TEST DRILLING REPORT - - PROCEDURES AND RESULTS OF TWO TEST HOLES DRILLED AT PILGRIM SPRINGS, ALASKA IN OCTOBER AND NOVEMBER 1979

by
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Brief Historical and Geological Background

Pilgrim Springs was a resort for miners during the height of early gold mining activity on the Seward Peninsula. Later the property was donated to the Catholic Church and shortly after 1917 the church converted the area into an orphanage and mission school for Eskimo children orphaned during the 1917 influenza epidemic. The springs and mission buildings were abandoned as an orphanage by the church in 1942. Subsequently the area was used as a recreational site for military personnel stationed on the Seward Peninsula.

Presently C.J. Phillips of Nome holds a long-term lease on the Pilgrim Springs property. With the assistance of the State of Alaska Division of Energy and Power Development (which recently sponsored exploration and feasibility studies in the area), Mr. Phillips hopes to develop the thermal resource.

Historically the thermal waters at the Springs have been used for space heating of buildings, bathing, and naturally induced warmth of the surrounding ground for small-scale farming.

During the summer of 1979 the Geophysical Institute of the University of Alaska and the Alaska Division of Energy and Power Development requested that the DGGS assist in a geophysical and geological reconnaissance of the Pilgrim Hot Springs area. The reconnaissance was an attempt to better define the nature of the Springs and if possible assess its potential for exploitation as an energy resource. Specifically the DGGS was to produce and field check a photogeologic field map, and to interpret surficial geologic expressions and deposits such as lineaments, terraces, erosion surfaces, abandoned drainages, and glaciofluvial deposits which might have a bearing upon the nature of the spring system and which might be interesting targets for further geophysical investigation.

Several surface features identified during the 1979 summer field studies and some features whose subsurface expressions were subsequently identified by geophysical methods (Turner and Forbes, 1980), suggest a high likelihood that Pilgrim Springs is located near the western edge of an actively subsiding graben. The fault bounding the western edge of this graben may act as a permeable zone along which thermal waters heated at depth find their way to the surface or into a shallow high porosity zone which acts as a hot water reservoir.

Many features of the regional tectonic setting are suggestive of a rift system or a zone of tensional fractures. Such systems are commonly associated with high geothermal heat flow, which in turn may be responsible for heating meteoric waters supplied to the system. The high salinity of thermal waters at Pilgrim Springs is probably due to deep circulation and water-rock reactions (Miller and others, 1975) and is commonly referred to as an alkali-chloride type hot spring (Motyka and others, 1980). This interpretation is somewhat speculative, however, and the precise history of the water remains problematical.

1979 Drilling Program

Shortly after the completion of the 1979 summer field season it was decided by Don Markle of the Division of Energy and Power Development to attempt a shallow drilling program to further localize the source of hot water and to gain a better understanding of subsurface lithologies, reservoir conditions, and flow regimes. Initially Geophysical Institute personnel recommended that a member of the DGGS staff be on site to log the drill-hole lithologies and a member of the Geophysical Institute staff be on site to measure and interpret the thermal regime of the system. Short notice and lack of available personnel precluded the on-site placement of a scientist or assistant from the Geophysical Institute.

Tom Williams, hydrologist from the DGGS Anchorage office, and I were assigned by DGGS to plan and execute all sampling, monitoring, and logging of the drill holes. Due to short notice, little advance planning was possible and most of the Division's water sampling and temperature monitoring equipment was committed to other projects. Tom Osterkamp of the Geophysical Institute kindly loaned us two thermistor probes, two telethermometers, and a conductivity meter to make temperature and electrical conductivity measurements of water down the hole and to monitor mud temperatures. Water sampling equipment and reagents were purchased in Fairbanks. Arrangements were made with Vic Mittasch, drilling contractor of Exploration Supply Company of Anchorage, for sampling tools and liners to be available and for plastic PVC pipe to be on site to place in drill holes so that future temperature logs could be obtained. All logistical and support arrangements were to be made by the drilling contractor and the Division of Energy and Power Development.

On-site transportation was to be by equipment owned and operated by Louie Green, a part-time resident at Pilgrim Springs. Unfortunately these vehicles were old and in poor repair which, along with inclement weather, caused several substantial delays in getting supplies and equipment to the drill site from the Kugruk Road.

After consultation with DGGS and Geophysical Institute staff, it was agreed that the maximum amount of subsurface information would be obtained by drilling three 150 feet holes at the apices of an equilateral triangle centering on the hottest thermal anomaly. This would enable us to construct three dimensional fence diagrams of temperature, lithology, and possible zones of flow or pressure. With this information we hoped to target a site for a deeper production hole. These plans were altered by the Alaska Oil and Gas Conservation Commission, which mandated that the first hole be drilled outside the 60°C ground temperature isotherm. This decision was made for safety reasons because uncertainty existed as to levels of subsurface temperatures and pressures. Since the Alaska Oil and Gas Conservation Commission and DGGS staff were somewhat unfamiliar with procedures used in geothermal drilling, they opted to regulate on the side of caution.

