MINERALOGY AND FLUID INCLUSION GAS CHEMISTRY OF PRODUCTION WELL MINERAL SCALE DEPOSITS AT THE DIXIE VALLEY GEOTHERMAL FIELD, USA

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ABSTRACT

Mineral scale deposits that formed on tubing inserted into Dixie Valley production well 28-33 were sampled at 44 intervals from inside the well head to 1227 ms depth. The scale minerals formed concentric bands around the tubing. X-ray diffractometry and scanning electron microscopy indicate that they consist predominatedly of calcite and aragonite and minor quartz and smectite. Fluid inclusion gases trapped in the scale minerals were released by crushing and analyzed by quadrupole mass spectrometry. The compositions of the fluids inclusions are have been compared to analyses of the production fluids reported by Goff et al (2002). The data indicate that the fluid inclusions trapped vapor from the boiling fluid contain lower CO_2/CH_4 ratios than the production fluids. This difference is interpreted to reflect the early trapping of highly volatile gaseous species in the fluid inclusions.

INTRODUCTION

Mineral scale deposits are common in geothermal wells. Scale inhibitors are often used to minimize or eliminate the problems caused by the precipitation of minerals within the well bore. Scale inhibitor was delivered into Dixie Valley production well 28-33 through tubing inserted into the well. The tube was removed after significant scale had formed on it, and the scale minerals were sampled. The distribution of the scale minerals provides insight into the effectiveness of the scale inhibitor. Because the scale minerals have formed in a well constrained environment, fluid inclusions trapped in the minerals can be used to characterize the behavior of the gases during their formation. In this study, we characterized the mineralogy of the scales using X-ray diffractometry and scanning electron microscopy (SEM). Fluid inclusions trapped in the minerals were analyzed by quadrupole mass spectrometry.
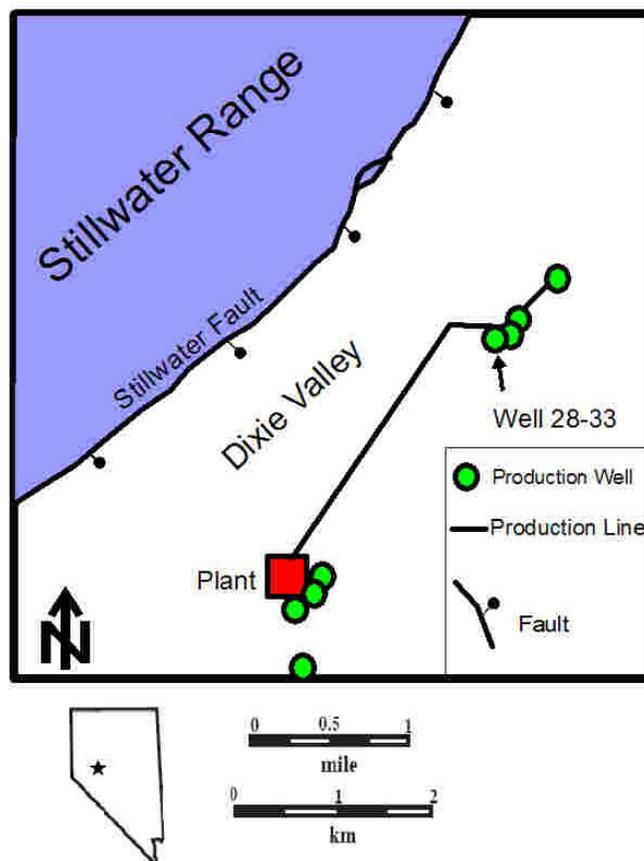

Figure 1. Location of Dixie Valley well 28-33. Modified from Goff et al, 2002.

STUDY AREA

The Dixie Valley geothermal system, located northeast of Fallon, Nevada in the Basin and Range tectonic province, has supported a 62-MWe double-flash power plant since 1988 (Goff et al., 2002) (Fig. 1). Dixie Valley trends north-northeast and is bounded by the Stillwater and Clan Alpine ranges

(Lutz et al., 1997). Geothermal fluids are produced from depths of 2800 to 3050 ms from a subsurface extension of the Stillwater fault zone (Goff et al., 2002). Formations in the production zones include Triassic to Jurassic marine and volcanic rocks (Speed, 1976). Well 28-33 is a production well located northeast of the power plant. The location of the power plant and well are shown in Figure 1. The reservoir temperature in this region was approximately 238° C (S. Johnson, 2008, personal communication). The tubing that was inserted into the well delivered a polyacrylate solution to a depth targeted to be 100 ms below the flash point. Each section of tubing was approximately 10 ms long, and a sample was taken from each section where scale minerals were found. Scale samples were taken at the top of the hole, and then at various depths between 674 and 1227 m depth. The bottom 40 ms of tubing had only a thin film of scale and was not sampled.

