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Felsic Dikes of the Coso Geothermal Field

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ABSTRACT

Virtually every production and injection well at the Coso Geothermal Field has at least five felsic dikes in the well bore. The average is 10, and wells on the East Flank portion of the geothermal field have up to 40 intrusions logged in the cross section. Felsic Dikes are part of the entire cross section of the well bore from 300-9000 feet. Average logged felsic dike thickness in cross section is 30 feet. Two high temperature signatures are located in the East Flank Area and a third is located below the BLM West Area of the field, with a depth of minus 5000 feet below sea level. These three high temperature zones are considered to have a magmatic signature. Well bore cross sections of five wells with the depth of each felsic intrusion are graphed. Coso has 160 geothermal wells, with over 1000 individual felsic intrusions logged. The felsic dikes were a heat source at the time of emplacement.

1. INTRODUCTION

The Coso volcanic field has over 30 volcanic features exposed at the surface, many of the volcanoes are dated. The vast majority of volcanism does not break the surface and is represented by rhyolite and multiple felsic dike intrusions in the sub surface that are not dated. Recent improvements in rock dating methods now make it possible to date rocks along the entire cross section and differentiate between each intrusion and the rhyolite domes. Comparison of dates with depth along with those already reported at the surface would be helpful to determine the timing of intrusion. Coso felsic intrusion can be close to the surface as shallow as 300 feet with alteration and secondary mineralization from the start of drilling and occur along the entire length of the well bore, compared to the Geysers Geothermal Field where the felsite body is at greater depth at the bottom of the well bore. Well bore depths of felsic intrusion are logged from 300-9000 feet.

In the BLM West area felsic dikes are fewer in number with depth, in particular well 46A-19 is the deepest well drilled at Coso, drilled to a depth of 12,000 feet, has no felsic intrusions in the last 3000 feet of the well. The BLM West area is at the southern end of the field and is the location of one of the sub surface documented high temperature features. The other two identified high temperature anomalies are on the East Flank portion of the field, see Figure 4. The East Flank area has a greater number of felsic dikes in cross section but these wells are also drilled to a greater depth.

If a well has a large number of felsic dikes it does not mean it will have a high fluid production rate every time, several wells with 20 felsic dikes did not become commercial wells.

The vast amount of resource is produced from well bore intersection of faults and fractures, but there is a large variation in depth to the production zones. At Navy I major production occurs from depths of just 2500 feet from shallow dry steam wells but just a short distance away two phase wells are several thousand feet deeper to reach commercial production zones. One of these deeper wells is 68-6 which a large whole rock $\delta^{18}O$ isotopic shift at 10,000 feet, see Figure 5. The morphology of the volcanic system plays a part in transfer of heat and fluids to the geothermal system at these varying depths, not just faults. A rhyolite dome starts from the surface in part of the Navy I Areas for shallow wells 77-7 and 87-7 the entire lithology cross section is rhyolite, but for well 52B-7 to the west the rhyolite is at the bottom in the last 500 feet, see Figure 3. The rhyolites are logged separate from the felsic dikes. The felsic dikes are intruded on a smaller regular basis and assumed shorter interval. The felsic dikes have more alteration associated with them.

2. FELSIC DIKES AND ALTERATION

Felsic Dikes are numerous at Coso but not a continuous homogeneous body like the Geysers Geothermal Field. They occur from close to surface to the bottom of the well with and average thickness of 20-40 feet. Thicknesses of 300 feet are in the field but rare. Alteration zones are close to or associated with felsic intrusions. Some alteration zones are stand alone and assumed to be zones that have had contact with hot geothermal fluids. The felsic bodies contribute to the local metamorphism represented by varying levels chloride alteration and in some cases contact metamorphism along with secondary mineralization such as garnets, epidote, calcite, along with chloride alteration of biotite. Felsite Dikes often have a change in texture compared to the surrounding host rock, the texture changes within felsic bodies often are described in more detail in the lithology logs than the secondary minerals.

Studies of clay alteration and fluid inclusion by Lutz, and Moore (1996), and of faults and fractures by Davatzes and Hickman (2010), describe alteration patterns in cross section. In contrast the alteration zones associated with the felsic dikes are horizontal and have connectivity between wells such as 38C-9 and 38D-9, the alteration zone at the bottom of these two wells is an area of large production flow rate, see Figure 1. East Flank well 51B-16 is drilled to the east away from one of the high temperature magmatic features and has fewer felsic dikes. Well 51-16 is drilled to the west and has more felsic dikes compared to 51B-16, 51-16 is a production well, 51B-16 did not produce, see figure 2. In the Navy I area well 88-1 has no felsic intrusion logged while, 83-11 has many all the way to bottom, 83-11 is drilled further to the west of the Navy I field. Both 88-1 and 83-11 did not produce and are considered out of the main reservoir.

