours. An inclination test at 746 feet (1°) required 1 hour. Repairs to transmission required 19 hours.

March 24  Core drilling from 764-875 feet yielded 96% recovery; 22 hours. Inclination tests at 796 feet (0°) and 846 feet (1-1/2°) required 2 hours.

March 25  Core drilling from 875-888 feet yielded 88% recovery; 4 hours. Handling rods required 2 hours. Servicing drill took 1 hour. An inclination test at 888 feet (1-1/4°) required 1 hour.

March 27  Core drilling from 888-977 feet yielded 100% recovery; 18 hours. Installing a bit (not specified) required 3 hours. An inclination test 943 feet (1°) required 1 hour. Equipment repair consumed 2 hours to fix brake band on wire line equipment.
March 28  Core drilling from 977-1,077 feet yielded 92% recovery; 20 hours. Handling rods for a bit change required 2 hours. Inclination tests at 996 feet (2°) and 1,046 feet (3°) required 2 hours.

March 29  Core drilling from 1,077-1,093 feet yielded 31% recovery. Of this, the last 7 feet yielded only 1 foot of core requiring a total of 15 hours. An inclination test at 1,093 feet (4-1/2°) took 1 hour. Difficulty in drilling such fractured ground, plummeting core recovery, stuck rods, and the very acute intersection of stratigraphic units caused us to terminate this hole at 1,093 feet. Stuck rods required 5 hours. Washing and reaming the hole required 8 hours.

March 30  Pulling rods required 5 hours. Drill maintenance required 3 hours. Crews spent 16 hours at DL-7 in Marquette County, readying site.

March 31  Standing by during Birdwell geophysical logging required 8 hours. Pulling casing required 4 hours. Rigging down required 4 hours. Moving to the next hole required 8 hours.

The relative straightness of the hole correlates with less conspicuous slaty cleavage than observed at DL-1, DL-3, and DL-7. Core recovery, averaging 96%, was less than at any other drill site of this project, as a consequence of the high degree of fracturing of the rocks involved. Caving and bridging of the hole likewise are related to the fractured nature of the ground. This rock property hampered geophysical logging.

ADDITIONAL GEOLOGIC DATA NOW AVAILABLE

Jack W. Avery's on-site diamond drill logs, my geologic interpretation including a cross section of gross structure, and my recommendations for further exploration are now available from Greg Wilson, Michigan Geological Survey Division of the D.N.R., Stevens T. Mason Building, Box 30028, Lansing, Michigan 48909; telephone (517)373-1256.
ENGINEERING REPORT
DIAMOND-DRILLING FOR GEOLOGIC INFORMATION
IN THE MIDDLE PRECAMBRIAN BASINS
IN THE WESTERN PORTION OF NORTHERN MICHIGAN

James Trow
Geologist-in-Charge
for
Geological Survey Division
Michigan Department of Natural Resources

1978

PREPARED FOR
U.S. DEPARTMENT OF ENERGY
AND
BENDIX FIELD ENGINEERING CORPORATION
GRAND JUNCTION OFFICE
PROJECT NO. 20-77-2132
INTRODUCTION

This report presents engineering details, history, and a very brief preliminary geologic summary of DL-7 in the East Baraga Basin. More geologic information will follow in a final report on all holes of the project, in which thin sections and chemical analyses will be reported. More detailed geological information including on-site well logs and tests for phosphate presence is immediately available from Greg Wilson, Michigan Geological Survey Division of the D.N.R., Stevens T. Mason Building, Box 30028, Lansing, Michigan 48909, telephone (517)373-1256.

LOCATION (lat. 46°45'41"N., long. 87°48'35"W.)

Drill location 7 is on rolling forest land at approximately 1,200 feet altitude in the SW1/4NE1/4 section 4, T. 50 N., R. 28 W., Marquette County, Michigan, approximately 1,900 feet west and 1,400 feet south of the northeast corner of the section. This site is reached by driving three miles on Marquette County Highway 510 generally southwest from its intersection with County Highway 550 (southeast from Big Bay), then three miles generally west-southwest on the Triple-A Road, then 0.4 of a mile west on another dirt road. The drill site is on the north side of the dirt road. See Figure 1.

