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INTER-OFFICE MEMORANDUM

SUBJECT: Review and Evaluation of TFD 88-11, Fish Lake Property, Esmeralda County, Nevada (5076A).

DATE: September 10, 1984

cc: P. D. Parker
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TO: H. J. Olson

FROM: J. E. Deymonaz

General

Fish Lake TFD well 88-11 was spudded at 3:30 a.m. on April 10, 1984 and reached TD in a massive loss circulation zone at 8149 feet at 5:00 p.m. on May 19, 1984 (a smaller bit was later run to 8156 feet and encountered minimal resistance). While this period encompasses forty days (Fig. 3), a total of twenty six days (620 hours) was actually spent in the hole. "In hole" time includes adding pipe, reaming, drilling and deviation surveys and averages to a penetration rate of 13.1 feet/hour. Actual drilling penetration varied from 6-45 feet/hour, generally running 12-22 feet/hour.

Completed cost of the well is approximately 2.25 million; however, when the well reached TD at 8,149 feet total cost to that point was just over 1.2 million (Fig. 3). Of this amount about $400,000 was expended in building the drill site and rig MOB. Actual drilling costs to 8,149 feet were about $800,000. Completion, including 9 5/8" casing, cementing 9 5/8" casing, flow testing, additional wellhead equipment and rig time, etc., exceeded 1.0 million.

While most aspects of rigging up and drilling progressed relatively smoothly and at a fairly rapid rate (Figure 3), the completion phase deteriorated into a well reviewed series of delays and problems. An anonymous statement sums up this aspect quite well: "We know how to drill dry holes; now if we can just learn how to complete a producer".

810 - 3920 feet — Tuffaceous sandstones and siltstones - Primarily medium to greenish gray with common rounded lithic fragments. A trace to 3% quartz, 1-5% fresh to argillized feldspars and a trace to several percent fresh to bleached euhedral biotite. Most of the fine matrix material has altered to clay minerals which caused much of the hole drilled in this interval to wash out to over 24 (?) inches in diameter (drilled with 12 1/4" bit). Although the accuracy of the single arm caliper utilized for this logging is in doubt, there is no question that this portion of the hole has been washed out of gauge to major proportions. The common green coloration seen in the tuffaceous material results from alteration to montmorillonite clay minerals.

Calcite veining is common and siliceous veining is rare. Pyrite occurs intermittently, comprises less than one percent when present and is finely dissiminated throughout the rock. Occassionally, pyrite occurs as small masses in calcite veins. Frequent, but minor amounts, of red and gray, laminated to massive, soft siltstones and the variety of textures in each sample indicate rapid changes in grain size. This is seen in the lower 1,000 feet of core from stratigraphic test hole 64-11 where similar material ranges from clays to conglomerates over intervals of a few inches to several feet.

The base of the Tertiary section is marked by red siltstone beginning at 3,900 feet.

3920 - 8149 feet — Siltstone, sandstone, quartzite, phyllite and limestone - Lower Cambrian Harkless Formation. Primarily hard greenish-gray siltstones and fine sandstones which become phyllitic with depth. Minor shales and quartzites were also noted. Calcite veining is common, less commonly chalcedony and quartz fill fractures. Pyrite comprises less than one percent of the rock but is common as finely dissiminated crystals and occassionally as masses in small fractures.

From 7530 - 7780 feet, thin, white crystalline limestone beds or thick calcite veins were penetrated.

A light to medium gray limestone interval was penetrated from 8050 - 8080 feet. Complete loss of circulation of drilling fluids occurred at 8149 feet, however, due to the bottoms-up lag time of circulating fluids the last cuttings retrieved were from 8120 feet.

Structures

Faulting in the Tertiary volcanics near 88-11 trends north-northwest, north-northeast and east-northeast. Most of these structures are high angle with modest displacement ranging from a few feet to a few tens of feet. In the underlying Paleozoic sedimentary rocks, faulting and folding is complex and occurs on a much larger scale. Most mapped pre-Tertiary contacts occur along low angle faults and the units are intensely folded, cut by normal faulting and occassionally intruded by plutonic masses correlative to the Sierra Nevada batholith.

