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Using Fluid Inclusion Stratigraphy Analyses to Distinguish Producing Wells from Non-producing Wells in the Coso Geothermal Field, California

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ABSTRACT

A method for using bulk fluid inclusion analyses performed on well cuttings is now being tested for possible use on geothermal wells. Similar analyses are used by the petroleum industry. Here we report preliminary results of this project - the use of fluid inclusion analyses to distinguish between producing and non-producing wells. Approximately 1,700 samples, from three producing Coso wells and one non-producing Coso well, were analyzed at a commercial laboratory, Fluid Inclusion Technology, in Tulsa, Oklahoma. Volatiles released from fluid inclusions in well cuttings crushed under vacuum were analyzed using mass spectrometry. Analyses of samples from producing and non-producing wells show distinct differences in relative concentration between select species including water, carbon dioxide, nitrogen, methane, and hydrogen sulfide, as well as the ratio of pentane/pentene. Water released during analysis of the non-producing well chips from all depths is about 2 orders of magnitude less than that from producing well chips. The low water yield is attributed to a low fluid inclusion density. Our preliminary results indicate that fluid inclusion analyses can readily differentiate producing wells from non-producing wells, and that this determination can be made before drilling is completed.

1 INTRODUCTION

Fluid Inclusion Stratigraphy (FIS) is a new technique developed for the oil industry in order to map borehole fluids (Hall, 2002). We are studying this method for application to geothermal wells, funded by the California Energy Commission. For this study, fluid inclusion gas geochemistry analyses are performed on chip samples from Coso geothermal field wells. The working hypothesis is that areas of groundwater and geothermal fluid flow can be inferred by the amounts of volatile species and the gas ratios in bulk fluid inclusion gas analyses of well cuttings. Analyses for this study were performed by Fluid Inclusion Technologies, Tulsa, Oklahoma, a commercial laboratory that performs fluid inclusion gas analyses for the petroleum industry.

Fluids trapped in inclusions as alteration minerals develop in geothermal systems are generally faithful indicators of pore fluid chemistry. Temperatures and composition of geothermal fluids are sensitive indicators of their origins, evolutions, and the processes that have affected them. Samples of these fluids are trapped in inclusions in vein minerals formed by circulating waters and in minerals within micro-fractures that form in the surrounding wall rocks. The results of mass spectrometer analyses of these inclusion gases show fluid sources and processes within geothermal systems (Norman 1997; Blamey 2002).

FIS is used in the oil industry to determine hydrocarbon-bearing zones, seals that limit fluid flow, and fluid interfaces. Intervals of hydrocarbon fluids are traced from hole to hole when several boreholes have been analyzed. The FIS method analyzes volatiles in fluid inclusions using mass spectrometry. The commercial process, developed in part by Fluid Inclusion Technology (FIT), is highly automated, with thousands of analyses made in a day. This results in turnaround times measured in days and costs that are comparable to other logging methods. The procedure gives a down-hole map of fluid distribution and chemistry when plotted on borehole logs.

The purpose of this research is to develop the FIS technique for geothermal reservoir assessment use. The assessment techniques seek to provide ways to distinguish non-producing from producing geothermal wells, and to identify major fluid flow zones and entrants of cold or steam-heated waters into the reservoir. As part of this continuing research, we have developed a preliminary method for determining if a well will be a production well or a non-producer.

The Coso geothermal system is located in California about 160 miles NNW of Los Angeles and produces about 272 MW of electrical power. The Coso geothermal reservoir is located in an active dextral strike-slip fault system (Wicks et al., 2001) and is hosted entirely within Mesozoic plutonic and metamorphic rocks similar in nature to those occurring in the southern Sierra Nevada. Reservoir rocks range in composition from leucogranite to gabbro and include a mixed complex (Whitmarsh, 1998). The geological complexity and age of basement rocks makes Coso an ideal place to test the FIS analyses on a geothermal system.