SITE SELECTION

When DL-1 was terminated short of its target because of grief in the hole (see DL-1 borehole history), an alternative means was sought to sample the basal Michigamme lithologies and the Precambrian W rocks in the East Baraga Basin. DL-7 was selected for a short vertical hole to encounter the stratigraphic interval of Precambrian X Michigamme Formation missed at DL-1. This location was chosen approximately 1,000 feet southwest from exposures of Precambrian W rocks on the northern perimeter of the basin to insure a hole less than 800 feet in depth, in terms of anticipated dips of Michigamme strata.

GEOLOGY

Pleistocene sandy overburden extends to a depth of 243 feet. Below this level typical Precambrian X Michigamme gray to graphitic black argillites and slates (red and green where oxidized) with sulfides (where unoxidized) occupy the interval 243-569 feet. In these beds the slaty cleavage dips from 37°-65°SW. Light gray massive argillites with ripped-up clasts of black slate between 315-332 feet are tentatively correlated with similar rocks at DL-1 between 2,100-2,104 feet. Algal stromatolites occur at 483 feet. Below 490 feet some of the strata are phosphatic, as determined by ammonium molybdate tests, unlike the strata tested in DL-1 and DL-3. Between 569-659 feet Precambrian X light gray cherty carbonate with algal stromatolites between 577-579 feet alternates with thin beds of conglomerate. All the abovementioned Precambrian X strata dip from 5°-70°SW, and they unconformably overlie coarsely grained Precambrian W granitic rocks which occur between 659 feet and the terminal depth of 697 feet. Scintillator measurements of the core by Jack W. Avery show less than two times background, with maximum radioactivity observed in gray and black slates between 500-530 feet, below an apparently east-trending vertical fracture zone at 500-502 feet. Minor galena, sphalerite, and chalcopyrite are at 573-575 feet.
Figure 1. Location map of DL-1, DL-3, DL-4, DL-5 and DL-7
DRILLING

After penetrating overburden to 243 feet, bedrock drilling in this short hole was started with NQWL bits. Severe loss of circulation in oxidized Michigamme lithologies was not cured by many attempts with mud, grout, and cement. Therefore, BW casing was set at 333 feet and drilling below that level was accomplished by means of BQWL bits. The smaller bore precluded the use of Sperry-Sun single-shot cameras for determining inclination, therefore acid-etch tubes were used for this purpose. This technique did not yield the bearing of the deviation. However, the presence of the regionally uniform slaty cleavage at DL-7, as at DL-1 and DL-3, suggests that the bearing of the deviation at DL-7 was the same as at the other two holes, between N.5°E., and N.21°E., as the bits attempted to penetrate the slaty cleavage perpendicularly. Core recovery was essentially 100%. The narrowness of the bore prevented geophysical logging at DL-7.

PRINCIPAL FIRMS AND AGENCIES

Funded by:
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado 81501

Contractor:
Bendix Field Engineering Corporation
Grand Junction Operations
Grand Junction, Colorado 81501

Subcontractor:
Geological Survey Division
Michigan Department of Natural Resources
Stevens T. Mason Building, Box 30028
Lansing, Michigan 48909

Drilling Subcontractor:
Longyear Company
P.O. Box 186
Keewatin, Minnesota 55753

Borehole Data

Location:
SW1/4NE1/4 section 4, T. 50 N., R. 28 W., Marquette County, Michigan; approximately 1,900 feet west and 1,400 feet south of the northeast corner of section 4.

Elevation:
Approximately 1,200 feet.
TOTAL DEPTH:
697 feet (on curving course deviating from initial vertical by 14-1/2° near
terminal depth), 510 feet above sea level.

DATES:

CASING:
NW surface casing was set at 250 feet with difficulty. This remains in the
hole. BW casing was set at 333 feet (to prevent circulation loss) and all
was successfully removed from the hole at the conclusion of drilling.

BIT SIZE:
5-5/8 inch rock bit used from surface to 250 feet. NQWL bits used from
250-333 feet. BQWL bits used from 333-697 feet.

