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WATER ENTRY BELOW STEAM PRODUCTION: A Case History at the Geysers

by George Frye

Burmah Oil and Gas Company has drilled over twenty (20 holes in the southeast portion of The Geysers steam field; to date only one has proved nonproductive. This report documents a case history unique to Burmah of a water entry below steam production.

HISTORY

A 12-1/4" hole was drilled to 3000' and 9-5/8" OD casing was cemented to the surface. Burmah then directionally drilled an 8-3/4" hole with air and encountered minor steam entries at 5120', 6335', and 6467', as shown on Figure 1. No additional steam entries were found below these depths. Total steam flow measured less than 20,000 pounds per hour.

At 7580' an increase of air pressure on the stand pipe from 420 psig to 580 psig was noted. The well started making 128 barrels per hour of water having a temperature of 188-190°F measured at the surface. The partial chemical analysis of this water is listed on Figure 2, Column 1. Air drilling continued to 7665' with no decrease in water production. Drill pipe was pulled out of the hole to 4363' and air circulated for four (4) hours. The well produced only steam, no water. No temperature or pressure survey was run. The lack of water at 4363' indicates a water pressure of less than 1355 psig.

Since the hole produced a sub-commercial rate of steam, Burmah decided to plug the hole and directionally redrill the hole in a more westerly location. Steam entries were encountered at 4259', 4362', 5480', 5660', 5943', 6731', 6858', and 6980'. Figure 1 shows the location of these steam entries. The hole produced approximately 120,000 pounds of steam per hour after the last steam entry. Again the hole produced water, but at a lower rate of approximately 80 barrels an hour. The analysis of this water is shown on Column 2 on Figure 2. The water entry indicated by the increase of standpipe air pressure was at 7138'. No pressure or temperature survey was run. The hole was plugged with 43 sacks of cement. The drill pipe stuck while pulling out of the hole. The best estimate of the top of the plug is 6830' measured by the free point indicator on the stuck pipe. The stuck drill pipe was partially recovered to 6062'. Further recovery attempts proved unsuccessful.

After the drilling rig was released, the surface well head pressure stabilized at 484 psig. A static pressure and temperature survey stopped

at 3515'. The survey indicated essentially saturated steam. At a later date the well, when first opened for a flow test, produced water along with steam. Column 3 of Figure 2 lists the partial chemical analysis. Subsequent flows at higher rates produced saturated steam with no entrained water. The isochronal testing indicated a flow rate of 86,000 pounds of steam per hour. An analysis of the steam condensate produced at this flow rate is shown in Column 4 of Figure 2.

