Logistical and Drilling Considerations Associated with Sulphur Exploration in High Arctic

By

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ABSTRACT

During 1969, a stratigraphic test hole program was conducted on Melville Island in the Canadian Arctic. The purpose of the program was to explore for sulphur bearing limestone caprock associated with salt domes. Two track-mounted seismic style drilling rigs were used to drill thirty-six holes to a maximum depth of 1000 feet.

In such a remote location and difficult environment, many transportation and support services were necessary that would not normally be required. Hercules type freighter aircraft were found to be the most efficient means of transporting exploration equipment into the Islands. Conventional tracked vehicles were quite suitable for surface transportation of the drilling equipment. Both a helicopter and a fixed wing aircraft were needed for personnel movements on and between the Islands.

Drilling in a permafrost environment presented unique problems which have not been extensively covered in the literature. The selection of the proper drilling fluid appears to be the most important consideration in planning a drilling program in permafrost areas.

Contrary to many widely publicized opinions, it does not appear that human or industrial activity has a serious or lasting effect on the ecology of the area.

INTRODUCTION

In July of 1968, King Resources Company secured sulphur exploration permits covering approximately 880,000 acres in the Arctic Islands from the Canadian Federal Government. These permits were obtained after geological studies indicated an abundance of salt domes in the Sverdrup Basin which is centered in the Canadian Arctic. This basin bears a marked resemblance to the Gulf Coast Basin in that both contain large thicknesses of Mesozoic sediments and both have intrusive salt domes. The target in this venture was to find sulphur in limestone caprock associated with these domes. Preliminary economic studies were conducted which indicated that if sulphur reserves of the order of 20 million tons could be discovered at depths suitable for normal Frasch mining, the sulphur would be competitive on the world market.

Early in 1969, planning began for an exploration program. Experience in the Gulf
Coast suggested that the most efficient initial exploration technique would be to conduct a detailed gravity survey over the area of interest and follow this with a stratigraphic test hole drilling program to check for evidence of domes. The purpose of this paper is to describe the operational considerations associated with the program and to discuss some of the results.

**OPERATIONAL CONSIDERATIONS**

**GEOGRAPHICAL SETTING**

The permits that were to be explored cover Sabine Peninsula which comprises the northern-eastern portion of Melville Island in the Canadian Arctic Islands. The centre of the project was situated at approximately 76° 45' N Latitude and 109° 00' W Longitude. The area of interest is 40 miles long by about 25 miles wide. Figure No. 1 is a map showing the location of the permits relative to the rest of North America. The closest major supply point is Edmonton, 1550 air miles to the south. The nearest airport serviced by an all-weather road is at Hay River which is 1000 miles from the project. Also shown on the map are the route of the Manchester, the Prudhoe Bay oilfield, the City of Calgary, and the City of Denver.

Until early in 1969, Melville Island was uninhabited except for a few caribou, muskox, foxes, and wolves. No communication or transportation facilities existed at that time. The nearest settlement is at Resolute Bay, 300 miles east, which comprises about 200 people. Resolute enjoys three times a week air service - twice from Montreal and once from Edmonton - weather permitting. Resolute is primarily a government weather and communication station; however, it served as the starting point for most scientific parties working in the islands in the past. About half of the population are Eskimo.

The surface terrain on Sabine Peninsula is essentially barren and relatively flat; however it is deeply incised where stream beds have been cut. Ground cover consists of mosses and lichens. Towards the north end of the peninsula two breached salt domes, each approximately 5 miles in diameter, rise to a maximum height of 900 feet above sea level. Otherwise, most of the peninsula is less than 200 feet above sea level.

The climate in the Arctic is severe. During the months from November through March, temperatures range down to as low as -60°F but are usually around -25°F. In April it begins to warm up until in July and August temperatures vary from +30°F to +50°F. The area is extremely arid, receiving annual precipitation of about 4 to 6 inches of water, primarily in the form of snow. Although winds in the Arctic are not normally as strong as in more temperate zones, even a 20 mph wind can be extremely uncomfortable in sub-zero temperatures. Gales of up to 70 mph are not unusual, however.