2 METHODS

Four wells from the Coso Geothermal Field were selected for the first round of analyses. These well locations are shown in Figure 1. Three of the wells are producers and one, Well 3, is a non-producer. One of the three producing wells has entrants of cold water, and another is an exceptional producer. Splits of 10 to 20 grams were taken from drill cuttings at 20-foot intervals for each well. A total of 1,729 samples were submitted to FIT for analysis. Analyses were performed on clean gram-sized samples by crushing the samples under vacuum to release the volatiles. The released volatiles are then pumped through multiple quadrupole mass spectrometers where molecular compounds are ionized and separated according to their mass/charge (m/e) ratios. Electronic multipliers detect the signal, which is then processed to create a mass spectrum for each sample. The output data for each sample is the magnitude of peaks for m/e 2 to 4 and m/e 12 to 180. The volatile CO_2 has a gram-formula weight of 44 and will be measured by the magnitude of the peak at mass 44, and so on. FIT returned their raw data within three weeks after the samples were submitted.

The raw data was converted using an Excel macro, which produced a row of data for each sample. For each well, the magnitude of each mass peak was plotted versus depth. Select m/e for common geothermal gaseous species and ratios of m/e peaks that represent selected gas ratios were then compared by plotting data for all four of the wells on similar graphs. For example, the N2/Ar ratio was displayed by plotting m/e 28/40 (28 and 40 are the respected GFW weights of N2 and Ar). The propane/propene ratio was approximated by m/e 43/39 or 43/41, which are the respective major mass spectrometer peaks for propane and propene.

3 RESULTS

Plots of Well 3 analyses are clearly different from those of Wells 1, 2 and 4 for a number of gas species and gas ratios. Examples given are the analyses for the water, CO_2, H_2S, and propene/propane peaks (Figs. 2 to 4). Well 3 analyses usually show lower values, lower sample-to-sample variations, and generally, the analyses from the top to the bottom of well 3 show less variation than do analyses for Wells 1, 2, and 4. Table 1 gives the species and ratios for which Well 3 analyses are clearly distinguishable from those for the other three wells. Well 3 analyses do no stand out as clearly for m/e = 15 (organic fragment), 26 (organic fragment) and 40 (argon). Well 3 argon analyses (Fig. 5) are somewhat different from those from Wells 1 and 4, but are similar to analyses of Well 2 chips. Aside from argon, m/e peaks for the major geothermal gas species can be used to differentiate producing and non-producing wells. Graphs of the water peak show the most remarkable differences between producing and non-producing wells.

4 DISCUSSION

A low amount of water in the fluid inclusions is a significant factor that distinguishes producing from non-producing geothermal wells. Geothermal fluid inclusions are comprised principally of water. FIT crushes each sample with an identical force. Therefore, low water in an analysis indicates few inclusions were opened, which implies a low density of fluid inclusions. We assume that Well 3 wall rock contains metamorphic fluid inclusions. The similarity of the fluid inclusion analyses from top to bottom of the well for most species agrees with a metamorphic origin for the inclusions. Regional metamorphism subjects rocks to uniform physical and chemical conditions over distances measured in kilometers, hence it is reasonable that metamorphic fluids were homogenous over the distance of a drill hole. It is not entirely clear why Well 3 has a low fluid inclusion density. It could be because there were limited fluids fluxing through Coso reservoir rocks during metamorphism. It could be because the high strain rates at Coso and the continuing deformation destroy inclusions over time. Our data at this point suggest that fluid inclusion density in country rock is quite low, and inclusion density is much higher in rock within a geothermal system. Water analyses suggest that rock at all depths in the Coso geothermal systems was affected by geothermal fluids.

The hydrogen sulfide and carbon dioxide graphs show that Well 3 does not contain the same amounts of fluid inclusion gaseous species as the three producing wells. This indicates that the geothermal fluids present in the producing wells were not the same as those present in Well 3.