The only obvious structural trend in pre-Tertiary rocks which transcends the area is a northwest series of faults and fold axis. These trends are very pronounced across the north end of Fish Lake Valley and in the Volcanic Hills as gravity (Lange, 1984) and magnetic trends (Berkman, personal communication). On the surface, Paleozoic units outcrop along this trend in the Silver Peak Range. Regionally this area occupies the western limb of the Silver Peak - Palmetto - Montezuma oroflex. The oroflex is a sixty-mile wide southwardly convex series of structures topographically expressed by the curving trend of ranges from which the name is derived. Within the ranges this trend is reflected by bedding, fold axes and faulting in pre-Tertiary formations.

Of particular interest is an outcrop of shale, siltstone, quartzite and phyllite of the Lower Cambrian Harkless formation located seven miles southeast of 88-11 along the west side of the Silver Peak Range. These rocks, exposed over a one square mile area, are very similar to those encountered below 3920 feet in 88-11. Many of the outcrops have steeply dipping (60 - 90°) beds striking northwest. Most frequently the beds dip northeast but southwest dips are also common. The strike of these beds agrees well with the previously discussed Silver Peak - Palmetto - Montezuma oroflex structures and similar structures probably continue in pre-Tertiary units beneath the 88-11 well site.

While drilling the upper 6300 feet of 88-11, deviation remained fairly constant at less than 5° (fig. 2). Starting in a west-northwesterly direction the well drifted in a broad counterclockwise arc. Lithologic variation in the Tertiary section and from 3920 - 6300 feet in the hard, layered and fractured Harkless Formation had little effect on hole deviation. In this section of the Harkless cuttings were very uniform suggesting either this interval is very homogeneous or the drilling assembly was penetrating bedding at a low angle. Given the steeply dipping nature and variations in similar rocks across the valley and in other surface exposures, the latter seems reasonable.

Between 6300 - 6600 feet, deviation dropped suddenly to 1 3/4° and drift direction changed nearly 180°. By 6800 feet the drift direction stablized in a N 19°-21° E direction which was maintained to TD. Following the change in drift a more flexible drilling assembly was run which resulted in a steady increase in deviation to 22° by 7947 feet and probably higher at TD. After turning northeast, lithologic variations in cuttings were much more frequent than previously noted, suggesting that the hole was penetrating the formation at an angle more normal to bedding than before.

The simplest reasoning for the sudden change in hole drift would be the influence of a northeasterly trending fault zone, and several small northeast trending faults do cut across the surface near the wellhead. However, no conclusive evidence of a fault was noted in the cuttings. pre-Tertiary rocks in the region are folded and prevasively broken by faulting which predated the Tertiary section and many of the structures influencing the lower portion of 88-11 are probably not exposed at the surface. The sudden change in, and following straight line drift direction strongly suggest the influence of a north-northeasterly 6rending fault zone which is probably related to pre-Tertiary structures in the Harkless Formation.

To aid in visualizing the actual configeration of the well mentally combine the vertical and plan views in Figure 2 for a three-dimensional picture. While the plan view depicts a wildly cavorting wellbore, the 1:1 scale of the vertical section, which is constructed as if all movement were along a flat plane (about 700 feet total horizontal drift), portrays the well in more realistic proportions.

Lost Circulation Zones

One of the primary criteria in siting the well was to offset it from any known faulting. The well was spudded 200 - 300 feet from the surface trace of any significant faulting. This was intended to minimize fractured formation and associated lost circulation problems in the upper portions of the hole. Due to the steeply dipping attitude of the faults, and the low angle of deviation (less than 5^{o}) above 6200 feet loss circulation was a very minor problem. Below is a summary of drilling breaks and fluid loss zones.