Another feature of the weather in the Canadian Arctic is the frequency of fog and ice crystals in the air. Particularly during the months from May through November, these conditions prevail when air temperatures in the +30°F to +40°F range combine with open water at sea to form fog or low clouds. These conditions seriously hamper flying operations.

Over much of Sabine Peninsula permafrost is present to a depth of about 1500 feet, however along the sea coast it begins to wedge out. Prior to the spring thaw, which begins around mid-June, the ground is frozen solid and the stream beds are packed full of hard snow. The flat areas are either bare or contain hard packed snow drifts a foot or two high. The drifted snow is extremely hard and will support heavy crawler tractors.

After breakup, the permafrost melts to a maximum depth of about two feet. The surface is composed of soft Cretaceous shales which become extremely sloppy during the spring run-off and make surface movement, even with tracked vehicles, difficult for about two weeks. Once run-off is complete and the surface has dried, tracked vehicles can move with relative ease except when crossing creek bottoms which remain soft until freeze-up, which begins around the first of September.

**OVERALL PROJECT PLAN**

The overall program was to first conduct a detailed gravity survey over the permit area. The information obtained from the survey was then to be used to select drill sites in search of sulphur-bearing limestone caprock associated with salt domes. A drilling depth limitation of 1000 feet was chosen for this preliminary exploration stage. This limitation was imposed because drilling beyond this depth would require much heavier equipment and would seriously hamper mobility.

The general plan was to begin moving to Melville Island during March, conduct the gravity program using helicopters in April, begin drilling in May, and continue through the summer. The reason for this timing was that
March and April provided the combination of good flying weather and daylight necessary to move in and conduct the gravity program. The relatively warm months from May through August would make operation of the drills more efficient.

Coincidently, Pan Arctic Oils Limited of Calgary began moving a rig to drill their first well Drake Point #1. They prepared a 5000 foot landing strip on the sea ice off Drake Point that was capable of handling Hercules type aircraft. It was decided to set up a camp about three miles from the Drake Point strip and move all equipment and personnel in through this point.

SELECTION OF DRILLING EQUIPMENT

Selection of drilling and related equipment began in February 1969. Several factors were considered. The general objective was to obtain as much stratigraphic information as possible down to 1000 feet over a wide area during a four-month period. Tabulated below are some of the parameters that were considered in planning the drilling program:

1. Drilling could take place in or below the permafrost layer.
2. Blowout control would be necessary.
3. Excellent cuttings samples would be needed.
4. Cores could be required.
5. Correlation logs would be run.
6. All holes would have to be abandoned according to Government specifications.

The short timing dictated that all equipment would have to be readily secured in Western Canada since less than three months were available to mobilize and move to the job site.

Studies indicated that a seismic style shot hole rig, equipped to drill with air as the circulating fluid and mounted on tracks, would be best suited to the job. It was further decided that since most of the money would be spent on such things as transportation, camp, communications, air support, and supervision, two rigs should be used to gain optimum utilization of the support services. As a result, the following equipment was selected:

2. Mayhew 1000 rigs, each equipped with 32' mast and mounted on a FN 110 Nodwell tracked vehicle. The drawworks and hoist were powered by a 180 HP GM diesel which also drove the vehicle during moves. Each rig carried a 1000 foot drill string which was made up of 100 feet of 3-1/2" drill collars and the remainder 2-3/8" EUE drill pipe.

- 600 CFM, 125 psi compressors.
- 1 - High pressure air booster to deliver air on one rig at 750 psi maximum.
- 1 - 5" x 6" duplex pump mounted on one rig for well killing and fluid circulation while coring.
- 2 - Nodwell FN 110 oilfield rigged winch trucks, equipped with 180 HP diesel engines.
- 1 - String "BX" wireline coring equipment, capable of cutting a 2-1/8" core.
- 1 - 6000' helicopter-portable logging unit, capable of running a Gamma Ray Log using 1-11/16" downhole sondes.
- 2 - Cyclone cuttings sample recovery units.
- 2 - Regan-Taurus 6" blowout preventers with associated manifolds.

TRANSPORTATION, COMMUNICATION & CAMP

Because of the remoteness of the job site, major supply and service facilities were required to support the drilling operation; these included:

1. A communication system.
2. A camp capable of housing and feeding 40 men.
3. Expendable supplies including fuel, casing, mud, and cement available at the job site.
4. Heavy aircraft to be chartered to move all camp, drilling equipment, and expendables to Halvillle Island. In addition, regular re-supply flight schedules established to rotate personnel and provide spare parts and groceries.
5. Helicopter and light fixed wing aircraft to provide field support.