2. HYDROLOGY

Lithology logs taken while drilling describe the felsite bodies with textures associated with local metamorphism and it is assumed water rock reactions occur to deposit the secondary minerals and create the texture. The lithology logs also identify many descriptions per well of chlorite altering the Biotite. Secondary mineralization zones occur throughout the cross section of each well, calcite is logged all the way to bottom of most wells, where as in the Geysers the calcite often falls off or disappears with greater depth. Alteration zones are included with the felsite bodies in figures 1, 2 and 3.The hydrology that helped deposit the minerals flows along faults and fractures but movement along the horizontal plane of the felsic dikes should be considered also. The alteration zones shown in Figure 1 at the bottom of wells 38C-9 and 38D-9 show interwell connectivity, evidence for this is when we do an acid job on one of the wells the adjacent well has a positive response and increase in production also.

The Travertine deposit dated at 307,000 year old age on the East Flank is considered the start of the geothermal system. Adams 2000. A mix of meteoric and magmatic water sources average in date at 100,000 to 200,000 years old, estimated from $^{36}Cl/Cl$ data, Nimz et al., (1997). The fluid mix described originated in sedimentary rocks with a portion coming from a magmatic source. The mix includes a meteoric water component from the Sierra Nevada source based upon hydrogen isotope data, Fournier (1980).

Detailed descriptions of metamorphism by Monastero et al (2005), that include the alteration zones and contact metamorphism along with partial reactions with water plus the regular intrusion of felsic dikes contributes to the regional metamorphism. The separation of the shallow volcanic domes and Felsic Dikes in the geothermal field from the deeper magmatic body may be a mylonitic shear zone. Even though lithology logs record felsic intrusions, and alteration zones in cross section close to the surface the largest amount of whole rock isotopic exchange is at the bottom of the cross section of the hole at -5000 feet below sea level for well 68-6.see Figure 5. So there is a deeper section closer to the heat represented the sub surface magmatic features and the conductive heat zone depicted in the schematic by Davatze and Hickman (2010).

3. CONCLUSION

The large number of Felsic intrusion with in the sub-surface of the entire Coso Geothermal Field indicates a strong magmatic component is was on a regular interval contributing to the heat source and start of the Geothermal Field at the time of intrusion. The water source itself having an average age of 100,000 to 200,000 years old is older than the surrounding surface volcanic features dated at an average age of 85,000 year old, Burgess (2021). Rhyolite has been recognized separately from the felsic dikes in the lithology logs. The Geysers Geothermal Field felsite body has multiple age dates of rocks at depth, Schmitt (2003). We currently do not have ages of the individual felsic dikes in the wellbores they can be considered roughly with the dated rhyolite domes, but because they are threw out the entire cross section of the well bores they more than likely have a range of dates. The lithology logs describe over 1000 individual felsic dikes in 160 geothermal wells. There is a complexity of fluid mixing with this large number felsic intrusion along with the cross cutting of high angle faults. The subsurface morphology or structure plays role in the mixing of fluids and transfer of heat in an unknown way. Age dating the felsic Dikes in several cross sections such as 52B-7 would be helpful to figure out the frequency of intrusion.

The magmatic pulse described by Adams et al., (2000), using fluid inclusion data to suggest a renewed magmatic heating could be occurring on a regular basis. A pattern related to the number and regular interval of felsic dike intrusion. The felsic dikes in cross section look to be intruded on a regular interval, like a pulse. The mechanism of regular pulses may be the part of volcanic system that contributes regular intrusions that build and sustains a volcanic field such as Coso. The combination of a lower pressure in geothermal reservoir, the shallow brittle ductile zone in close proximity to the geothermal resource, plus a seismic setting with a thinner crust associated with a step over fault, collectively creates a scenario for a smaller but active volcanic system. This could not on its own create enough friction to make the volcanic system as whole but it may contribute the described pulse for felsic dike intrusion.