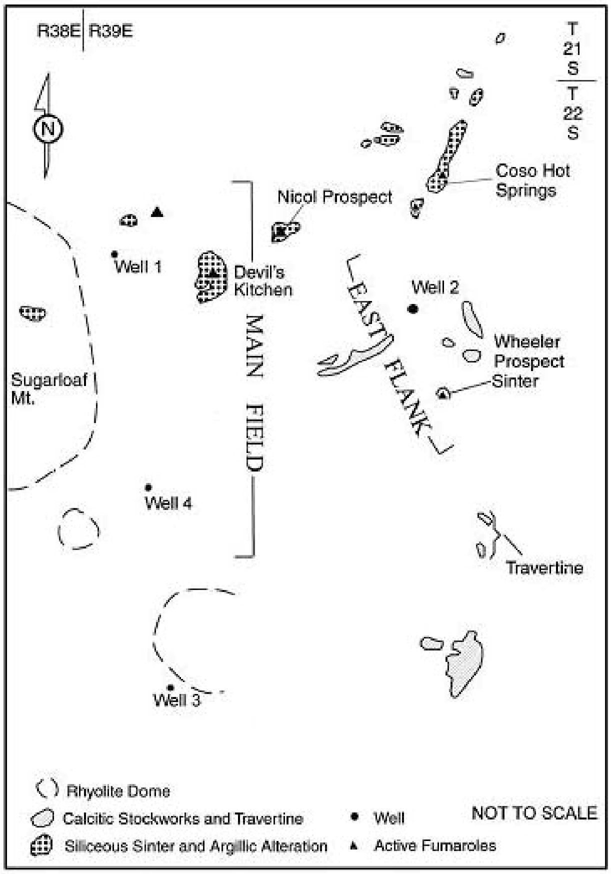

Figure 1. Location of wells used in the study shown on the surface features of Coso. (After Lutz et al., 1999).

The m/e 18 analyses from producing wells vary from values similar to Well 3 to peaks up to two orders of magnitude higher. There is ample evidence that these peaks are associated with entrants of geothermal and cool waters into the wells (Dilley et al., 2004). Therefore the data suggest that limited areas of the producing wells have background levels of inclusions, and the areas with higher densities of inclusions are related to fluid flow that most probably was directed along fractures.

Species other than water also show alternating background values similar to Well 3, as well as peaks of much higher values. However, the peaks are commonly higher in specific portions of the wells. For example, H_2S maximum values occur between about 4,500 and 6,000 ft in Well 2 and below 7,000 ft in Well 3. This is expected if a recognizable fluid stratigraphy is present with fluids of different compositions occurring at specific depth intervals. Overall, the differences between Well 3 CO_2 and H_2S analyses and those from the producing wells indicate that fluids of different chemistries fluxed through the reservoir rocks. Although Well 3 analyses generally show lower amounts of hydrogen sulfide and carbon dioxide with respect to the producing wells, this is not the case with some of the other species, as selected intervals of Well 3 have analyses similar to those from producing wells. Producing and non-producing wells do not show a difference between CH_3^+ or NH^+ (15), $C_2H_2^+$ (26) and Ar (40) amounts. Table 1. indicates which species are useful in distinguishing a producing well from a non-producing well.