The communication system was comprised of radio equipment that allowed voice contact between the camp, all field vehicles and aircraft, other camps operating in the area, or any point in the North American telephone
system through a radio-telephone answering service based in Edmonton. The main transmitter-receiver was powered with 500 watts and operated in various frequency bands between 9000 and 14000 kilocycles when in contact with the Edmonton operator. For local calls, the power output could be varied from 25 to 500 watts, depending on transmitting conditions, and operating frequencies were between 4000 and 6000 kilocycles.

Two different styles of field accommodation were used. One was a wooden frame construction 8' x 8' x 16' rigid building which weighed 3800 pounds and was designed to be moved by helicopter. The other was a Quonset style, nylon exterior, 16' x 16' building weighing about 1600 pounds. It had approximately 2" of insulation laminated to the nylon and folded up into a packing box which served as a floor when the building was erected. Each type of building housed four men.

Most of the expendable supplies were purchased in Edmonton and trucked to Hay River to be moved by the airlift to Sabine Peninsula along with the camp and drilling equipment. The estimated 30,000 gallons of diesel fuel needed to fuel the drilling equipment and heat the camp was purchased at Resolute.

A Hercules C-130 freighter was chartered to move the equipment and expendables to the job site. The move required thirteen trips - each with a payload of approximately 35,000 pounds - to move rigs, camp, drilling expendables, and drummed fuel from Hay River to Drake Point. An additional six trips, carrying 5000 gallons each time, were flown from Resolute to move the diesel fuel to the job site. The re-supply flights were scheduled for once every fourteen days, using either DC4 or DC6 aircraft. They were fitted to carry a passenger and freight combination and had a payload to the job site of approximately 15,000 pounds.

The light aircraft support in the field was as follows:

1. Hiller SL-4, 1000#, sling load or 3-passenger, piston-driven helicopter.

2. De Havilland DHC-3, piston engine Otter with 1500# payload on wheel-skis. (Used prior to break-up)

3. Dornier 28, 1350# payload, twin-engine, piston-driven STOL type airplane on balloon tires. (Used after break-up)

The helicopter was used to rotate crews from camp to rigs, while the fixed wing aircraft were used to pick up personnel or small spare parts that arrived at other points in the islands. The reason for the change in fixed wing support after break-up was two-fold: first, the Dornier's extra engine added a safety margin when flying over open water, and secondly, the Dornier has better STOL capabilities on soft terrain than the Otter.

**Drilling Program**

As previously mentioned, the general objective was to drill expendable holes to 1000 feet to gain stratigraphic information. Tabulated below is the drilling program that was planned:

1. Drill 6-3/4' surface hole to 100 feet.

2. Run 5-1/2", J-55, 14# casing and cement to surface with cement fondue.

3. Install BOP and drill 4-3/4" hole to T.D. after 24 hours WOC.

4. Catch cuttings samples on 10 foot intervals from cyclone sample catcher, from surface to total depth.

5. Run Gamma Correlation Log from T.D. to surface.

6. Abandon hole by dumping 5 sacks cement on bottom and wooden plug plus 1 sack plug at top of surface casing. If any water, oil, or gas shows, these must be covered with a cement plug.

Both rigs were equipped with 600 cfm, 125 psi compressors complete with after-coolers designed to maintain the circulating air temperatures at +25°F or colder. The purpose of this was to keep the holes frozen, if possible, so that problems associated with water flows in air drilling would not occur. The drill string on both rigs was comprised of 3-1/2" drill collars plus 2-3/8" external upset drill pipe. This drill string and compressor combination allowed for annular velocities up to 2000 ft/sec on surface hole and 5000 ft/sec, on the remainder of the hole. The rigs were to work in tandem as much as possible so that in the event a pump was required, either for well killing or converting to conventional drilling, the rig with the pump could take over while the rig equipped only with air equipment could move on. In the event that water-based drilling fluid was required, calcium chloride was stocked at the base camp to lower the freezing point of the fluid.
One string of mining style coring equipment was moved to the job site and left at base camp until called for. The plan was to drill directly to total depth, log samples, and if a core was desirable, then move over and drill a twin well. The second well would be drilled conventionally to a pre-designated core point, at which time the drill strings would be changed and coring operations would be conducted through the interesting zones.