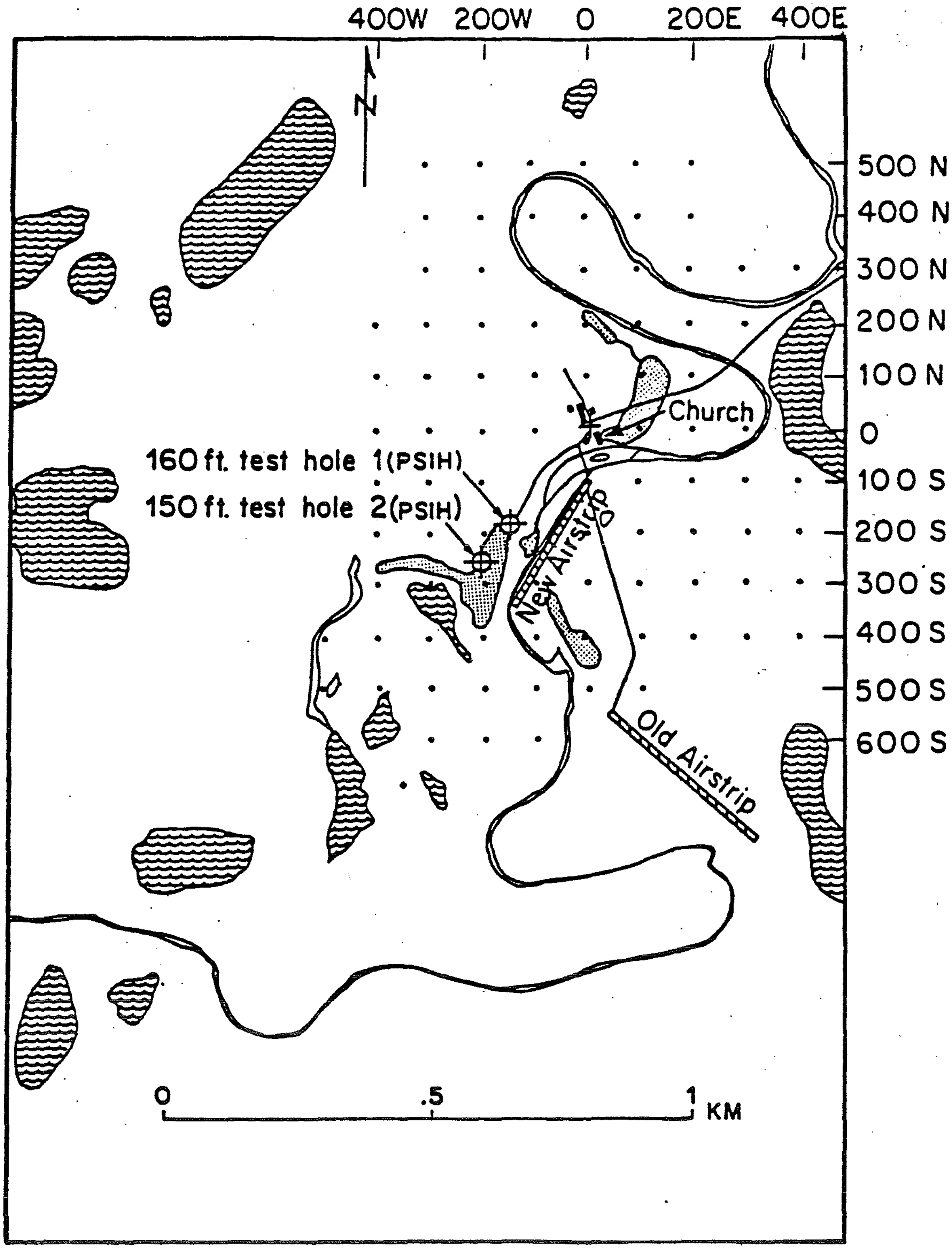
Tom Williams and I (with our personal and sampling gear), arrived at Pilgrim Springs by single engine Otter on the morning of October 16, 1979. Andrew Lockhart of the Geophysical Institute accompanied us to take gravity measurements in the vicinity. The drill and drilling crew had not yet arrived. The first four days were spent renovating a small bunkhouse, installing a door, removing refuse to make a suitable cooking and eating area, and making a workable heating system. The location of test hole #1 (PS-1) was sited and marked using a Brunton compass and nylon tape. The 100-meter grid set up by the Geophysical Institute was used as a reference with locations reported as grid coordinates. Point 0 + 00, 0 + 00 was located at the basketball court just north-northeast of the old church building. The site for PS-1 was 200 m south and 150 m west on the controlled grid. A later attempt to accurately survey the well sites using previously surveyed property corners as bench marks was unsuccessful due to lack of time, short daylight hours, inclement weather, and an insufficient number of personnel.

The drill rig arrived late on October 25, 1979, nine days after our arrival at the site. The next day was spent preparing the rig and assembling equipment. Most of the necessary drilling supplies had not yet arrived. It was decided the rig should be set up on timbers so it would fit over the blowout preventor and valve. The timbers were requested by radio October 26 and from C.J. Phillips on October 27, when he arrived with a reporter and Representative Fuller.

While waiting for equipment and supplies to arrive, two 25-foot holes were drilled and logged in a permafrost area approximately 1 mile west of the old church. These holes confirmed the presence of permafrost containing massive ice and small interstitial ice lenses. Bottom hole temperatures were taken for both holes, but were probably not in equilibrium due to friction and heating from drilling. The temperatures were for PS-PF-1 and PS-PF-2 were -4°C and -3.5°C respectively, as recorded by a YSI telethermometer.

By noon, October 31, 1979, enough equipment had arrived to start drilling the first hot hole. Drive samples were taken at 10 foot intervals and mud temperatures were monitored constantly during drilling. Fifty feet were drilled the first afternoon on PS-1. The following day casing was welded and set in the hole. Cementing was accomplished by noon of the following day and the cement cured overnight before drilling was resumed. A flange for a 6-inch full-hole valve was welded to the top of the upper casing and the valve and stripper assemblies were bolted on prior to further drilling. The stripper was removed every 10 feet of drilling so the drill bit could be replaced with the split tube sampler. This was time consuming and dangerous because the stripper was extremely heavy and there was very little working space below the rotary table. An annular preventor which opens to full hole diameter without removal would have been more efficient and safe. High density and induration of sediments made drive sampling ineffective below 100 feet. In lieu of drive samples, cutting samples were collected every 5 feet from circulating mud.

The use of a drilling mud system was extremely important for lateral support in the hole to prevent sloughing of the first 60-80 feet and as a suspension medium for the barite used to control back pressure exerted by fluids in the formation. It was also necessary to lubricate the drill bit. Control of thermal artesian flow by cold water was not successful; the flow was subsequently controlled by pumping weighted mud into the hole. This worked as long as the mud remained in suspension, however, the high salinity of the thermal water caused the beneficiated bentonite clay to flocculate. It then dropped out of suspension and settled to the bottom, decreasing the density of the system to a point where spontaneous flow resumed.



Location of 1979 drill holes and 100 m grid. Strippled areas indicate agricultural fields. Wave pattern indicates lakes and ponds.

The above observations were made after total depth was reached. Mud was flushed out to see if a producing aquifer had been reached. Initial cleaning of mud from the hole was accomplished by lowering drill stem into the mud-filled hole at 5 foot increments and moving the mud out with air. At 65 feet, spontaneous flow began as an eruption of gas-charged water from the blooey line and increased in intensity until the heavy 4-inch escape line was whipped violently and knocked down several small trees in the area. Gradually the amount of escaping gas decreased and was replaced by an increasing flow of hot water initially measured at 88°C. After 15 minutes the rate of flow through the 4-inch line was about 100 gal/min with the end of the line elevated to approximately 2 feet above the ground surface. After 30 minutes of flow the rate increased to an estimated 200 gal/min as measured by the length of time required to fill a 55 gallon drum; the temperature had stabilized at 90.5°C. Further increase in flow was not noted and the rate and temperature remained constant after flowing overnight.