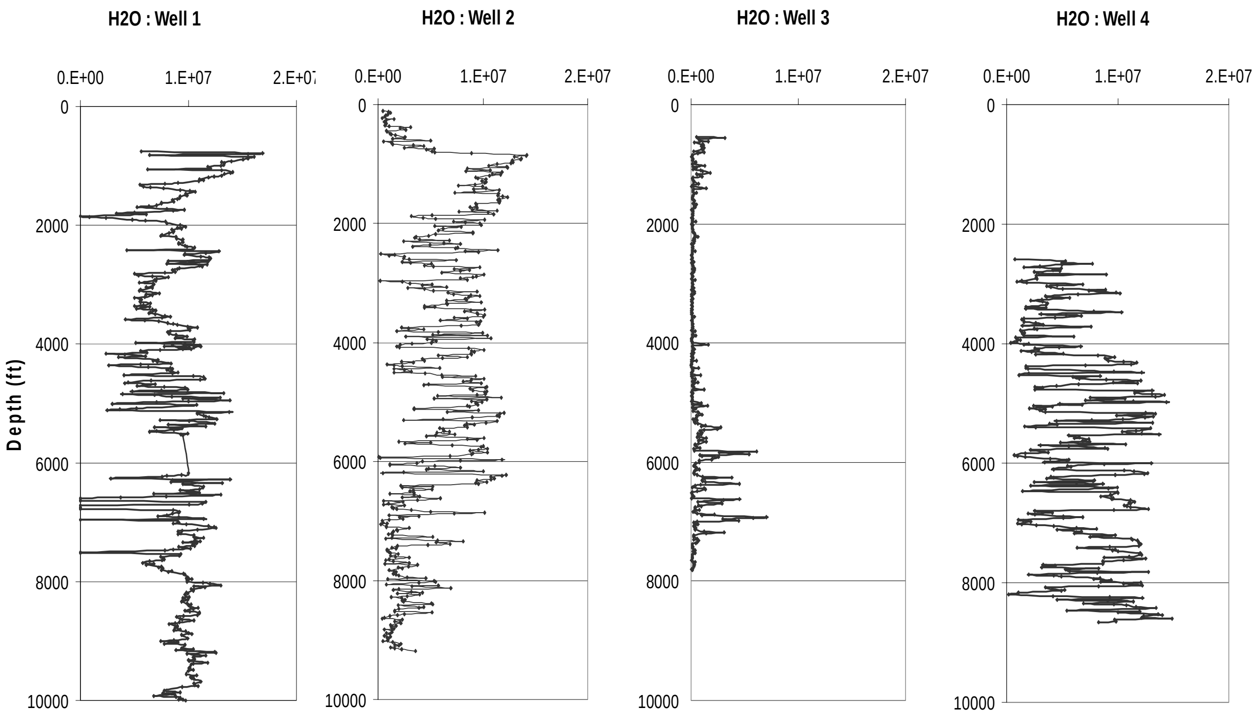

Figure 2. Water peak heights (m/e = 18) plotted for all four wells. Wells 1, 2, and 4 are producers and Well 3 is a non-producer. The amount of water released by crushing is less for Well 3 than for the other wells

Mass Peak	Species
2	Hydrogen
4	Helium
14, 28	Nitrogen
16	Methane
32, 34	Hydrogen Sulfide
43/39, 43/41	Propane/Propene
44, 45	Carbon Dioxide
44/16	Carbon Dioxide/Methane

Table 1. A summary of the species determined by this study to be useful for distinguishing producing from non-producing wells.