OPERATING RESULTS

During the course of the program, numerous difficulties arose that might have been avoided given more lead time for planning and a less remote location. The majority of these difficulties fell into three general categories:

1. Problems connected with moving goods and personnel from Southern Canada to the Islands (Transportation).

2. Problems associated with moving equipment and personnel around Sabine Peninsula. (Field Support).

3. Drilling problems related to the permafrost.

TRANSPORTATION

As previously discussed, the plan was to move the major equipment, expendables, and camp to the job site, using Hercules aircraft, and then to re-supply the operation on a regular basis with DC4 and DC6 aircraft. The Hercules can move freight for approximately $0.30 to $0.40/ton mile, while the cost of DC4 and DC6 service is in the order of $1.00/ton mile. The latter aircraft can, however, carry passengers while the Hercules is restricted to freight use only.

During the early part of 1969, only one Hercules plus several DC4 and DC6 aircraft were available for charter in Canada. Demands by three companies exploring in the Arctic combined with previous commitments made by the carrier, far exceeded the capacity of the lone Hercules. Simultaneously, the American carriers were extended to the limit providing similar service to the north slope of Alaska. The result of this equipment shortage was near chaos. Because of aircraft maintenance problems, unsuitable weather conditions, and demands for emergency flights, schedules were soon abandoned. Some equipment was hauled by DC4 and DC6, however this proved unsatisfactory; both from a cost standpoint, and also because the aircraft are not suited to the job. Loading and unloading is very slow because of the high side door, as compared with the Hercules' low level rear door.

Apart from the obvious need to get the majority of equipment to the job site before any useful work could be done, it was expected that the landing strips would begin to break up around the first of June. Most of the equipment necessary to begin drilling arrived by the first week of May. Only some fuel, casing, and cement arrived after that time.

The re-supply flights were attempted on a fourteen-day cycle but it was found that, as a result of maintenance to the DC4 and DC6 aircraft, it was impossible to maintain this schedule on a regular basis. After break-up no re-supply flights were possible to Melville Island for approximately three weeks. During this period, the necessary freight and personnel were taken to Resolute Bay and then moved to Melville using the Dornier or Otter.

Subsequent to the spring run-off, it was possible to land heavy aircraft on a sand bar near Sherrard Bay - about thirty miles south of the camp site. Lending at Sherrard Bay was an improvement over Resolute which was 300 miles away, but the strip was very soft and heavy aircraft quickly cut deep ruts. As a result, pilots were extremely reluctant to land at this strip during the summer.

Later in the summer, two more Hercules became available for hire in Canada and the heavy freight service improved; however, this did not occur until the bulk of the year's supplies had been moved in.

FIELD SUPPORT

Initially, the drilling began adjacent to the campsite; however, once equipment shake-downs were complete the drills started moving in a general north-westerly direction until most of the drilling was concentrated around the two breached domes. This left the camp between 18 and 25 air miles from the rigs during most of the operation. The problems of rotating crews every 12 hours became difficult during fog and icing conditions. The SL-4 helicopter performed very well in this service, but occasionally crews were stranded at the rigs for up to 24 hours. Pilot fatigue was of considerable concern, since daily flying hours were often much higher than normal.

Prior to break-up, travel on the surface was not too difficult except for occasional hazardous surface conditions. Some of the gullies were not completely full of snow and a machine could drop into a hole and need
assistance getting out. During breakup, surface movement was nearly impossible. The surface was sloppy and the stream beds were soft or filled with several feet of water. Once the run-off was complete, surface travel was easier; however the gullies still had to be scouted to make sure the bottom was firm. The tracked drills were able to move around reasonably well, but the winch trucks, at times, experienced difficulties when hauling the compressors. The heavy compressors, due to their size, tended to make the loaded winch truck rear-heavy causing the front of the vehicle to lift from the ground.