Depth (ft.)	Loss Circ.	Remedy	Total Fluid Loss	Lithology
928	100%	L. C. pills	450 bbls	Tuffaceous sandstone
2876	partial	drill ahead	150 bbls	2 ft. drilling break in tuffaceous sandstone with chalcedony filled fractures
3077	none	drill ahead	-	2 ft. drilling break in tuffaceous sandstone
5420	partial	drill ahead	20 bbl	5 ft. drilling break in siltstone and sandstone (Harkless Formation)
5820	partial	drill ahead	160 bbl	Harkless siltstone and sandstone.
8149	100%	-	2000 bbl	No cuttings below 8120, probably fractured limestone interbedded in phyllites.

Contributing to the "tightness" of the hole is the upper 3920 feet of relatively soft tuffs and tuffaceous sedimentary rocks which appear to function as a sealing cap over the harder, more fractured Paleozoic section. The Harkless Formation, while pervasively fractured, does not tend to maintain large open fractures in the phyllite and phyllitic siltstone/sandstone interval drilled. The convective nature of the temperature gradient below 3920 feet, however, suggests either nearby movement of fluids in a fracture system or fluid movement throughout the pervasively fractured unit (i.e., sponge effect). Below 7550 feet several thin beds of limestone were intercepted and H_2S, CO_2 and methane gasses in the drilling mud increased indicating increased formation permeability. Due to bottoms up time no cuttings were recovered from below 8120 feet, however, the massive loss circulation zone from 8149 - 8156 feet is likely in fractured or cavernous limestone. Since the phyllite encountered previously did not maintain significant open fractures.

The static water level in 88-11 is about 150 feet. This also tended to minimize fluid loss problems by maintaining a relatively low hydrostatic pressure differential between the mud column and formation fluids. Using a mud column fluid pressure of 68 - 74 psi for the upper 150 feet and a 19 - 60 psi/1000 feet pressure difference between the mud column (average 8.7 - 9.5 lbs./gal.) and formation fluids, the pressure differential at 8149 feet would be 222 - 560 psi. Of course pump rates, friction, fluid vicosity and movement of the drilling assembly will increase pressure on the formation but this is the baseline pressure which must first be considered. By contrast, if hydrostatic pressure had only been sufficent to maintain the water level at 2,000 feet, the pressure differential at TD would have been 1050-1300 psi.

Shallow Hydrothermal System

88-11 was spuded in rhyolitic lithic-crystal-air fall tuff which is exposed in cuts around the drill site. At the surface numerous fractures are commonly filled with chalcedony, opalite and quartz deposited during past hydrothermal events. Within the immediate area of the wellhead, fumerolic activity has resulted in extensive argillic alteration, deposition of native sulfur and mercury mineralization along fractures. The nearest surface exposure of sulfur is about 200 feet east of the wellhead. Small north-northwest, east-northeast and northeast trending, high-angle faults provided conduits for the fumerolic activity.

The first cuttings were retrieved when the hole had been drilled 50 feet. These are identical in composition to the surface material with abundant angular to subrounded pumice and aphanitic silicic lithic fragments and crystals of feldspar, quartz and sanidine. From 50 - 110 feet the cuttings have a distinctive pale pink color, while the surface exposures are very light gray. From 110 - 810 feet the color changes to shades of light to light-medium gray with the same general composition as the upper portion. Considerable silicic veining and silica replacement occurs from 210 - 495 feet which reduced penetration substantially during drilling.

In hole 81-14, 250 feet east, a siliceous cap of chalcedony and quartz completely replaced much of the tuff from 429 - 440 feet (Deymonaz, 1983). At 440 feet, 318°F fluids were encountered with intermittent intervals of silicic veining and replacement below. The equillibrated temperature profile in 81-14 after tubing was cemented in place has a very pronounced temperature spike at 440 feet with a sharp 35°F reversal below. Figure 5 illustrates possible relationships within the shallow thermal system.

No hot fluids were noticed while drilling this interval in 88-11, however, 81-14 was air drilled while 88-11 was drilled with mud, and a small hot water aquifer could easily go unnoticed. The temperature profile of 88-11, measured 23 days after shutting it in shows a very similar temperature spike at 480 feet (Fig. 1), although the maximum temperature is 30°F lower. Obviously both holes pass through a sealing cap which prevents present day surface fumerolic activity. Below 495 feet penetration rates picked up and only minor siliceous veining was encountered.