The following day an attempt was made to bracket the zone of flow. As no downhole flow measuring equipment was available, we devised a system using cold weighted mud. Initially, the flow was stemmed by pumping cold thick barite-weighted mud into the hole. The drill stem was then withdrawn and mud was added to replace the volume reduction caused by removal of the drill string. The uptake hose for the mud pump was placed in a tank of cold clear water and the mud was removed from the top down by flushing with water in 5 foot increments down the hole until spontaneous flow resumed. At this point the drill string was quickly removed and a temperature probe lowered through the flowing column of 90.5°C water until a temperature discontinuity was reached, i.e. the interface with cooler mud still resting below the zone of flow. The probe was passed back and forth across this discontinuity until it stabilized. We assumed this represented the bottom of a zone of vigorous artesian flow capable of washing out the remaining mud. Spontaneous flow commenced when mud was washed out of the hole to a depth of 65 feet by flushing and it continued to wash itself out naturally to a depth of 85 to 90 feet. Water escaping at the blooey line and down to 55 feet was 88°C, at 60 feet it had increased (in the flow) to 89°C, and from 70 to 90 feet it was 90°C. Below 90 feet the temperature gradually decreased as the cooler mud was encountered. The interval between 70 and 90 feet seems to be the dominant zone producing the 90.5°C flow seen during earlier and subsequent free flow tests. This procedure was repeated twice with similar results. Following each test, mud was removed from the hole by washing with clear water and the well was allowed to flow freely for several hours.

Stradle packers had been requested to sample flow rates from sealed intervals in the hole and to obtain selected water samples once casing had been placed to total depth and perforated. It is recommended that some such isolating device be provided for more accurate sampling and assessment of various depth intervals during future testing at Pilgrim Springs. There is a promising amount of hot water at depth, but a more accurate determination of its zone of origin must be made when assessing such a shallow reservoir.

Repeated static temperature measurements made down the drill stem after remudding and flow ceased showed that there were specific intervals where conductive heating seemed more rapid. The most prominent occurred between 85 and 90 feet, and is suggestive of a stronger horizontal subsurface flow at this level, allowing for more rapid heat transfer.

Water sampling was carried out at PS-1 after a 24 hour flow period to allow flushing of contaminants from the beneficiated bentonite (Quick-Gel) and its additives (Quick-Trol and barite). The water appeared clean and free from sediment when the water samples were collected at a small valve located at the stripper. Prescribed sampling techniques were followed for both wells, as detailed by Presser and Barnes, 1974; six water samples (2 acidified and filtered, 1 unacidified and filtered, 1 unacidified and unfiltered, and 2 unacidified filtered and diluted x 10 with double distilled water) were collected at each well. On-site conductivity measurements of water recovered from PS-1 were 9,750 micromhos at 19°C.

On November 9, 1979, the drill was moved to the well site for PS-2, grid location 258 m south, 207 m west. The drill was set up on leveled timbers and mud pits were dug. Drilling commenced the following day. Completion of PS-1 was not yet accomplished due to lack of casing and sufficient cementing supplies. We moved to PS-2 in hopes that these supplies would arrive before much more drilling occurred. Adequate supplies were on hand to drill the first 50 feet of PS-2. Aside from increasingly severe weather, drilling of PS-2 was similar to drilling of PS-1 except we had a somewhat better idea of what to expect in the subsurface. Because Tom Williams went to Nome to expedite delivery of our supplies, we were even more short-handed. Drilling continued as supplies slowly trickled in and as weather allowed. The driller refused to work in blizzard conditions because of limited visibility on the mast. I heartily concurred with this policy. On November 19, 1979, PS-2 was drilled to total depth. Flow tests revealed a significantly greater flow and pressure than PS-1. Piezometric water surface flow and pressure than PS-1. Piezometric water surface was 3 feet above ground level on PS-1 and 7 feet 3 inches above ground level on PS-2. The flow from PS-2 was estimated at between 300 and 400 gal/minute.

Four-inch casing was emplaced to total depth in PS-2. An attempt was made to insert the 1-inch PVC pipe supplied by the U.S. Geological Survey for temperature profile measurements. The pipe was softened by heat and collapsed in the hole. In the future such pipe should be more heat resistant and thicker walled.

Tom Williams had returned from Nome by snow machine a few days earlier and took ill about this time. He was evacuated on November 23, 1979, by a Nome State Trooper. PS-1 was completed and inner casing cemented by November 25, 1979, after arrival of inner casing.

Downhole Geology of PS-1 and PS-2

As previously mentioned, continuous inspection of cuttings, observations of drilling rates and character, and drive and cuttings sample collection were performed during the entire drilling process. A drilling log was compiled daily from all observations. A detailed camp log was also kept so equipment requests and arrivals could be monitored.

Most sediments encountered in the drill holes were alluvial, typical of a meandering stream system, and tended to coarsen downward. The sediments consisted predominantly of fine- to medium-grained sands and silty sands with occasional thin fibrous organic layers or partings in the upper 50 to 60 feet.

Occasional gravel lenses probably represent channel lag deposits which do not have a wide lateral extent. Medium-grained sands and silty fine-grained sands represent point bar and overbank deposits respectively. Silty fine-grained sands with copious organic partings are probably cut-off channel fillings.

Detrital grains examined from cuttings and drive samples reveal that the sediments are derived predominantly from the surrounding metamorphic terranes, especially from the Kigluaik Mountains. Lithic fragments as well as individual mineral grains are present. Microscopic examination of selected samples and subsequent X-ray diffraction analyses show that the dominant primary minerals are quartz, mica, and feldspar. A typical fine- to medium-grained sand with trace to some silt commonly contains 50-60 percent quartz, 20 percent lithic fragments (usually slate or gneiss), 10-15 percent mica (including muscovite, biotite, and chlorite), 5-10 percent feldspar, and 1-5 percent garnet, apatite, and wollastonite. Trace amounts of cassiterite and scheelite were also detected. Very little magnetite was seen in any of the samples analysed. This is somewhat puzzling since it is a common accessory mineral associated with the metamorphic rocks of the area. Silt content of sandy intervals appears to generally decrease below about 100 feet in PS-1 and below about 90 feet in PS-2. Whether this represents a significant change in environments of deposition is unclear. Proper assessment of sedimentary characteristics was difficult where only cutting samples could be obtained.

Of particular interest was the occurrence of authigenic minerals and siliceous cement at depth in both wells. In PS-1 induration due to cementing was first observed at a depth of 70 feet and was well established in the interval between 70 and 75 feet. In PS-2 cementing material first became apparent at 60 feet. A softer interval, as indicated by an increased drilling rate, occurred between 65 and 70 feet. At 70 feet sediments are more tightly cemented and large pyrite cubes appear. Sediments at this depth are thinly laminated siltstone with trace to some fine sand. Authigenic pyrite and pyrrhotite are widely disseminated in the cemented zone; however, zones occur where sulfides are abundant and where they are virtually absent. Euhedral quartz overgrowths were noted on clastic quartz grains between 80 and 150 feet in both holes. Along with chalcedony cementing material and fissure fillings these indicate hydrothermal mobilization and redeposition of silica at shallow depth. This may have an effect upon the chalcedony geothermometer; if the SiO_2 concentration of the thermal waters in a shallower and presumably cooler reservoir reequilibrates then it would no longer reflect possible higher temperatures at depth. This effect would not necessarily be concordant with other chemical geothermometers and a discrepancy should be apparent if several geothermometers were used. It is interesting to note that the depth of cementation of the alluvial sediments corresponds nicely with the seismic velocity increase picked up along east-west seismic line B-B′ (Kienle and others, 1980).