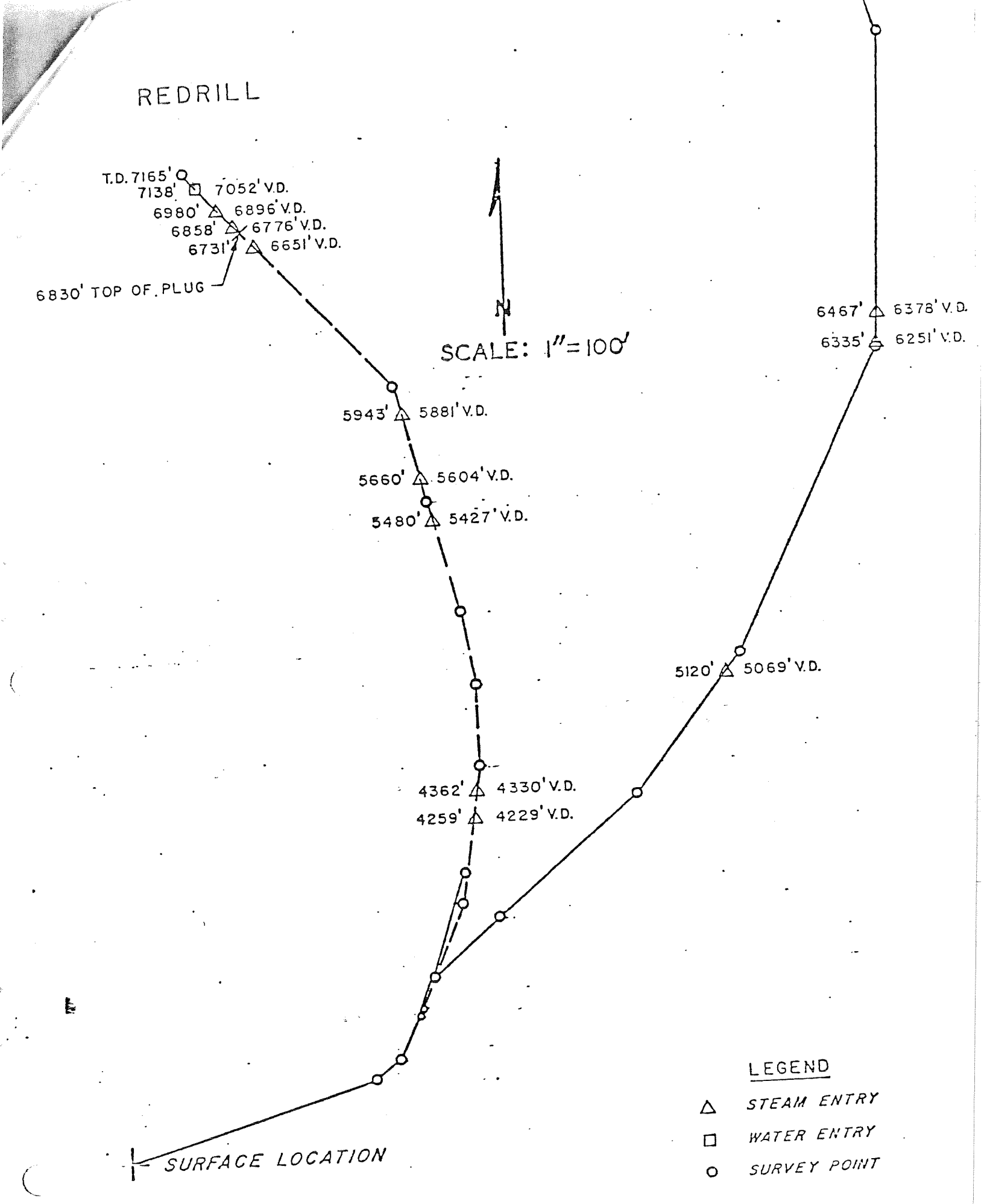
DISCUSSION

The chemical analyses of the two water entries are similar but not identical even given allowances for sampling and testing errors. The samples are dissimilar enough to preclude the positive conclusion that they are the same water. It is plausible that the two waters, though sharing a common origin, are located in separate fracture systems. Both water entries are in silicious argillites.

The water produced on the first test (Column 3) indicates contamination from cement (pH and chloride) and also some evaporation of the deep water as inferred from the increased boron concentration. The analysis of the steam condensate is typical of steam condensate analyses of wells in the surrounding area. A physical chemistry analysis has not been attempted to determine if the chemical constituents of the water and steam are in equilibria.

A review of the wells in the surrounding area shows this well to be bounded by commercial production 2100' to the north, 4000' to the west, 1100' to the south and 3700' to the east. None of these wells showed any indication of deep water entries. It should be noted, however, that none of these wells reached the equivalent vertical depth of the water entries in the original hole or redrill of the subject well. Other wells at greater distances always have been drilled to at least 700 vertical feet below the deepest water entry. The vertical and horizontal difference between the two water entries of 407' and 540', respectively, indicates a possible structural rather than an hydrological control of the water in this localized area. Because temperature and pressure surveys were not conducted while the holes were producing water, conclusions about steam-water communication and equilibrium are difficult.

Due to the physical condition of the hole (apparent sharp dog leg and pipe left in the hole), it is not possible to positively demonstrate by temperature and pressure surveys that the water has been shut off by the cement plug. However, it is certainly inferred indirectly by the quality of the steam produced during the well test. The loss of steam flow rate indicates also that at least the bottom two steam entries were effectively plugged.



BURMAH OIL AND GAS COMPANY

CHEMICAL ANALYSES

	1	2	3	4
pH	5.3	5.1	8.4	5.7
Specific Conductance μmhos/cm @ 25°C	650.0	1000.0		
Calcium, mg/l	<10.0	10.0		<.1
Magnesium, mg/l		37.0		.005
Ammonia, mg/l		43.1		25.2
Sodium, mg/l	146.0	117.0		<.1
Iron, mg/l				1.0
Boron, mg/l	82.8	24.1	142.0	2.4
Potassium, mg/l	110.0	86.0		<.01
Aluminum, mg/l		<.02		<.1
Mercury, μg/l		54.0	1.5	2.4
Sulfate, mg/l		414.0		10.0
Chloride, mg/l	41.0	10.0	26.0	2.0
Fluoride, mg/l		8.0		<.01
Bicarbonate, mg/l		12.2		80.0
Nitrate, mg/l		2.2		15.5
Silica, mg/l		400.0		1.2
Sulfide, mg/l				100.0

1. Water entry of original hole.
2. Water entry of redrill.
3. Water produced on initial well flow.
4. Steam condensate at 85,000 pounds per hour flow rate.