MINERALOGY OF SCALE DEPOSITS

Concentric bands of scale minerals were deposited on the tubing (Fig. 2a and 2b). The mineral abundances in the scale were estimated for 36 depth intervals using X-ray diffractometry. SEM was used to characterize the mineral textures. A semi-quantitative energy dispersive unit (EDX) allowed determination of the chemical compositions of the minerals. (Fig 2c). The scale minerals consist mainly of calcite and aragonite with minor amounts of Mg-rich smectite and quartz. Mineral abundances for the 36 depth intervals are plotted in Figure 3. The individual bands are monomineralic and consist of calcite, aragonite or smectite. The quartz is found in trace amounts between 844 and 888 m. Between 1112 and 1125 m depth, there is a distinct change between calcite and aragonite as the dominated carbonate mineral in the scale. While there are trace amounts of aragonite throughout the calcite dominated interval, there is very little calcite in the scale found deeper than 1125 m.

There are several possible reasons for the distinct boundary between the calcite dominated and aragonite dominated depth intervals. One possible explanation is that the scale inhibitor added to the well through the pipe may have inhibited the formation of calcite, but could not prevent the precipitation of aragonite deeper in the well. The calcite then precipitated at a depth where the scale inhibitor was no longer effective. Sodium polyphosphate is one example of an additive that causes the preferential precipitation of aragonite over calcite (Deer et al, 1966). Although polyacrylate was used as the inhibitor, it may have
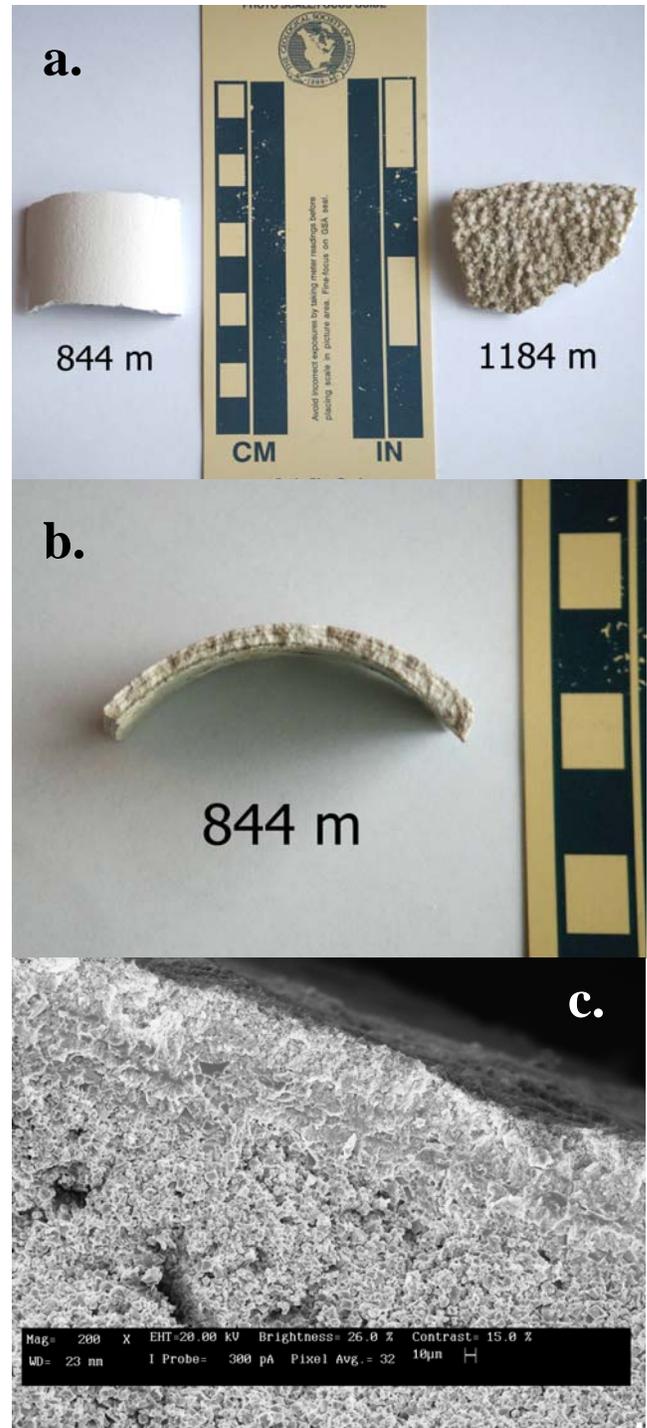