While in the field, mention was made of the strong resemblance of the consolidated sediments encountered in the holes and indurated Tertiary sediments found elsewhere in Alaska. This was merely a casual field observation and does not imply a Tertiary age for indurated sediments encountered in the drill holes. It is possible that Tertiary-age sediments do exist in this sedimentary basin, but their occurrence is problematical at this point. Under an active hydrothermal regime such as occurs in the sediments in the Pilgrim

Springs area, the process of induration, alteration, and cementation could be tremendously accelerated. This would indicate sedimentary rock characteristics common to sediments lithified over a much longer period of time. Another characteristic of some of the Pilgrim Springs downhole sediments is their dominant bimictic composition of white quartz and black slate giving rise to a bright "salt and pepper" appearance.

Further work on the mineralogy, especially of the authigenic minerals, is planned when time permits. This would be especially useful in identifying chemical and thermal similarities between the Pilgrim geothermal system and other similar geothermal systems.

The two geologic logs produced during drilling operations in October and November, 1979, at Pilgrim Springs are attached.

Conclusions and Recommendations

A more satisfactory drilling procedure should be sought if future geothermal development is undertaken at Pilgrim Springs. Advantage should be taken of the expertise and technical sophistication of established geothermal drilling contractors, the overall lack of expertise and adequate sampling and measuring equipment at Pilgrim Springs was alarming. Delays due to logistical bottlenecks and poor weather took their toll of time and dollars. There was not adequate communication between the project manager, me, and the contractor prior to mobilization, nor time for proper planning and consultation with experts in the lower 48. This would have greatly aided our efforts. Much of the engineering and completion procedures were improvised on site due to inadequancy of equipment and supplies. It was painfully apparent that we were "reinventing the wheel" since in other areas of the country and world such procedures are commonplace. In spite of technical difficulties, we were able to demonstrate that water with a temperature of at least 90.5°C exists, probably in large quantities, under natural artesian or thermal artesian pressure at relatively shallow depths and in a relatively large area surrounding and between the naturally occurring springs.

The following are a number of specific observations and conclusions which resulted from this preliminary drilling effort.

1) The zone of major flow in PS-1 and PS-2 is between 70 and 110 feet.

2) Cementing of the sediments begins to appear between 75 and 80 feet in PS-1 and at 60 feet in PS-2. This roughly coincides with the top of the inferred zone of maximum artesian flow.

3) Time allowed only a 24 hour continuous flow test from each well prior to completion. During this period flow rates and temperatures were carefully monitored and remained constant after the first hour. While this degree of testing is inadequate to assess true reservoir potential, it is encouraging that we did not see a decline in output or temperature. Had we seen such a decrease, we could have assumed that mixing with a cold water aquifer and/or local decreases in gas pressure were occurring. This would indicate that effects at the well-head were local and that possibly an insufficient volume of hot water was available to maintain output at the well site for long periods of production.

4) Another indication that the volume and source of the 90°C water reservoir are large is that pressure is maintained despite leakage to the surface of significant volumes of hot water along terrace scarps. The most active springs along the scarps seem to occur where more permeable channel lag gravels and coarse sands are breached by the scarp rather than in the more silty less permeable overbank deposits.

5) All sediments encountered downhole are of fluvial origin as determined by available sampling techniques. Once the cemented zone was encountered, drive sampling attempts proved fruitless. No undisturbed core samples suitable to check parameters of reservoir rock such as porosity, permeability, grain orientation, vertical variability, percent and type cement, and sorting could be obtained. Only cutting samples could be successfully recovered below 90 feet in PS-1 and below 65 feet in PS-2. These provide information on the lithologies present to total depth, but are inadequate for proper assessment of the reservoir parameters.

6) It is important to keep in mind the essential similarities between geothermal and oil exploration, drilling, and reservoir assessment. Oil companies expend enormous amounts of dollars to insure safe and productive drilling efforts, and with good reason. Prior planning is extensive and attention is given to every detail of data acquisition and interpretation. From their data and interpretation reasonably sound judgements are made as to potential economic returns on an investment of more time and money. The quality of these judgements has its foundation in the quality and completeness of the basic data.

7) Personnel with considerable geothermal drilling and reservoir engineering experience must be employed. Their expertise will advance our assessment abilities and help bypass some of the pitfalls encountered and identified in previous work. Ignorance of existing technology and expertise is wasteful as is starting from scratch. The initial investment pays off.

8) It is strongly recommended that a comprehensive list of all equipment and materials used by the drilling contractor and technical personnel for drilling and assessment be compiled and reviewed carefully by several qualified personnel.

   It is further recommended that all listed equipment and supplies be assembled in one place and carefully checked by a designated field manager prior to shipment to the drilling site. It is much easier to correct omissions or shortfalls prior to departure for the field than to discover them when the materials are critically needed. A similar inventory should occur when the materials have reached the site.

9) All gear should be transported to Nome in a single chartered cargo plane and from Nome to Pilgrim Springs by single engine Otter. The Otter should be retained at Pilgrim Springs for the duration of the project.

The following list of equipment would have proved useful during drilling at Pilgrim Springs and some items were requested but never received prior to or during the drilling project in the fall of 1979.

1) Electric and gamma logging device. Such a device would be invaluable for measuring significant formational changes responsible for control of subsurface fluid movements.

2) Downhole flow meter: a small impeller-type device used to locate and measure zones of fluid flow and their fluid velocities; Schlumberger or Haliverton produce and market or lease such devices.

3) Surface flow meter: may be used in conjunction with a surface ditch and used to accurately measure total flow from the wellhead.

4) The brass themistor probe weights made by the Geophysical Institute were very useful but could be improved. These should be slightly narrower and redesigned so that more weight can be added to reduce buoyance in high specific gravity mud systems. We encountered a problem with cable drag and with ability to sound the hole bottom when hole depth exceeded 100 feet with a bentonite and barite suspension mud system.

5) Below about 75 feet density of the sediments makes collection of drive samples impractical. A rotary sampler would be useful to cut a core below this depth. Continuous diamond drilling of the formation would be ideal.

6) A mud compatible with saline water should be used. Beneficiated bentonite mud (Quick-Gel) was used during 1979 drilling, and it had a strong tendency to flocculate and drop out of suspension. The driller suggested using Salt-Gel which is compatible with saline water; other brands of salt-water-compatible muds are also available.

7) All mud system components and additives should be of known chemical composition to predict possible contamination of water sampled for chemical analysis.

8) Sets of straddle packers of appropriate diameters should be available to temporarily seal off intervals in the hole for the purpose of taking selected samples and doing tests on flow or pressure within a specific interval.

9) An adequate number of perforating shaped charges should be available for casing perforation in all zones where testing or production is desired.

10) On site surveying gear is necessary for accurate wellsite description and for measuring the height of the wellhead relative to a datum.