Temperature Surveys

As of July 13, 1984, seven temperature surveys have been run in the well since reaching completion depth of 8156 feet (Fig. 1). The following is a brief summary of each survey:

Pruett 03	6/03/84	Run after initial flow test (6/2/84). Stops at 800, 1060, 2000, 3000, 4000, 5820, 6820 and 7435 ft. where hole was bridged.

Pruett 01	6/09/84	Traverse run after cleaning out hole, hanging seven inch slotted liner to 8140 ft., and attempting unsuccessfully to initiate self-flow by unloading hole with nitrogen for 2 1/2 days.
Pruett 02	6/11/84	Traverse run after attempting unsuccessfully to initiate self-flow by unloading with nitrogen for 4 1/2 days.
Pruett 03	6/11/84	Traverse run in upper 2700 feet of hole just after pumping 1000 bbls. of fresh water down hole under pressure.
Pruett 04	6/21-22/84	Traverse run from 700 - 1750 feet and 6000 - 8100 feet with stops at 3000, 4000 and 5000 feet. Start run 80 min. after shutting in well after 5 days of self-flow.
Pruett 05	6/22/84	Traverse run from 270 - 700 ft. and 6000 - 8100 ft. Start run about 10 hrs. after shutting in well after 5 days of self-flow.
Pruett 08	7/13/84	Traverse run from 40 - 8124 feet 22 days after shutting in well.

An equillibrated temperature profile from hole 81-14, located 154 feet east of 881-11, is also plotted in Fig. 1, as are the mud in/out temperatures recorded whle drilling 88-11.

The most recent survey was run after the well had been shut in for 22 days and appears to be nearing equillibrated formation temperatures. In the upper 2000 feet, temperatures parallel those in 81-14 closely, although the 12 - 30°F lower temperatures seem excessive in respect to the short horizontal distance between the two holes. Breaks in gradient correlate well with the Tertiary/Cambrian contact at 3920 feet and the wells interception with a postulated fault zone between 6100 - 6500 feet. The sudden temperature increase at 7950 - 8050 feet coincides with a limestone interval penetrated at 8050 feet. During drilling, the interval below 7500 feet exhibited an increase in CO_2, H_2S and methane gases. Comparing the mud in/out temperatures, recorded while drilling, to the July 13 survey reveals correlations which may be useful during future drilling activities. Addition of fresh water, drilling breaks and use of a mud cooler produce considerable "noise" in the plot. However, the general trends as related to downhole temperatures are still quite obvious.

Mud temperatures increased very rapidly to about 600 feet then increased at a much slower rate to 900 feet where loss circulation and addition of fresh water cooled the system. Shortly thereafter at 1055 feet, 13 3/8" casing was set and cemented, cooling the system again. This artificial cooling enhances the correlation with the July 13 survey although the relative importance of this versus the formation temperature is not known.

After drilling out of the casing, mud temperatures increased rapidly to about 1700 feet and remained basically unchanged from 1700 - 3000 feet. While part of this increase and change in the rate of increase is simply rebounding of the cooled system, it also coincides with an interval where the gradient is about half of that above 1700 feet. From 3000 - 3900 feet mud temperatures again increase rapidly in an interval with a 54^{o}C/km gradient.

The Tertiary/Cambrian contact is at 3920 feet and below this point the gradient is only 3 - 5^{o}C/km to 6550 feet. Unfortunately, three trips for drilling assembly changes were made between 3910 and 4425 feet during a 72 hour period. From 3900 - 4200 feet the system reflects a cooling trend then increases during a period of two closely spaced bit changes. A mud cooler was incorporated into the system at 4500 feet and reduced temperatures 40 - 50^{o}F in less than 24 hours.