Figure 2. (a.) Mineral scale removed from the tubing from 844 and 1184 m depths. A distinct difference in texture is apparent between the calcite scale from 844 m and the aragonite scale from 1184 m. (b.) A side view of the mineral scale from 844 m shown in (a.). This view shows the banding and the thickness of the scale. (c.) SEM image of mineral scale from 741 m depth. The layer on the lower left half of the image is sparry calcite. The top layer of the scale is smectite.
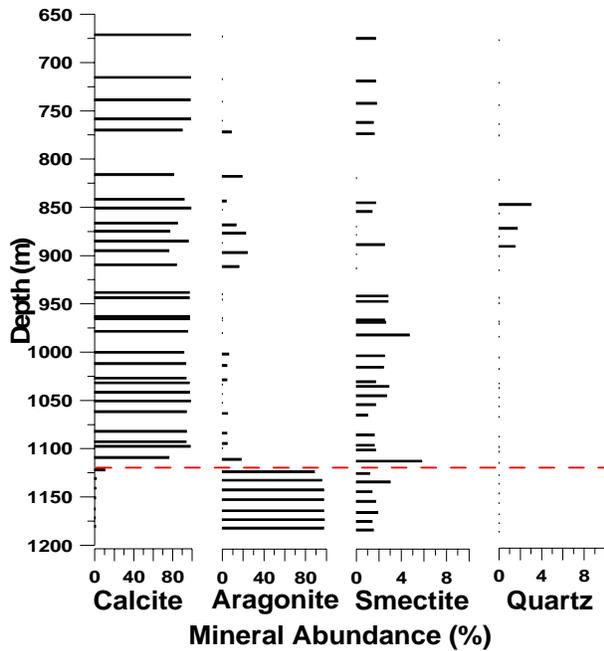
Figure 3. Mineral abundances of calcite, aragonite, smectite, and quartz in the scale estimated using X-ray diffractometry. The red dashed line indicates the change from calcite to aragonite as the dominated carbonate mineral.

effects similar to polyphosphate in promoting the precipitation of aragonite over calcite. Another explanation could be the differences in the specific gravities of calcite and aragonite. Kinetics may also be a factor in the preferential nucleation of one polymorph over another (Rimstidt, 1997). Ostwad's step rule predicts that the more soluble phase, in this case aragonite, will nucleate and grow before the less soluble phase, calcite (Stumm,1992). In this case, greater supersaturation of $CaCO_3$ would lead to the nucleation and formation of aragonite, and decreasing supersaturation would lead to the nucleation of the calcite polymorph. Although aragonite commonly inverts to calcite, it is unlikely that the calcite in the scale mineral samples is either wholly or partially inverted aragonite, as there is little to no calcite observed in the aragonite dominated depth interval.

FLUID INCLUSION GASES

Fluid inclusion gases trapped in the scale minerals sampled from 23 depth intervals were released by crushing and analyzed by quadrupole mass spectrometry. The gases were analyzed for H_2O, as well as H_2, He, CH_4, N_2, H_2S, Ar, CO_2 and a range of hydrocarbons. In general. the inclusions in the calcite dominated depth interval are gas rich, but vary greatly, ranging from 0.52 to 100 mole % gas with most between 1 and 15 mole %. In the aragonite dominated interval the inclusions are generally gas poor, ranging from 0.13 to 11.17 mole % with most