11) Adequate cementing equipment should be on site so that, if necessary, all casing can be properly cemented, and in the event of hole abandonment completely stemmed with cement. This is an especially important consideration where artesian or thermal-artesian pressures exist, and later erosion and leakage around the exterior of the casing could be catastrophic.

12) The wellhead design should be carefully and critically analyzed to insure that adequate safety and access for sampling and measurements exists. A full-hole annular blowout preventor would allow tools to be taken in and out of the hole without removal of the whole upper tree. The latter operation was necessary when using the passive stripper during the fall 1979 drilling and resulted in extensive time loss and compromise of safety.

13) At least two 2-inch capacity gasoline-operated pumps should be on site to remove water from the drilling area to the creek or other appropriate disposal sites. Sufficient 3 or 3-1/2-inch fire hose should be available to carry pumped water from the drill site to a disposal site.

14) The mechanics of all sampling procedures should be worked out in advance. This will save considerable on-site time and avoid possible delays while unanticipated equipment needs are filled.

15) An assortment of bell reducers, street L's and nipples should be available. This is especially important since the stock of useable antique fittings at Pilgrim Springs has been severely depleted by the 1979 drilling operation.

16) Communication arrangements should be made with Trident Enterprises in Anchorage. Their rates are reasonable for high traffic operations and they have the added advantage of all-night service on 3201.0 kHz. The field radio for HF operations should have both 5167.5 and 3201.0 kHz.

17) A fixed wing aircraft or helicopter should be on site at all times during the program. Dependence on local air carriers has proven unsuccessful in the past. Their performance during the fall drilling program was inadequate. It is also recommended that all materials and supplies be shipped to the site on chartered aircraft after being thoroughly inventoried by the project manager.

18) Adequate first aid facilities are essential as drilling is hazardous and serious accidents are not uncommon.

19) A few pieces of steel pipe and some steel plate stock 1/4 inch or thicker should be on hand for fabrication and repair.

20) Wellhead pressure gauges which measure relatively low pressures (1-10 psi) should be included for static pressure checks.

21) A substitute should be found for the 1-inch plastic PVC pipe which was to be placed in each hole for later measurements.

22) Wellhead caps should be engineered to provide easy and safe access for all anticipated tests and measurements and to allow for some production or flowing of the wells in the future. It may be advisable to flow the wells at regular intervals since self sealing is a possibility.

Acknowledgments

I wish to thank Tom Williams, whose assistance in performing the tasks at hand and whose advice was indispensable during the drilling program. I also wish to thank Mark Knight, our driller, who despite his lack of former experience at drilling geothermal or other water wells, had a wealth of common sense and ability to improvise when breakdowns occurred or when a difficult situation arose. Without him it is doubtful that in the light of logistical difficulties and foul weather, either of the two wells could have been successfully drilled. Thanks to Tom Osterkamp of the Geophysical Institute for the loan of conductivity and temperature measuring instruments and advice on siting the wells. Blair Wondzell of the Alaska Oil and Gas Conservation Commission gave us several good technical suggestions concerning drilling and testing as well as safety. Thanks to Andy Lockhart who lent us a hand in preparation of our accommodations during our first few days at Pilgrim Springs.

And finally thanks to whoever it was that warned us to take extra food with us out there.......

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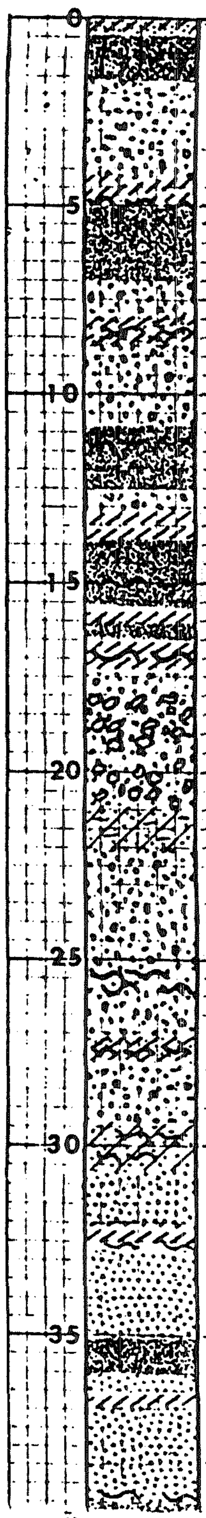


0-10 ft. Medium sand interlaled with thin silt lenses, sandy pebble gravel layers, and 3 to 5-cm partings of fibrous peat.

Mud temperature reaches 16°C this interval

Bottom hole temperature following drive sample = 32°C

Sample taken at 10 ft Sampler penetration = 12½ blows/ft. (hammer wt = 140 pounds)

PS-1-1 Med. Sand with trace to some silt. Minor amounts of clay present as streaks

10-20 ft. Coarse sand and pea gravel intercalated with layers or lenses of fine to med. sand and thin organic layers or smears. Drilling rate decreasing gradually over previous interval. Drilling character indicates possible thin cobble layer between 18 and 20 ft.

Mud temperature stable at 17°C entire interval

Bottom hole temperature during drive sample = 38°C

Sample taken @ 20 ft. Gravel near bottom caving badly. Sampler penetration 99 blows/ft

PS-1-2: Upper 12" of sample from pea gravel of quartz and slate. Lower 9" recovered coarse to med sand with trace silt and organic smears.

20-30 ft: First 1½ ft pebble gravel stuff from above followed by 1 to 1½ ft fine sand with trace silt and clay. Remainder of interval alternating layers of sandy pebble gravel and silty sand containing trace organics. Dark organic layer @ 27-28 ft.

Mud temperature 19°C this interval

Bottom hole temperature 30°C

Sample taken @ 30 ft. Sampler penetration = 46 blows/ft

PS-1-3 Med to fine silty sand with trace to some peat smears, streaks and lenses intercalated with micaceous silt overbank deposits in layers 2-4 in thick

30-40 ft. Notable decrease in drilling rate. Drilling smooth in fine to med sands and silts. Mud temperature decrease noted at 35 ft.

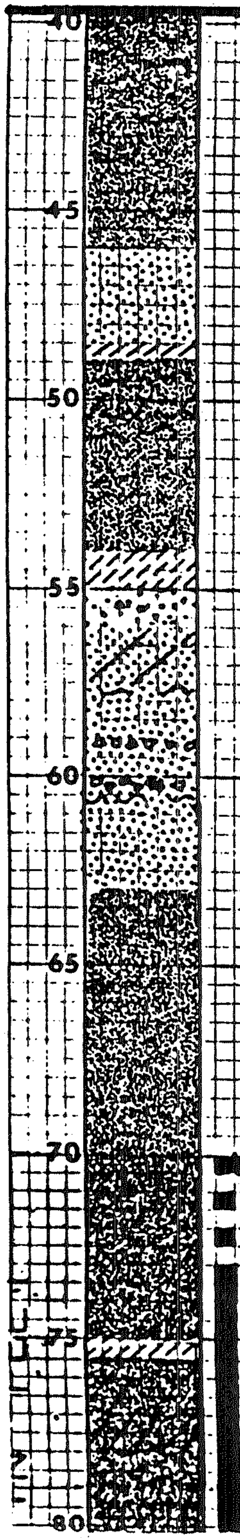
Mud temperature varies from 16-19°C this interval

Bottom hole temperature after sampling = 40.2°C

Sample taken @ 40 ft. Sampler penetration = 137 blows/ft

PS-1-4: Dense, wellsorted fine sand. Peat smears and streaks common. Organic partings contain recognizable plant fragments. Some of these may be datable. Entire sample contains less than 12% silt.