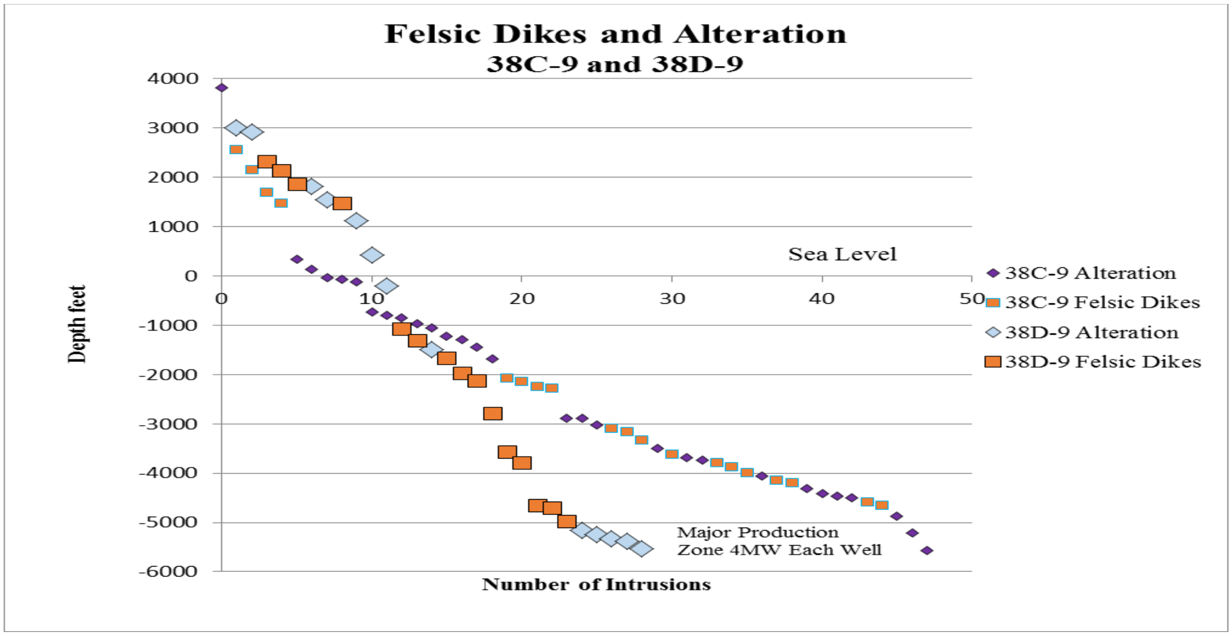

Figure 1: Felsic Dike and Alteration Zones of Wells 38C-9, and 38D-9.

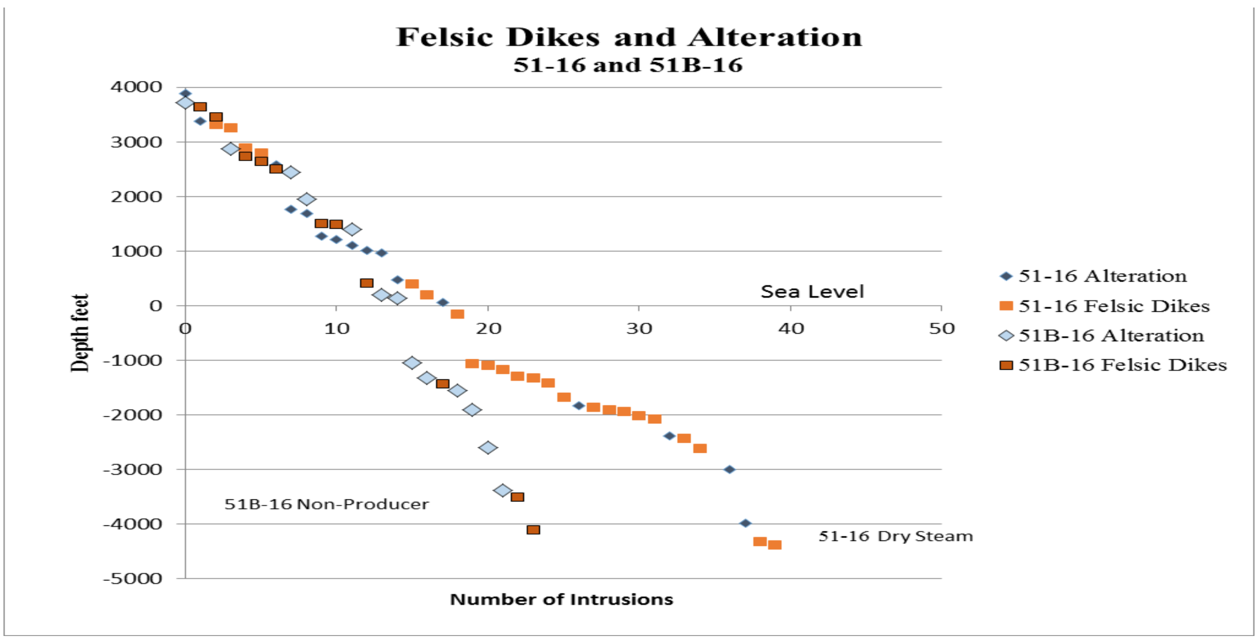

Figure 2: Felsic Dike and Alteration Zones of Wells 51-16, and 51B-16.