less than 1 mole %. Figure 4 shows the mole % gas for each analysis with depth. The CO_2-CH_4-H_2 compositions of the fluids inclusions are plotted in Figure 5 along with the gas data from production fluids reported by Goff et al. (2002). The general trend of the data implies progressive open system boiling (Moore et al., 2000, 2001). The difference in the solubilites of the gases leads to enrichments in CO_2 in the gas phase as boiling progresses (increasing y values). Y values near 0.0005 are required to produce the extreme enrichments in CH_4 in aragonite-hosted inclusions that plot near the CH_4 corner of the ternary diagram. However, the compositions of the aragonite hosted inclusions that fall close to the CO_2-H_2 join cannot be explained by progressive boiling of a fluid whose initial CH_4-H_2 ratio was near 0.1. The low CH_4 content of these anomalous samples suggests trapping of a CH_4 poor gas (Moore et al, 2001).
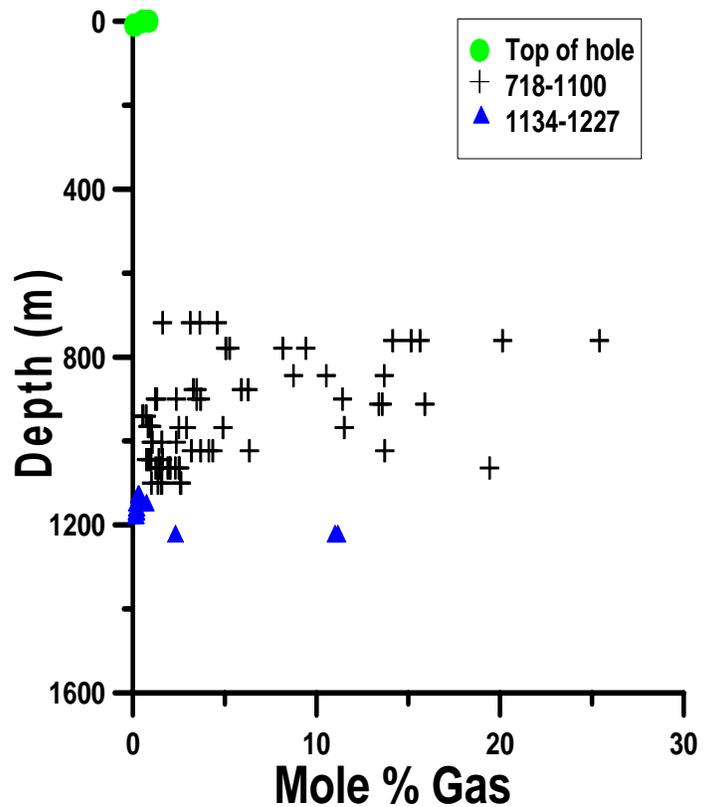

Figure 4. Mole % gas for each analysis with depth. The samples with the highest mole % gas are concentrated in the calcite dominated interval, while the aragonite dominated interval is generally gas poor. An analysis that yielded 100 mole % gas at 1100 m depth is not shown.
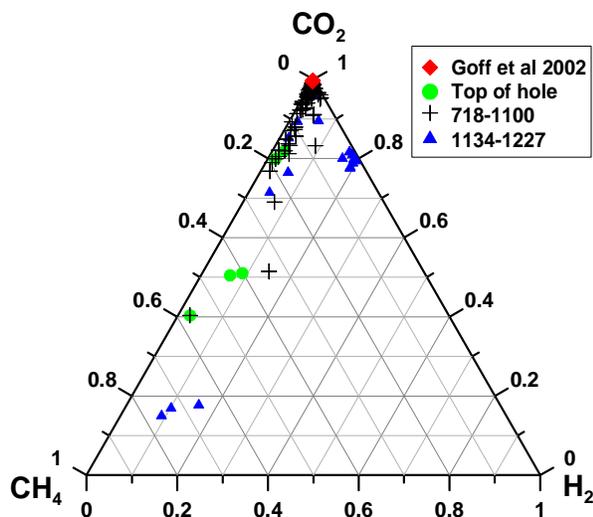
Figure 5. Gas compositions of fluid inclusions from mineral scales in well 28-33 and from production fluids. The composition of the production fluid (diamond) comes from Goff et al. (2002). Scale from 718-110 ms is dominated by calcite; from 1134-1227 ms by aragonite. Scale from the top of the hole is dominated by amorphous silica.

CONCLUSIONS

The mineral scale deposited on the tubing inserted into Dixie Valley production well 28-33 has provided new insight into the geochemical behavior of the production fluids as they flash in the well bore. Mineral analyses of the scale demonstrate that aragonite is the dominated carbonate mineral formed during the initial flashing of the fluid. The formation of aragonite over calcite, the dominant carbonate scale mineral at shallow depths in the well, is due to reaction of $CaCO_3$ in solution with the polyacrylate scale inhibitor. It is not clear at this point whether the transition from aragonite to calcite reflects decreasing effectiveness of the inhibitor or kinetic reaction rates. Systematic variations in the compositions of gases trapped in scale-hosted fluid inclusions reflect the progressive boiling of the fluid and preferential trapping of the gases. With continued boiling the CO_2/CH_4 increases.

ACKNOWLEDGEMENTS

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