Field Work
PS-1



40-50 ft. Most of this interval medium sand. Drilling rate uniform for entire interval. Little or no gravel present.
Mud temperature 21°C
Bottom hole temp. = 42.5°C following sampling and prior to mud removal from hole for casing.
Sample taken at 50 ft. Sampler penetration = 138 blows/ft.
PS-1-5: Fine to very fine bedded sand with trace silt. Peat smears and other organic fragments common.
Casing set to 50 ft and cemented. Cementing plug drilled out and an aquifer test produced 40 gal/min (pumped) at temp. of 74°C. Static water level in hole is 3 ft below ground surface.

50-60 ft. Drilling character and cutting returns indicate sand and silt to depth of 55 ft where a 1-2 ft gravel layer is encountered then back into sand from 57-60' with one small gravel interval encountered about 59 ft.
Mud Temp = 44 to 47°C this interval
Bottom hole temp not measured due to cable problem.
Sample taken @ 60 ft. Sampler penetration 182 blows/ft
PS-1-6: Top 4 cm gravel - may be slough from above. Next 1-3 cm fibrous peat. Lower 12 cm of sample below peat is moderately well sorted medium sand with a trace silt. Color dark grey to dusky brownish grey.

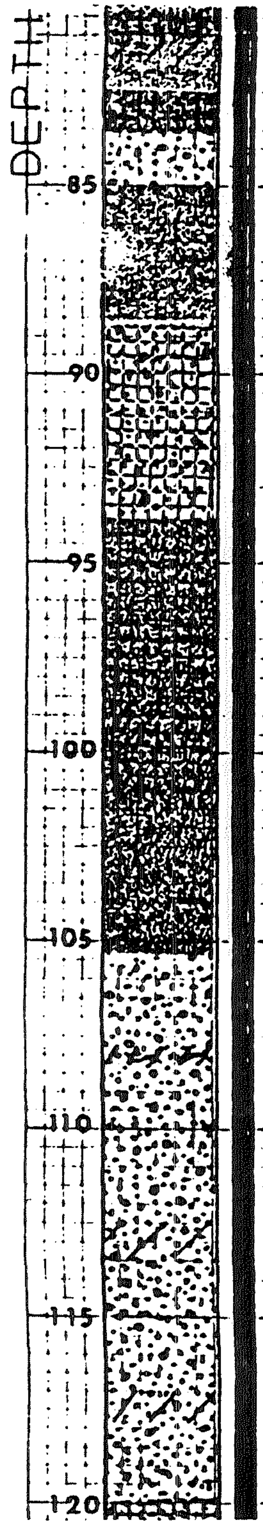
62-70 ft: Drilling rate slowing dramatically between 60 and 68'. Most of this interval med. to fine sand with a trace or less organics and silt.
Mud temp = 49°C
Bottom hole temp. estimated @ 84°C

Sample taken @ 70 ft. with difficulty 640 blows/ft.
PS-1-7 Sample incomplete due to large chunk of aluminum from cementing plug (presumably) wedged in split barrel. 13 cm sample consisted of fine sand with deformed or dipping organic streaks and silt partings. Color med. to dark grey.

70-80 ft: Drilling rate slows dramatically. Authigenic minerals such as pyrite and pyrrhotite begin to appear in cuttings and are accompanied by fragments of cemented fine and med. sand. Fragments of siltstone recovered near 75 ft depth.
Mud temp = 40°C
Bottom hole temp 58°C after 1 hour
Sample recovered @ 80 ft. Sampler penetration 100 blows per inch!
PS-1-8 Only 8 cm of penetration achieved after 800 blows. Sample recovered was well cemented fine to medium grained sandstone containing about 10% sulfides.

Test Well
PS-1

12



80-90 ft: Drilling [illegible] well cemented, interbedded sandstone and siltstone. Pebble gravel intervals encountered between 85 and 90 ft.

Mud temperature = 38°C

Bottom hole temperature - not recorded

No drive sample recovered due to hard formation. Cutting sample collected while drilling between 90 and 95 ft.

PS-1-9 (cuttings): Micaceous sandstone with evident pyrite. Organic fragments noted in cuttings.

90-100 ft: Pebble conglomerate with evident pyrite changes to med. pyrite rich sandstone @ 94 ft.

Mud Temp = 37°C

Sample recovered with great difficulty and hammer weight increased to 240 pounds, estimate 2400 blows per foot.

6" sample recovered.

PS-1-10 - Consisted 3/4" thick sandstone discs separated by thin partings of micaceous silt causing cleavage. Pyrite and pyrrhotite crystals abundant but somewhat less than in previous interval. Suggests that sulfides may occur in [illegible] stratiform.

100-110 ft: Coarse sand intercalated with 3-6 in pebble conglomerate intervals. Sands composed of 60% quartz, 30% lithic (slate) fragments, 10% accessory mineral grains by field estimates. Formation well cemented. Some material strongly resembles some "salt and pepper" sands of Tertiary age in the Healy area.

8 in organic silt interval occurs at 108 ft.

Mud temperature = 42°C

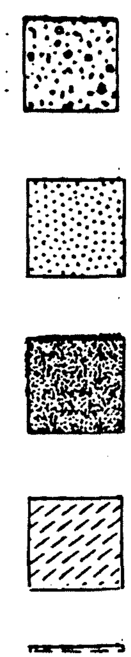
Cutting samples collected at 105 and 110 ft. Confirm above callouts for this interval: PS-1-10.5c, PS-1-11c

110-120 ft: Conglomerate with clasts to 3 in and interbedded coarse sands. Drill vibrates and bounces vigorously in coarse conglomerates. Possible outwash gravels. Material bright "salt and pepper" grey.