Since the mud cooler and closely spaced breaks in drilling occurred at about the same time as the hole passed into sediments of the Harkless Formation, the effect of the change to a very low formation temperature gradient is difficult to observe. Mud out temperatures, after the initial decline, do continue to increase below this point but at an average rate of 6.5°F/1000 feet while prior to using the mud cooler they increased over 12°F/1000 feet. Had the formation temperature gradient continued to increase at a higher rate, the mud temperatures would have likely continued at a similar rate of increase even after installation of the mud cooler. Mud temperatures below 7500 feet increase a bit more rapidly, however, the increase is very minor when observing the overall rate of increase. A more interesting comparison is the difference between mud in/out temperatures. Prior to installing the mud cooler, in/out differnce were 10 - 12°F and after installing the unit a 20 - 22°F spread was noted (Fig. 1). This is to be expected since the mud cooler operates between the surface intake and discharge.

From 6550 - 6650 feet, formation temperatures increase rapidly about 8°F as the hole turns parallel to a northeasterly trending fault zone. During part of this time interval the mud cooler was off line allowing the mud system to heat up quickly. Below 6700 feet the difference in mud in/out temperatures increases steadily to 47°F at 8000 feet signifying an increase in formation temperatures. The July 13 temperature survey does not reflect a steady increase in temperature, rather it indicates the existence of two sharp temperature increases; an increase of 7.5°F from 6485-6653 feet and a 10.9°F increase from 7889-8049 feet. Below 6800 feet the hole is open around a slotted liner and convection or vertical fluid movement in the annulus may be masking true formation temperatures. Based on the uphole correlation between mud and formation temperatures, the actual formation gradient below 6800 feet is probably more gradual than depicted on the July 13 survey.

Another possible alternative for the two sharp increases is simply an instrumental one. According to this theory the Kuster temperature tool was jarred as it passed over the lip of the 9 5/8" x 7" liner hanger at 6563 feet resulting in a purely mechanical jump in recorded temperature. A sudden change in recorded temperature due to a physical shock is a fairly commong occurrence with Kuster temperature equipment in which the driving mechanism is a bimetallic coil which expands as temperature increases. The free end of this coil is attached to a stylus which scratches a blackened metal foil. The operation is similar to ordinary dial type window thermometers that use a metal coil to move a small pointer. Hole deviation at this depth is 3.75° and the 1 3/4 inch tool was most likely sliding along the 9 5/8 inch casing which would insure contact with the 1 1/2 inch wide liner hanger lip.

There are several problems which tend to negate this explanation: 1) the upper increase begins at 6485 feet and the reported top of the liner hanger is at 6563 feet; 2) the increases are gradual when studied in detail; the upper step occurs over a 168 foot interval during a 12 minute period and the lower increase over a 160 foot interval during an 8 minute period, whereas mechanical increases I have observed occur very suddenly; 3) the travel rate was about 20 feet/minute (4 inches/second) which would result in a very minimal impact between the bullnosed 1 1/4 inch tool and the 1 1/2 inch beveled liner hanger lip; 4) at the lower temperature jump, no obstacles are known to exist and no indication of one was noted during the survey; 5) due to the compressed depth scale on Figure 1 the gradients at these steps appear extremely high; in reality the upper and lower temperature increases have average gradients of 4.47 and 6.80^{o}F/100 feet respectively.

Production appears to be primarily from the section below 8000 feet. On the July 13 log, only this interval approaches temperatures measured shortly after flowing the well. Actual production is most likely from the massive loss circulation zone below 8149 feet. The kick at 8000 feet may represent either local convection in the wellbore or an increase in the open interval resulting from initial open hole flow testing. Upon reentering the well after initial testing a blockage was encountered at 7435 feet. When the hole was cleaned out prior to running the liner, large volumes of finely broken formation were cleaned out of the hole. If the fractured producing zone is in close proximity to the well, the initial testing, which included unloading fluids with nitrogen from this interval, may have literally blown away a portion of the wall rock separating the two.

The very low gradient in the pre-Tertiary certainly suggests fluid convection along or near the wellbore. If this is the case, numerous small fractures may provide an undetermined percentage of fluid when flowing the well.

In retrospect, mud in/out temperatures provided an excellent parallel to formation temperature gradients encountered while drilling. Both increases in mud temperatures and spreads between in and out temperatures reflected actual downhole changes.