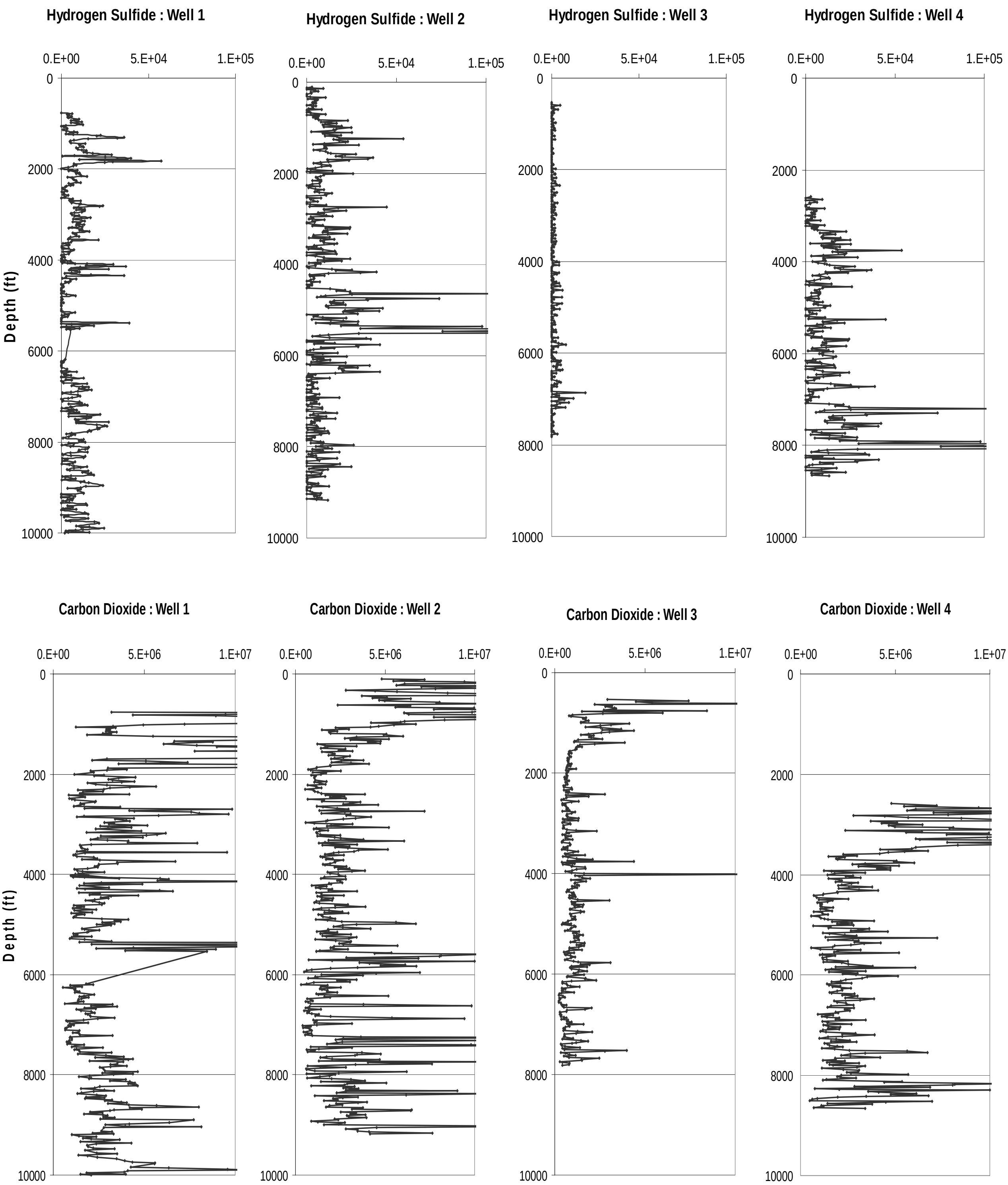

Figure 3. The amounts of $CO_{2(}$ (bottom) and H_2S (top) distinguish the non-producing well 3 from the producing wells.

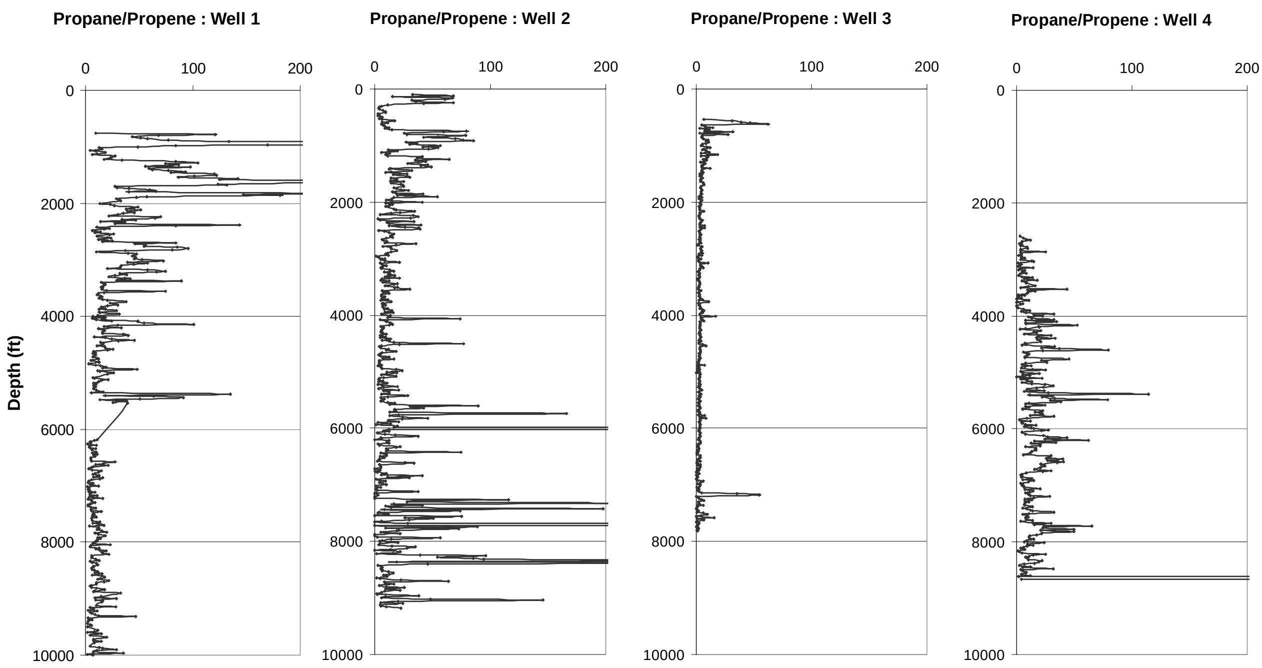

Figure 4. The ratio of propane/propene (mass 43/39) distinguishes the non-producing well 3 from the producing wells