Mud Temp = 46°C

Cutting samples collected @ 115 and 120 ft. PS-1-11.5c, PS-1-12c

EXPLANATION



SANDY PEBBLE GRAVEL

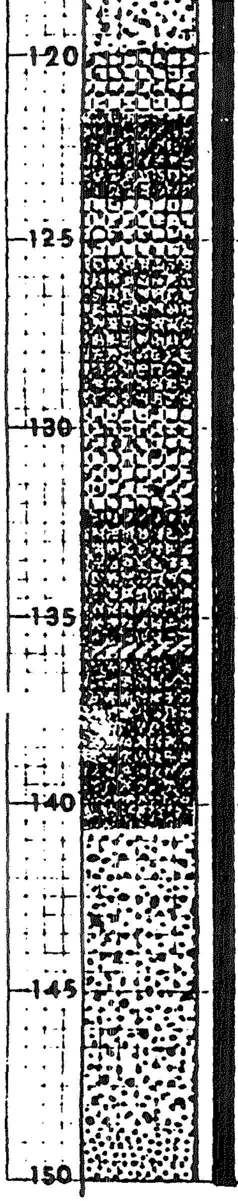
MED. TO COARSE SAND

FINE TO MED. SAND

SILT

Test Well PS-1

Pg 15



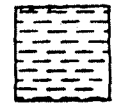
120-130 ft: Cutting samples and drilling rates indicate less gravel and more coarse to med. sandstone this interval. Cementing seems less tight. Sulfides still evident.
Mud Temp. = 47.5 °C

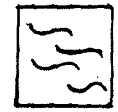
Cutting samples collected at 125 and 130 ft.
PS-1-12.5c, PS-1-13c

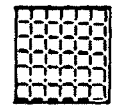
130-140 ft: Upper 2½ ft this interval is sandy pebble gravel, followed by 3 ft coarse pyritic sandstone.
a silty interval just below 135 inferred from drilling characteristics. Coarse sand encountered again 136-140 ft.
Mud temperatures average 48 °C this interval.
Two cutting samples collected, one @ 135 ft and one at 140 ft.
PS-1-13.5c; PS-1-14c

140-150 ft: From 140 to 145 ft. Clean sandy pebble gravel. Poorly cemented medium sand and gravel.
145 to 150 ft

Bottom hole temperature measured after
4 hours = 48 °C


CLAY

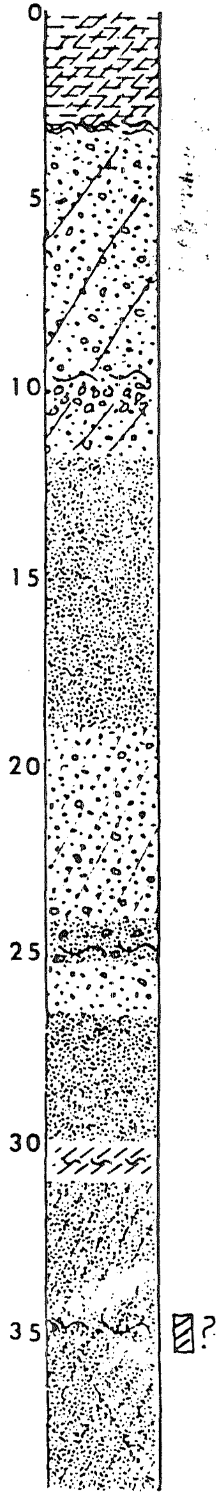

ORGANIC MATERIAL


AUTHIGENIC PYRITE
(INCLUDES OTHER
SULFIDES)


INDICATES PRESENCE OF
INDURATED SEDIMENTS

TEST WELL
PS - 1

Grid Coordinates: 200m S
150m W



0-10 ft Top 10-12" disturbed sandy silt - med brown mottled with bright orange streaks. Next 24" is dark blue gray silt and clay. Buried organic horizon occurs at 3'.
Rest of interval (3-10 ft) is interlayered sand and silt with stringers and lenses of gravel.

Mud temperature = 16°C this interval
Bottom hole temp. = 24.5°C
Circulated clear water to check water table at this location. Water table at -2 ft.

Drive sample taken @ 10 ft - sampler penetration 15 blows/ft

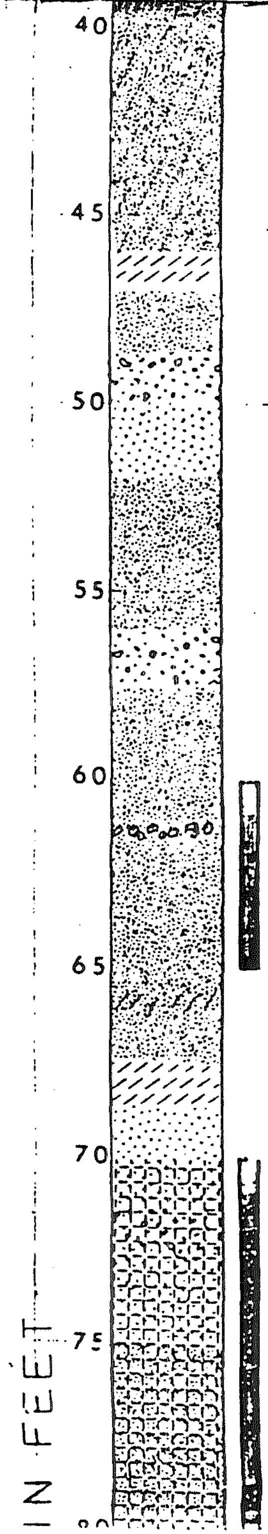
PS-2-1 Med. to coarse sand with some silt and very fine sand, trace pebble gravel.

10-20 ft: Sand and silt to 14'. Gravel layer encountered at 14 ft. which continued to end of this interval. gravel having clasts to 2 in diameter.

Mud temp = 19°C
Bottom hole temp. = 30°C
sample taken at 20 ft. sampler penetration 37 blows/ft.
PS-2-2 Coarse to med compacted sand with some pebble gravel and trace silt.

20-30 ft: Sand and gravel with trace or less silt to 25 ft. Fine to med. sand with organic streaks and plant fragments and trace pebbles to 26.5 ft. Fine to med. sand 26.5-30 ft.
Mud temp. = 21°C
Bottom hole temp - not measured.
Drive sample taken at 30 ft. Sampler penetration = 100 Blows/ft.
PS-2-3 Poorly sorted silt and coarse to med sand with trace organics.

30-40 ft: Difficult drilling 30-34 ft. Drill had to be pulled up and down to accomplish cutting. Possible weakly cemented zone occurs about 35 ft.
fine sand with trace silt 34-40 ft (easier drilling)
Mud temp = 17°C
Bottom hole temp. = 30°C
Sample taken @ 40 ft. Sampler penetration 24 blows/ft.
PS-2-4 Poorly sorted sand with some silt.



10-50ft Drilling very easy thu interval to 49ft where rate slowed. Mostly encountered fine sand with trace to some silt and silt layers. Sandy gravel 49-50ft.

Mud temp = 20°C

Bottom hole temp 85°C at 50ft.

> 75 gal/minute water produced by pumping

Vigorous degassing from hole. H_2S detectors show weak reaction. Gas not flamable. Probably CO_2

Drive sample taken @ 50ft sampler penetration 125 blows/ft.

PS-2-5 med sand with trace to some silt.

Top casing emplaced and cemented.