Due to minimal lost circulation problems and a fairly steady drilling rate, mud temperatures while drilling 88-11 produced an excellent correlation to formation temperature changes. While the use of a mud cooler greatly depressed mud temperatures, increases in formation temperatures resulted in a considerable spread in the in/out temperatures and a slight increase in mud out temperature. In wells with major and fairly continuous loss circulation problems and frequent breaks in drilling the correlation between mud and formation temperature would not be so pronounced as in 88-11. However, it is still the most direct continuous (hopefully) and available physical link between formation temperature and the process of drilling the hole and should be used as a qualatative indicator of changes in formation temperature.

Two time-temperature surveys were made while drilling the well. On May 2, a six-hour survey was run at 4319 feet. Although the Kuster tool was moved several times and the resulting data of dubious quality, a temperature of 361°F was projected. Formation temperature at this depth from the July 13 log is about 336°F.

The second time-temperature survey was run on May 11 and 12 at 6147 feet and the tool remained static for six hours. Equillibrated formation temperatures were calculated using methods published by Crosby (1977) and Roux and others (1980). Using the Crosby method a formation temperature of 365 - 68°F was forecast, and the Roux, et al. method gave a temperature of 405°F. Measured temperature from the July 13 survey is 338°F.

As with other time-temperature projections I have observed, where later equillibrated temperature measurements were made, the projected temperatures have been high. Calculations for these projections must be based on several assumptions, some or all of which do not occur in most wellbores. I believe the most important is the assumption of conductive heating and cooling with no fluid movement outward from the wellbore. Unfortunately, this does not seem to be a very realistic assumption.

On the positive side, the projected temperatures (Fig. 1), using Crosby's method indicates a very slight increase in formation temperature from 4319 to 6147 feet and this is reflected on the July 13 log. As with mud temperatures and other parameters which can be measured during drilling operations, time-temperature projections should not be used as "proof-positive" of absolute formation temperatures. Utilized together with lithologic information, gas entries and mud temperatures reasonable estimates of increases and/or decreases in formation gradients and to a lessor degree, formation temperatures can be made.

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REFERENCES

Albers, J. P., and Stewart, J. H., 1972. Geology and mineral deposits of Esmeralda County, Nevada; Nevada Bureau of Mines and Geology, Bull. 78.

Crosby, G. W., 1977. Prediction of final temperature: Second Annual Workshop on Geothermal Reservoir Engineering, Stanford University, California.

Deymonaz, J. E., 1982. Drill history, well 81-14, Fish Lake property, Esmeralda County, Nevada: AMAX Exploration, Inc. I.O.M.

Deymonaz, J. E., 1983. Evaluation of well 81-14, Fish Lake project, Esmeralda County, Nevada: AMAX Exploration, Inc. I.O.M.

Deymonaz, J. E., 1984. Hydrologic control of the shallow heatflow anomaly on the Fish Lake project, Esmeralda County, Nevada: Steam Reserve Corp. I.O.M.

Lange, A. L., and Avramenko, W., 1984. Report on gravity survey, Emigrant property, Nevada: for Steam Reserve Corp.

Robinson, P. T., 1964. Cenozoic stratigraphy and structure of the central part of the Silver Peak Range, Esmeralda County, Nevada: Ph.D. Thesis, Univ. of California, Berkley.

Robinson, P. T., and Crowder, D. F., 1973. Geologic map of the Davis Mtn. quadrangle, Esmeralda and Mineral Counties, Nevada and Mono County, California: U.S. Geol. Survey Geol. Quad. Map GQ-1078. Scale 1:62,500.

Robinson, P. T., Stewart, J. H., Miola, R. J., and Albers, J. P., 1976. Geologic map of the Rhyolite Ridge quadrangle, Esmeralda County, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ-1325. Scale 1:62,500.

Roux, B., Sanyal, S. K., and Brown, S. L., 1980. An improved approach to estimating true reservoir temperature from transient temperature data: 50th. Annual California Regional Meeting, Society of Petroleum Engineers.