BITS USED:

<table>
<thead>
<tr>
<th>No.</th>
<th>Size</th>
<th>Depth In</th>
<th>Depth Out</th>
<th>Total Feet</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5-5/8 inch rock bit</td>
<td>Surface</td>
<td>250</td>
<td>250</td>
<td>Hole cemented from 206-263 redrilled</td>
</tr>
<tr>
<td>2</td>
<td>NQWL 75-35657</td>
<td>250</td>
<td>264</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>NQWL 75-41890</td>
<td>264</td>
<td>324</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>NQWL 75-? *</td>
<td>324</td>
<td>333</td>
<td>9</td>
<td>Cased and reduced</td>
</tr>
<tr>
<td>5</td>
<td>BQWL 75-54936</td>
<td>333</td>
<td>571</td>
<td>238</td>
<td>Chert</td>
</tr>
<tr>
<td>6</td>
<td>BQWL 75-54935</td>
<td>571</td>
<td>626</td>
<td>55</td>
<td>Chert and &quot;granite&quot;</td>
</tr>
<tr>
<td>7</td>
<td>BQWL 75-54940</td>
<td>626</td>
<td>676</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>BQWL 75-54938</td>
<td>676</td>
<td>697</td>
<td>21</td>
<td></td>
</tr>
</tbody>
</table>

INCLINATION (By acid-etch tubes):

<table>
<thead>
<tr>
<th>Depth in feet</th>
<th>Deviation from vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>276</td>
<td>1/2°</td>
</tr>
<tr>
<td>340</td>
<td>2°</td>
</tr>
<tr>
<td>446</td>
<td>4-1/2°</td>
</tr>
<tr>
<td>526</td>
<td>8°</td>
</tr>
<tr>
<td>606</td>
<td>11°</td>
</tr>
<tr>
<td>686</td>
<td>14-1/2°</td>
</tr>
</tbody>
</table>

MUD USED:
Twenty-eight 50 pound sacks of Quick Seal for a total of 1,400 pounds. One
40 pound sack of Hy-Seal for a total of 40 pounds. Failure of the filter
cake to prevent loss of drilling fluids caused 2,058 pounds of Fondu to be
used in another futile attempt to stop loss of circulation. The problem
finally was solved by BW casing.

*On the daily drill report sheet the driller recorded the serial number of the
bit removed (75-41890) instead of the number of the bit applied.
1978

April 1  Skid-mounted 44 K-2 rig was moved from DL-6 in Iron County to DL-7 in Marquette County, 24 hours.

April 3  Continued moving rig; 5 hours. Rigged up; 5 hours; Hauled water; 1 hour. Drilled 33 feet of overburden with 5-5/8 inch rock bit; 5 hours.

April 4  Drilled from 33-223 feet in overburden with 5-5/8 inch rock bit; 21 hours. Hauled three loads of water and mixed mud with fourteen 50 pound bags of Quick Gel; 3 hours.

April 5  Drilled from 223-250 feet with 5-5/8 inch rock bit encountering ledge at 243 feet; 7 hours. Mixed mud with three 50 pound bags of Quick Gel; 1 hour. Six loads of water were hauled. Handling rods required 2 hours; cleaning hole required 5 hours. Surface casing was set with considerable difficulty requiring 6 hours. NQWL bit 75-35657 was installed and 100% core recovery obtained from 250-259 feet; 3 hours.

April 6  Loss of water circulation occurred in the green, partially oxidized, Michigamme argillite. Handling rods required 1 hour. Preparing and grouting hole occupied 2 hours. In all, six 100 pound bags of Fondu cement were used. Stuck casing required 5 hours. Setting casing required 8 hours. Drilling and further circulation grief occupied 8 hours.

April 7  Drilled from 259-263 feet with 100% core recovery, but loss of water caused the rods to bind; 8 hours. Freeing and handling the rods, preparing the hole for grouting and setting eight 100 pound bags of Fondu cement required 16 hours.

April 8  At this point the hole was cemented back to 206 feet. Drilling the cement and washing the hole consumed 14 hours. Repairing transmission on rig required 16 hours. Other servicing of drill required 2 hours.

April 10 Drilling cement occupied 7 hours; hauling water occupied 1 hour; repairs required 4 hours. A trip to Crandon, Wisconsin, to acquire a power take-off unit and mud materials such as Hy-Seal to attempt to cure circulation losses required 10 hours.

April 11 Drilling from 263-276 feet with 100% core recovery required 6 hours. Handling rods required 2 hours when bit NQWL 75-41890 was applied at 264 feet. Water still being lost. Conditioning hole with five 50 pound bags of Quick Gel required 2 hours. Four loads of water were hauled. Replacement of power take-off required 2 hours.
April 12 Drilled from 276-316 feet with 100% core recovery; 10 hours. Five loads of water were hauled. Four 50 pound bags of Quick Gel were utilized in conditioning hole for lost circulation requiring 2 hours. Handling of rods for an inclination test at 276 feet (1/2°) required 1 hour.