50-60: Coarse sand with trace to some silt and med sand to 56ft. 56 ~~to~~ 57ft sandy gravel

57-60ft fine to med. sand.

Mud temp 20°C

Bottom hole temp 80°C

Sample taken @ 60 ft sampler penetration 87 Blows/ft

PS-2-6 Predominantly med. sand with trace silt plus scattered intervals of coarse sand and pebble gravel.

60-70ft: Drilling rate decrease and cuttings indicate weakly cemented zone 60-65ft of med. sand with Thin pebble intervals. Hole degassing vigorously 65-70ft appear to be back in uncemented sands and silts

Mud temp = 20°C

Bottom hole temp = 82°C

Sample taken @ 70ft. sampler penetration 150 blows/ft.

PS-2-7 Cemented pebble gravel with some coarse sand pyrite cubes to 20mm diameter.

70-80ft. Drill chattering and bouncing violently. Pyritic hard sandstone siltstone and conglomerate. Large pyrite cubes recovered in cuttings; very micaceous.

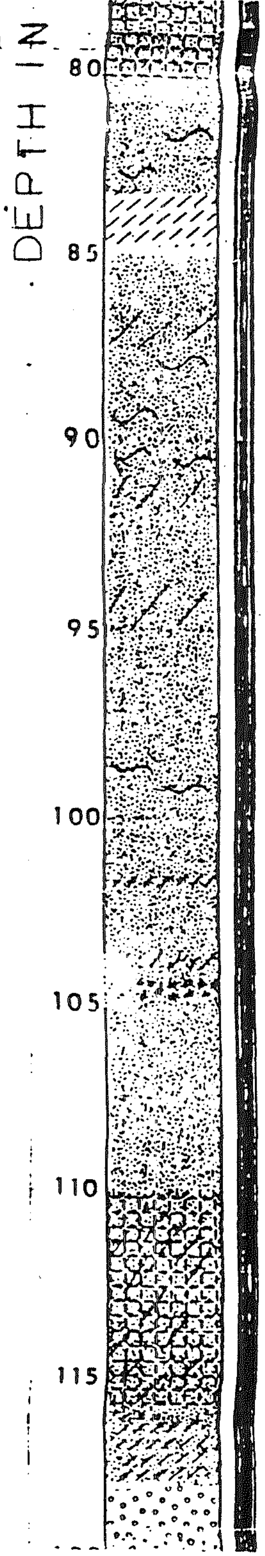
Mud temp = 22°C

Samples of cuttings collected at 75 and 80ft

PS-2-7.5 and PS-2-8 both med pyritic sand. Quartz grains show euhedral secondary growth.

Test Well PS-2

Pg. 18



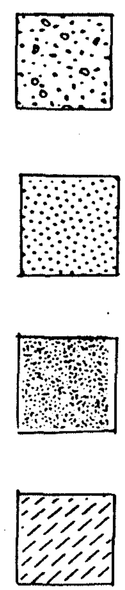
80-90 ft – Silt and fine to med. sand containing mica, organic fragments. Presents as siltstone and subgraywacke. Less pyrite
mud temp = 24°C
Cutting samples collected @ 85 and 90 ft
PS-2-8.5 and PS-2-9

90-100 ft: Cemented fine to very fine sand micaceous showing differential dissolution and redeposition of quartz on grains. Hydrothermal alteration of micas obvious. Some silty intervals
mud temp = 26°C
cutting samples collected @ 95 and 100 ft.
PS-2-9.5 and PS-2-10 – med to fine sand and siltstone fragments less well consolidated than in previous interval at 95 ft
well consolidated at 100 ft.

100-110 ft: Well cemented fine grained well sorted micaceous sandstone with minor siltstone and sandy gravel conglomerate intervals
Mud temp = 30°C
Cutting samples taken @ 105 and 110 ft
PS-2-10.5 and PS-2-11
Cuttings @ PS-2-11 suggest thin bedded sands composition estimated at 80% quartz 10% mica 5-7% cement 3-5% zircon garnet feldspars? and amphiboles

110-120 Conspicuous pyrite zone begins 110-116 ft. Granular coarse poorly sorted silty sand. With some [illegible] pebble gravel layers
Mud temp 25°C
Cutting samples @ 115 and 120 ft.
PS-2-11.5 and PS-2-12
PS-2-11.5 – Coarse grained poorly sorted sandstone with very fine sand and silt ground mass. trace granules (lithic) and pebbles (predominantly quartz)
PS-2-12 – Poorly cemented pebble gravel.

EXPLANATION



SANDY PEBBLE GRAVEL

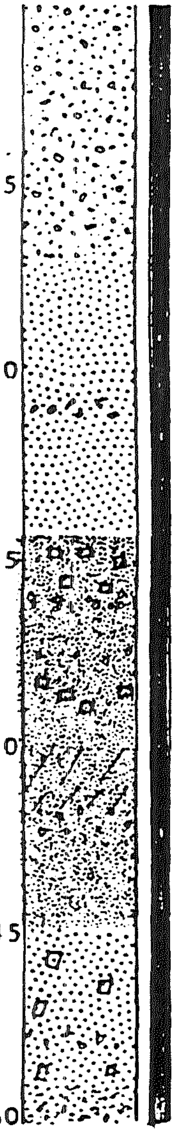
MED. TO COARSE SAND

FINE TO MED. SAND

SILT

Test Well PS-2

Pg. 19



120-130 - Sandy pebble gravel. Clasts sub-angular to sub rounded, mostly lithic and composed of gneiss, mica schist, quartz and slate. Some chalcedony cement looks opalescent. Clastic components suggest short distance of transport.

Mud temp. = 23°C

Samples collected @ 125 and 130 ft.

PS-2-12.5 and PS-2-13

130-140 ft: Coarse Sand first four feet this interval changing to fine to med sand 134-140 ft. Scattered pebble intervals throughout.

Mud temp 20°C

Samples collected at 135 and 140 ft

PS-2-13.5 and PS2-14

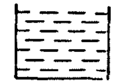
Coarse granular Sand with trace pebbles. Some sulfides occur but seem sparse

PS-2-14- Fine Sand intercalated with med. sand moderately well cemented.

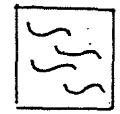
140-150: Medium to coarse sandstone with trace to some silt (Poorly sorted) Opal like cement again noted in what appear to be fissure fillings between 140 and 145 ft

145-150 ft - Coarse to granular arkose sandstone and minor conglomerate. Very minor amounts of sulfide present. Authigenic components more varied. Possibly fluorite. Sorting poor.

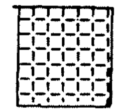
Bottom hole temp after standing overnight = 96.2°C



CLAY



ORGANIC MATERIAL



AUTHIGENIC PYRITE AND OTHER ASSOCIATED SULFIDES

INDICTES PRESENCE OF INDURATED SEDIMENT.

TEST WELL PS - 2

Grid coordinates: 258 m S
207 m W