Moving diesel fuel from Drake Point to the drills proved to be the most time-consuming supply problem. The winch trucks could carry approximately 1000 gallons of fuel per load; however, what would normally be a 40-mile round trip by air might cover 60 to 70 surface miles to avoid difficult terrain. Each of these trips took up to 24 hours to complete.

Once the drilling activity became concentrated around the domes, satellite camps of two buildings each were located near the domes. These camps were intended to provide emergency accommodation for the drill crews, and to serve as an intermediate point for a three-man surface geological party which was studying the domes at the same time. In retrospect, moving the total camp to the south dome would probably have been wise; however, at the time it was thought that too much time would have been spent on the move instead of drilling.

The helicopter and both fixed wing aircraft were used to move personnel and supplies from the base camp to the drills. The helicopter, in particular, was able to move 1000 pound loads in about 30 minutes if flying conditions were good. When the re-supply flights began landing at Sherrard Bay, the helicopter and the Dornier were used together to move the new supplies to camp.

Radio communications were variable. Daily reports were made to the head office in Calgary, if possible; however, transmission difficulties often made communication difficult. On one occasion, a total radio blackout occurred for seven days during a magnetic storm. The result was frustration at both ends, as well as delay of ordering spare parts and necessary supplies.

Of the two styles of camp building used, the quonset style fold-away buildings were the most satisfactory. They provided more interior space and were easily moved. These extremely light buildings are suitable to an operation requiring a high degree of mobility; however, large frame buildings appear to be better suited to conventional drilling camps that are to be left in one spot for several months.

**DRILLING PROBLEMS**

On May 21, 1969, the first two holes were spudded adjacent to base camp. The primary purpose of these two holes was to allow a shakedown of equipment and personnel. The drills then moved north and west towards Barrow Dome. The initial intent was for one rig to move on ahead and set surface casing on several wells which would permit the second rig to move in behind and drill to total depth, log and abandon. This did not work out too well. The move-in and rig-up time took longer than expected and it was very difficult to provide fuel, casing, and cement to the first rig as it got further from camp. Another major problem with this approach resulted from modifications in geological interpretations as data became available from completed wells. Locations were changed, and some holes that had surface casing cemented were never completed. For this reason, this approach was discontinued after the first few holes.

In all, 36 holes were drilled for a total of 23,317 feet. The average hole was 645 feet deep and took slightly less than six days to drill and complete. Move and rig-up time is not included in this figure. The following table illustrates a time breakdown for the operating period from May 21, 1969 to September 1, 1969, while the rig was on the test hole program:

<table>
<thead>
<tr>
<th>Operation</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling surface hole</td>
<td>13.6%</td>
</tr>
<tr>
<td>Wait on Cement</td>
<td>12.0%</td>
</tr>
<tr>
<td>Drill open hole, log and abandon</td>
<td>46.4%</td>
</tr>
<tr>
<td>Major repairs</td>
<td>3.8%</td>
</tr>
<tr>
<td>Moving and rigging up</td>
<td>24.2%</td>
</tr>
<tr>
<td></td>
<td>100.0%</td>
</tr>
</tbody>
</table>

As the table shows, 72 percent of the total time was spent in the drilling operation—breakdowns and rig moves using the remainder. Approximately 60 percent of the total time was spent either drilling, conditioning hole, or logging. It is not possible to report the proportion of time spent on each of these operations, because accurate logs were not kept; however, a large part of this time was used for conditioning hole.

A total of 901 feet of core was cut on four holes. Core recovery was around 97 percent.
Generally, coring operations went very well averaging approximately 60 feet per day, contrasted with 120 feet per day while drilling conventionally.

Hole conditions proved to be the single biggest drilling problem. Even though the air compressors were equipped with after-coolers, apparently the action of the bit in frozen shales sometimes created enough heat to thaw out the cuttings. The result was that the cuttings and melted water would form a paste and build up on the drill pipe and hole wall preventing adequate circulation.

Several different methods were attempted to overcome the problem. These included the injection of slugs of diesel fuel, foaming agents, and salt water. Additionally, air circulation rates were varied; however, none of the above techniques gave adequate results. Reamer subs were then placed in the drill string at 100 foot intervals. Prior to making each connection, the pipe was worked and extra time was spent cleaning the hole. This method gave the best results in sticky shales.