April 13 Drilled from 316-332 feet with 100% core recovery; 4 hours. Changing from NQWL 75-41890 bit at 324 feet required 2 hours*. Two loads of water were hauled. Trying to recover lost circulation, two 50 pound bags of Quick Gel and one 40 pound bag of Hy-Seal were mixed and pumped down hole and then washed, requiring 5 hours. Equipment repair required 1 hour.

April 17 Starting and drilling from 332-333 feet with 100% core recovery consumed 1 hour. Continued loss of fluid circulation called for handling rods, 4 hours; setting seven 94 pound bags of Fondu cement, 8 hours; drilling, 7 hours; and conditioning hole, 4 hours.

April 18 Further conditioning of hole, 7 hours, failed to restore fluid circulation, so decision was made to case the hole and to reduce to BQ drilling. Standing by consumed 7 hours while awaiting the arrival of BQ tools.

April 19 More standing by required 5 hours. BW casing was placed at 333 feet, 4 hours. BQ drilling with BQWL bit 75-54936 from 333-353 feet with 100% core recovery required 4 hours. Eight loads of water were hauled.

April 20 Drilling from 353-406 feet yielded 100% core recovery; 12 hours. Four loads of water were hauled.

April 21 Drilled from 406-446 feet with 100% core recovery; 10 hours. Acid inclination tests (required by smaller size of hole) yielded deviation of 2° at 340 feet and 4-1/2° at 446 feet; 2 hours. Five loads of water were hauled.

April 22 Drilled from 446-496 feet with 100% core recovery; 11 hours. An oil change required 1 hour. Eight loads of water were hauled.

April 24 Drilled from 496-536 feet with 100% core recovery; 10 hours. An acid inclination test at 526 feet indicated a deviation from the vertical of 8°; 1 hour. Installing a new pump liner required 1 hour. Four loads of water were hauled.

April 25 Drilled from 536-571 feet with 100% core recovery; 7 hours. Changing to BQWL 75-54935 bit at 571 feet required 3 hours. Station engine failure caused a loss of 2 hours. Two loads of water were hauled.

*Driller erroneously recorded serial number of bit removed rather than number of bit applied, on daily drill report.
April 26  Drilled from 571-622 feet with 100% core recovery; 22 hours. Cleaning rig and changing oil after power take-off came loose required 2 hours. Five loads of water were hauled.

April 27  Drilled from 622-692 feet with 100% core recovery; 16 hours. Handling rods required 6 hours to change bits twice in tough cherty rock. Changed to BQWL 75-54940 at 626 feet, and to BQWL 75-54938 at 676 feet. Acid inclination tests at 606 feet indicating 11° from the vertical, and at 686 feet indicating 14-1/2° from the vertical, consumed 2 hours.

April 28  Drilled from 696-697 feet with 100% core recovery; 2 hours. Three loads of water were hauled. Handling rods required 4 hours. Pulling casing required 9 hours; 334 feet of BW casing were successfully retrieved; 250 feet of NW casing were left in the hole as this surface string was irretrievably stuck. Rigging down required 5 hours.

April 29  Demobilization required 4 hours. Water truck with all BQ tools returned to Crandon, Wisconsin.

Four statements summarize the drilling characteristics of the rocks at DL-7: (1) It is almost impossible to maintain a straight vertical hole in the Michigamme Formation of the East Baraga Basin. (2) Almost perfect core recovery is routine. (3) Oxidized green and red argillites and fractured and broken slates within the top 100 feet of bedrock cause complete loss of circulation of drilling fluids. Typical mud and/or cement techniques fail to improve fluid recovery. Therefore, even short holes should be started with sufficient diameter to allow for reductions to smaller diameters resulting from the setting of casing. (4) Hard, tough cherty age X strata below slates and argillites, and above age W basement rocks, require frequent changes of rapidly dulled bits.

ADDITIONAL GEOLOGIC DATA NOW AVAILABLE

Jack W. Avery's on-site diamond drill logs, William T. Swenor's ammonium molybdate determinations of phosphate in the core, my geologic interpretation including a cross section of gross structure, and my recommendations for further exploration are now available from Greg Wilson, Michigan Geological Survey Division of the D.N.R., Stevens T. Mason Building, Box 30028, Lansing, Michigan 48909; telephone (517)373-1256.