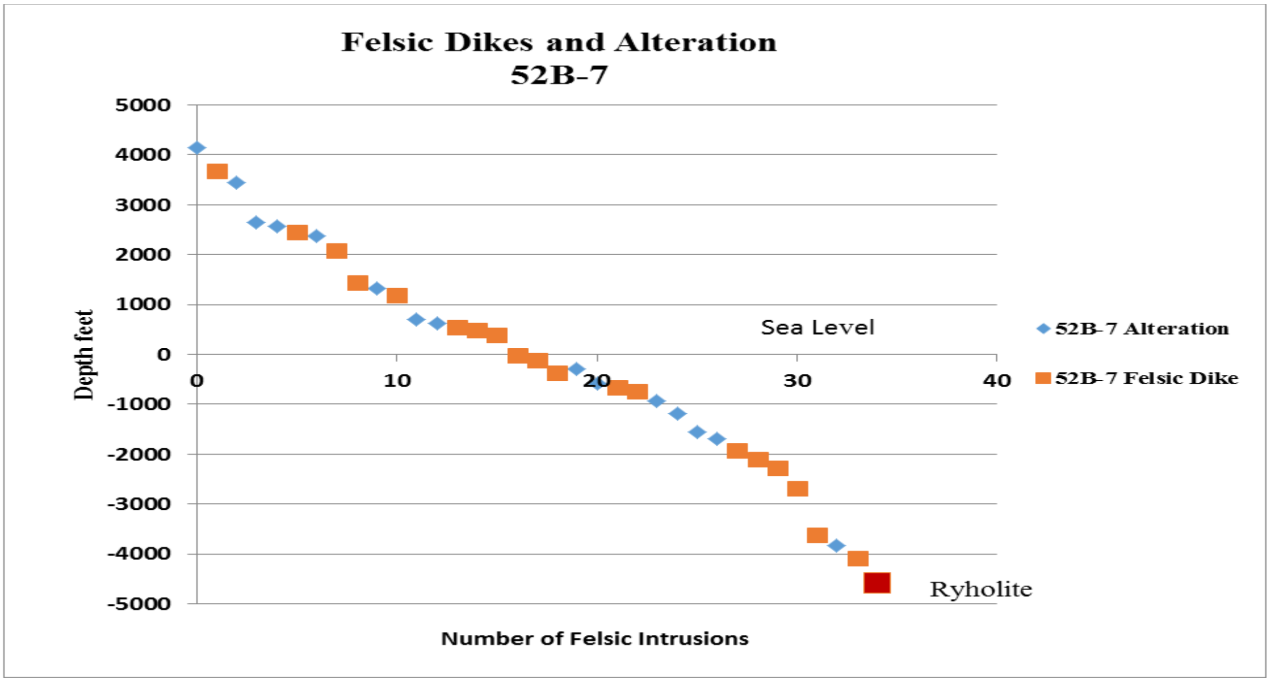

Figure 3: 52B-7 Felsic Dikes and Alteration Zones with Rhyolite at the bottom of the well.