Figure 2

INVESTIGATION OF A FLUID BOUNDARY

George A. Frye
Aminoil USA, Inc.

Aminoil is a subsidiary of R. J. Reynolds Industries, Inc., and successor to Burmah Oil and Gas Company. Our drilling activities in the southeast part of The Geysers area have proved geothermal steam reserves to power 300 megawatts of electric generating capacity. In the past year Aminoil has conducted exploratory drilling activities outside of the proven productive area in order to establish additional reserves. One of these areas is discussed in the paper.

The area of investigation is characterized by the intersection of at least three regional lineaments. These lineaments are discernible from satellite imagery of the NASA LANDSAT (formerly ERTS) program. The lineaments are confirmed by medium to low altitude color stereo pair photographs. On the surface these lineaments sometimes lack enough discernible ground displacement to be characterized as faults. These lineaments do coincide with cliffs, truncated ridges, major creeks and stream offsets. Figure 1 indicates the location of these lineaments by long, dashed lines.

Shown also on Figure 1 by smooth, continuous lines are isopleths of heat flow gradients. They were obtained from Aminoil's extensive shallow (300 to 1000 feet) hole drilling in the area. The intersection of the lineaments also coincides with closely spaced isopleths. Heat flow gradients, while a good indication of geothermal resources at depth, do not always assure commercially productive wells.

Locations A through E indicate holes drilled to at least 7200 feet on Figure 1. Locations B and C are commercially productive steam wells. Even though Locations A and E are located in areas of higher heat flow than C, only minor steam entries were encountered at depths from 6000 to 8000 feet. A minor steam entry was also encountered in Location D.

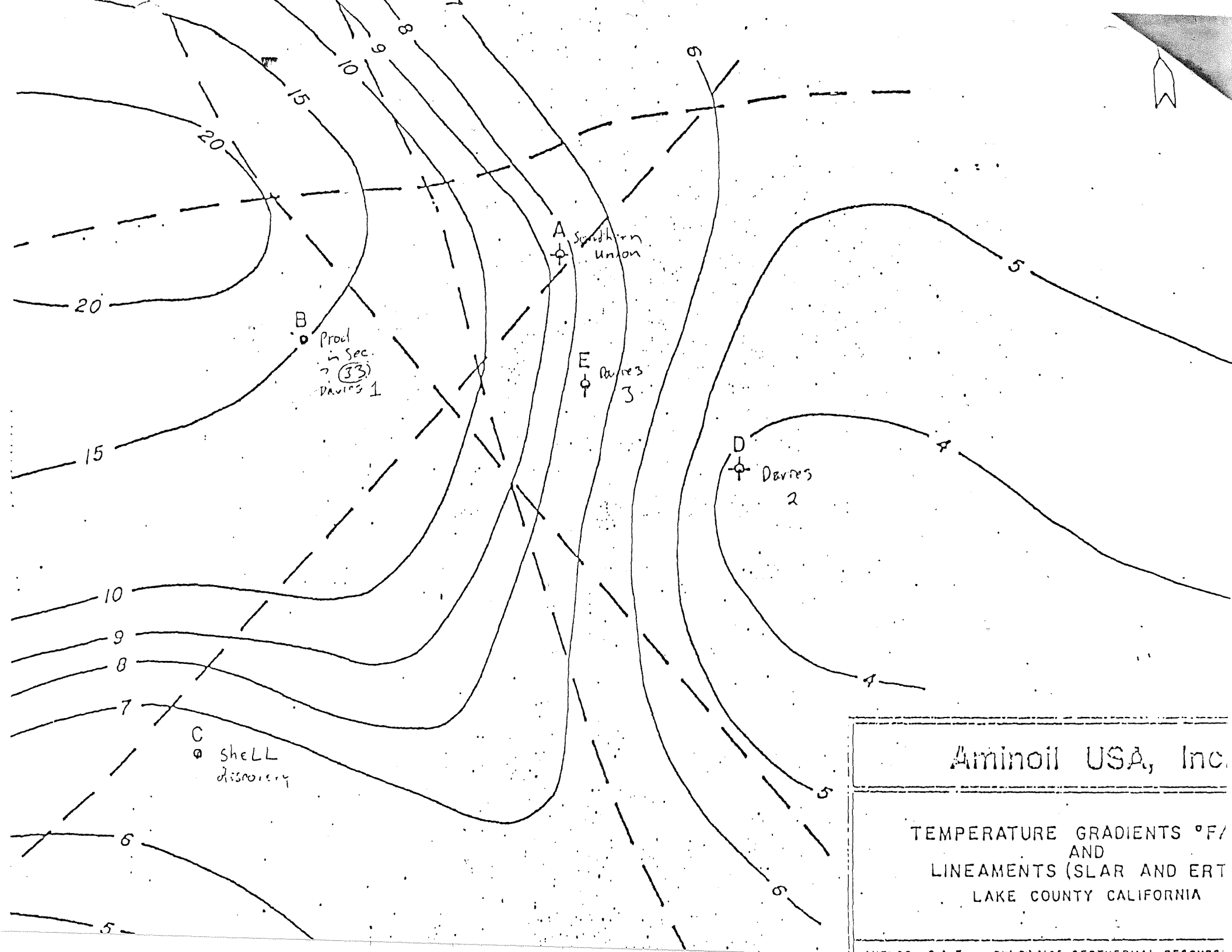
The rocks of the steam-producing zones of Aminoil's proven areas are predominately silicified metagraywackes with lesser varying proportions of greenstone, chert, serpentine and argillite and may be more accurately described as a melange unit of the Franciscan formation. Locations B and C fit this description. Comparison of the productive sections with those encountered in Locations A, D, and E show the sections of the two areas to be quite different. The last three holes all drilled thick sections of argillite with minor interbedded metagraywacke.