Occasionally, condensation of moisture inside the drill pipe and subsequent freezing caused plugging of the pipe. This problem required time-consuming thawing procedures.

While drilling near the coastline, salt water flows were encountered at depths of about 400 feet. The permafrost appeared to wedge out from the bottom creating temperatures at which formation waters would not freeze. Air drilling would not work in these holes. An attempt was made to drill with calcium chloride brine instead. Unfortunately, two holes were junked while using this method when the pipe became frozen in the hole. This can be explained by reference to Figures 2 and 3.

Figure 2 shows a temperature profile in an observation hole at Resolute Bay and shows that permafrost probably reaches a minimum temperature of +8°F approximately 100 feet below surface, then begins warming at 2.16°F per 100 feet of depth.

Figure 3, a phase equilibrium chart for calcium chloride solutions, shows that only with concentrations between 180,000 and 350,000 ppm would the brine remain liquid at +8°F. The rather crude facilities that were available in the field made it difficult to keep the saturations within this range. When the brine passed through the coldest portion of the hole, it froze and the pipe was stuck. Cost of fishing operations would have exceeded the value of the pipe to be recovered, so the holes were junked.

**OTHER ACTIVITIES**

Concurrent with the drilling operation, several other endeavours were conducted from the base camp. A three-man scientific party spent about six weeks measuring ice thickness, ice movement, water currents, bottom conditions, and general sea conditions around Melville Island.

A three-man surface geological party spent about two months studying surface geology of the breached domes and in particular, mapping outcrops containing elemental sulphur.

During mid-July, 49 miles of seismic were shot around the flanks of the two breached domes. Most of this work was done with houm-portable equipment; however for about 10 days the two drills were taken from the stratigraphic test hole program to drill shot holes. Approximately 12,000 feet of hole was drilled during this period by tracked rigs.

In August, the facilities of the base camp were made available to personnel from an Alberta game farm while they conducted a hunt to capture Peary Caribou.

Although these auxiliary activities added considerably to our knowledge of the Arctic, they placed an added burden on the support facilities.

**EFFECTS ON THE ECOLOGY**

Considerable publicity has recently been given to the effects of mineral exploration on the ecology of the Arctic. As previously mentioned, wildlife on Melville Island is limited to caribou, muskox, wolves, and foxes. The surface is covered with mosses, lichens, and a few poppies. Nothing grows more than 3 inches above the ground.

During the season, a fox might occasionally wander into camp to pick over the scraps from the garbage dump, but otherwise the animals that live on the island appeared to show only mild interest in the operation. Hunting these animals is forbidden by law, and none were killed.

Travel over the surface during the wet season created ruts; however in most cases, moss quickly grew back over them. Only one or two washouts occurred adjacent to creeks where ruts had been cut; however, these were relatively minor and were quickly grown over with moss. In general, our presence in the Arctic appeared to have little or no effect on the local environment.
## SUMMARY AND CONCLUSIONS

A successful stratigraphic test hole program was conducted on Sabine Peninsula in the Canadian Arctic during the summer of 1969. Tabulated below are some of the more important results and conclusions:

1. The strat hole drilling program served as a pilot project for future conventional oil and gas exploratory work. Invaluable experience was gained that should assist in planning larger programs.

2. Hercules type air freighters are a practical means of moving heavy equipment into remote areas rapidly.

3. Tracked equipment can move around in the islands efficiently without seriously damaging the surface, except during spring breakup.

4. Air drilling techniques can be successful in permafrost providing no water flows are encountered.

5. Calcium chloride brine does not make a satisfactory drilling fluid. Oil base drilling fluids should be tried.

6. Effective exploration operations can be conducted in the Canadian Arctic, and men and equipment can be economically moved to the job site and supported.

7. Although critical path planning was not used in this program, it appears that this type of analysis would be ideally suited to exploration programs in remote locations.
Fig. 1 - Location map of North America showing distances to major centers.
THERMAL LOG OF HOLE 20, RESOLUTE BAY, WITH EXTRAPOLATION OF TEMPERATURE VS. DEPTH CURVE TO ESTIMATED BOTTOM OF PERMAFROST (AFTER MIESZKOWSKI)

Fig. 2 - Temperature profile.
Fig. 3 - Phase equilibrium diagrams
NaCl and CaCl₂.