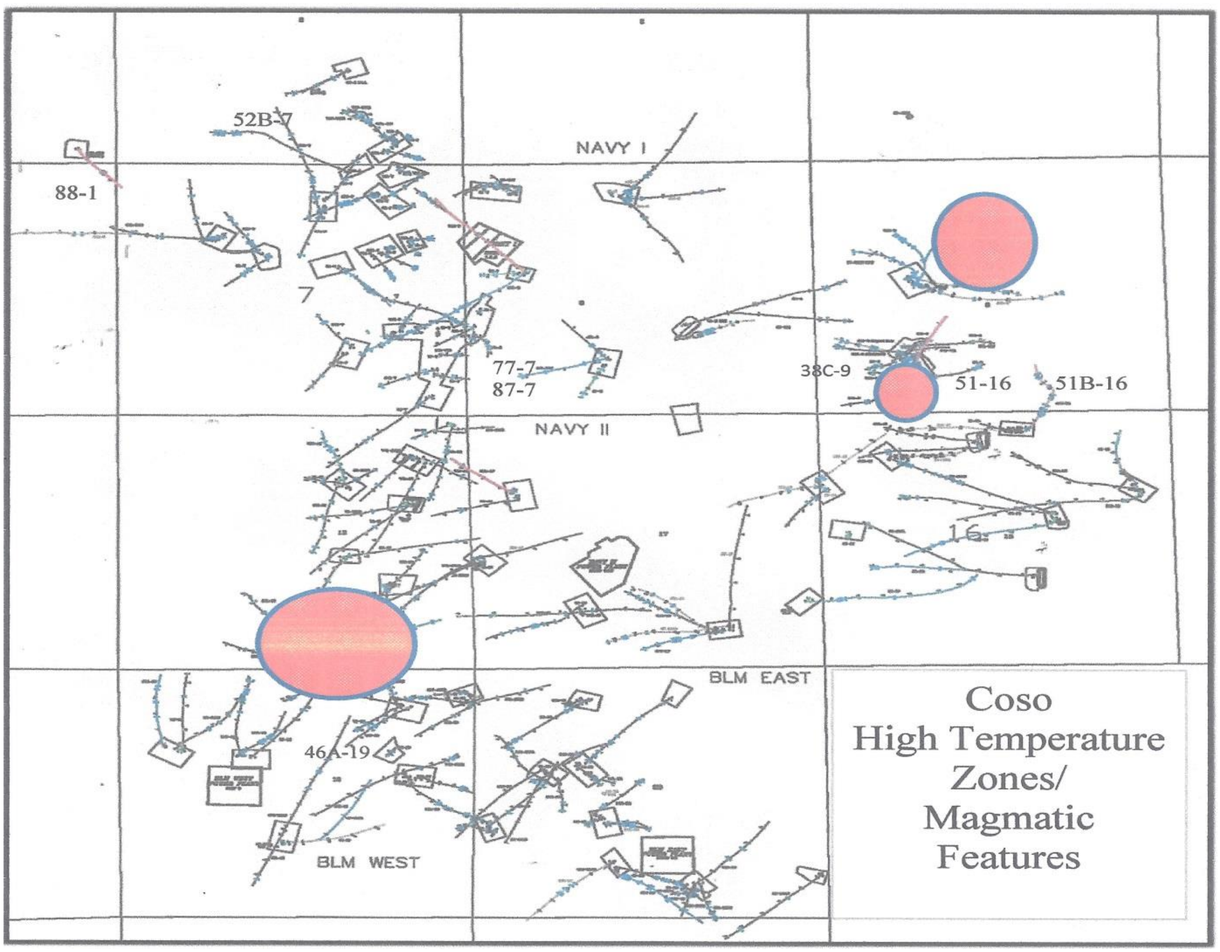

Figure 4: Sub Surface Magmatic Features, -5000 foot image.

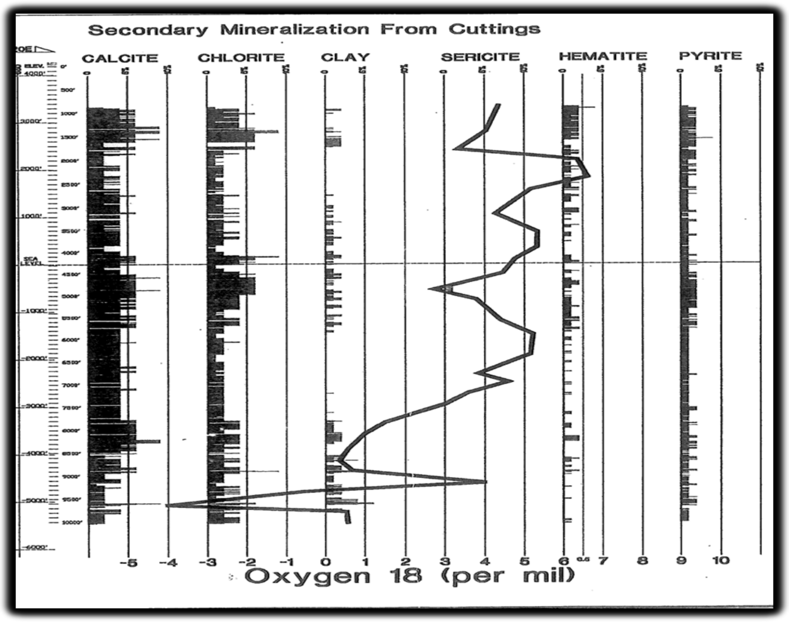

Figure 5: 68-6 Whole Rock Isotope Data with secondary mineralization, the large O18 exchange is at -5000 feet.

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