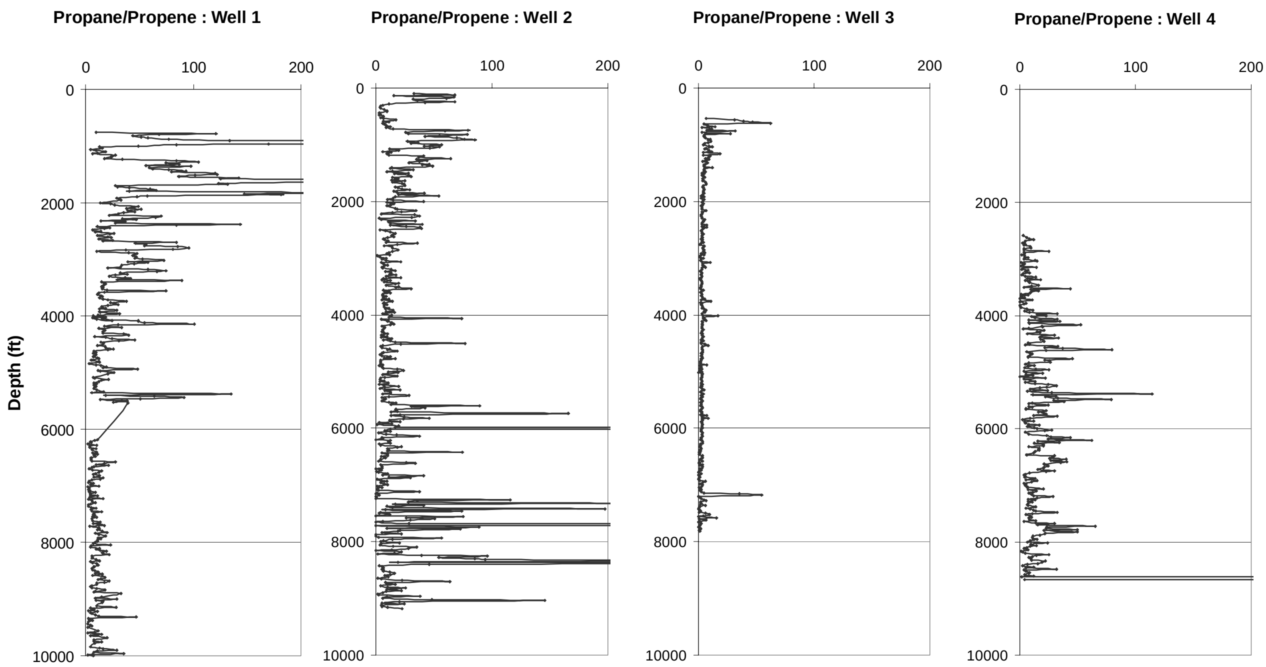

Figure 5. This figure shows a comparison of the argon content in all four wells. Note that Well 3 has low but variable amounts of argon, which is similar to Well 2. Compared to Figure 3, distinguishing producing from non-producing wells based on the argon content is not as clear-cut

5 CONCLUSIONS & FUTURE WORK

We preliminarily conclude that FIT analyses can readily distinguish producing wells from non-producing wells. Non-producing well inclusions at Coso have lower amounts of the common geothermal gaseous species carbon dioxide, methane, nitrogen, and hydrogen sulfide, and remarkably lower levels of water. The ratio of propane/propene also readily distinguishes producing wells from non-producing wells. Indeed, most mass peaks show graphs with differences between non-producing and producing wells. The differences between producing and non-producing wells are obvious in the first few thousand feet of cuttings, which suggests that this method could be used to stop drilling at an unproductive well site before its completion.

Future work will include conducting fluid inclusion stratigraphy on eight additional wells. Of these eight wells, there will be at least one more non-producer. The gaseous species used to determine the non-producing well from the producing well in this preliminary study will be compared for the eight additional wells to determine if this methodology is repeatable across the field. The method will also be tested using two wells while they are being drilled at Coso to analyze the method for use in real-time resource evaluation.

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