These three holes never drilled out of this sequence. The entire sequences in these three holes are also characterized by their general lack of silica. Silica is common in the majority of Aminoil's producing wells. A few of these deeper wells may have penetrated an argillite section below productive metagraywacke and show minor or no production from those zones. Argillites did occur in the steam zone of one well but were associated with up to 60 percent silica.

Of particular interest is Location E. A water entry encountered at approximately 5100 feet was analyzed and is shown on Figure 2. A sample was collected while air drilling and this analysis shows the water to be considerably more saline with less hardness than the water entries reported at the 1975 Stanford Geothermal Reservoir Engineering Workshop. Additional drilling encountered a minor steam entry below 7500 feet. The hole is now suspended and surface wellhead pressure is approximately 50 psia. The steam to noncondensible gas molar ratio is about 50 or more than a tenfold decrease of Location B. Methane and nitrogen account for most of the increase of noncondensible gases. An analysis of the steam condensate is shown on Figure 2. The sulfide content over twice Aminoil's field average and is consistent with the overall increased amount of noncondensible gases.

Fifteen days after the drilling rig was released at Location E, a static temperature and pressure survey was conducted. Saturated steam was recorded to a 7070 foot fluid level. Below this fluid level the liquid continually increased in enthalpy with increasing depth. A maximum temperature of 464° F., was recorded at total depth.

The phenomena discussed above led to the tentative conclusion that there is a fluid boundary with Locations B and C on the productive side and A, D, and E, all nonproductive. Aminoil believes the change in rock types to be significant. The change may be attributed to the lineaments although structural correlations in the Franciscan formation are difficult to substantiate. Even though there were minor steam entries in the nonproductive holes, the heat gradient surveys indicates a rapidly decreasing heat flux from the productive area. Changes in gas to steam molar ratio and the increased hydrogen sulfide at Location E may be attributable to the small volume of the steam entry with relation to the open hole surface area. However, the increased percentage of methane supports a fluid boundary conclusion. Further examination of the water in the hole at Location E is planned using a bottom hole sampler. These analyses will be designed to test for thermodynamic phase equilibrium of the fluid with known equilibria phenomena of the productive area.



Aminoil USA, Inc.

TEMPERATURE GRADIENTS °F/
AND
LINEAMENTS (SLAR AND ERT
LAKE COUNTY CALIFORNIA

CHEMICAL ANALYSES, LOCATION E

	Water Entry	Condensate
pH	9.0	6.1
Specific Conductance μmhos/cm @ 25° C	2250	400
Calcium, mg/l	<1.0	<.4
Magnesium, mg/l	<1.0	<.2
Sodium, mg/l	530	0.6
Potassium, mg/l	55	0.05
Sulfate, mg/l	65	<0.5
Chloride, mg/l	480	1.5
Boron, mg/l	66	.06
Fluoride, mg/l	5.2	<.01
Aluminum, mg/l	<0.1	-
Mercury, μg/l	<0.002	.0
Silica, mg/l	205	1.3
Sulfide, mg/l	-	210
Ammonia	1.5	35
Bicarbonate	-	240