European Geothermal Congress 2022
Berlin, Germany | 17-21 October 2022
www.europeangeothermalcongress.eu

3D Modelling and Characterization of Scale Types in Hyper Saline Geothermal System in Tuzla Geothermal Power Plant, NW Turkey

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Keywords: Tuzla, Geothermal fluid, Scaling, 3D Modelling

ABSTRACT

Tuzla geothermal field (TGF) is located in an active tectonic zone on the Biga Peninsula in Northwestern Turkey. Geothermal waters offer hypersaline water characteristics, and the reservoir temperature of geothermal waters can reach 173°C. Scale problems in the TGF are the most important problems affecting the efficiency of the power plant. In this study, the scale types in the TGF are examined in full detail under two headings: (1) the scale types in the surface equipment system, (2) the scale types in the geothermal wells. The morphology, structure, and elemental composition of scale types were revealed by XRD, XRF, and SEM observations. The findings revealed that the scale types are mainly composed of PbS (galena) and aragonite and calcite forms.

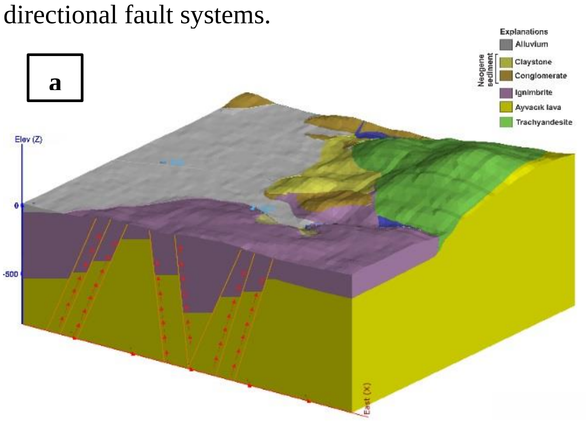
1. INTRODUCTION

TGF is an active tectonic field 80 km to the south of Çanakkale and 5 km to the Aegean Sea. (**Fig. 1**). The geothermal field covers an area of approximately 50 km^2, including the Tuzla river and its tributaries. Studies in Tuzla geothermal field have been continuing since 1966. Different researchers have studied the general volcanology and geological characteristics of the area. (Şamilgil, 1966; Urgun, 1971; Alphan, 1976). A total of 10 gradient wells, with depths varying between 50 and 100 m, were drilled in 1974 with the findings obtained from geological and geophysical studies. In some of these wells, the temperature was measured as 145 °C at about 50 m (Karamanderesi and Öngür, 1974). The environmental and chemical characteristics of the site were evaluated by Baba (2003), Baba and Ozcan (2004), Baba et al. (2005), and Baba and Armannsson (2006). As it is known, while the geothermal fluid reaches the surface from the deep, it dissolves different minerals as a result of the water-rock interaction and gains their chemical composition. (Gunnlaugsson, 1989; Kristmannsdóttir, 1989; Honegger et al., 1989; Ölçenoğlu, 1986; Patzay et al., 2003). Changes in temperature and pressure during production reduce mineral solubility and cause scale problems in geothermal wells. Different scale problems are seen in geothermal fields depending on the selection of production conditions and reservoir lithology. The most common scales are calcite, silica, and sulfide-type scales. Scale formation is a significant problem for many geothermal power plants (Arnórsson, 1989; Juranek et al., 1987; Potapov et al., 2001). The scale thickness and its location are directly related to the temperature, pH, chemical composition, and CO_2 content of the fluid (Garcia et al., 2005). Turkish geothermal fluids cause scale problems with a thickness of about 3 cm in production facilities and reduce production loss by 50% (Ölçenoğlu, 1986; Şimşek et al., 2005). TGF with Organic Rankine Cycle (ORC) is an area where the silica-based scale problem is seen. This scale problem causes economic losses in the TGF and reduces the efficiency of the plant. PbS (Galena) and $CaCO_3$ (aragonite or calcite) were detected in the production wells and surface transmission line (Demir et al., 2014). In this study, the mechanism of scale formation was tried to be understood by using the 3D conceptual model of the TGF and different geochemistry programs. The geochemical model data of the site provide valuable information about the scale formation mechanism that can improve our understanding of the causes of scaling.

Figure 1: Location map of the TGF

2. GEOLOGY OF THE TGF

Tuzla and its surroundings have been the subject of various geological research before due to both being on an active fault zone and being one of the most important geothermal fields in Turkey in terms of geothermal (Ercan and Türkecan, 1985; Karamanderesi, 1986; Mützenberg, 1990; Şamilgil, 1966; Şener and Gevrek, 2000). Paleozoic aged metamorphic rocks form the basement of the study area. This basement is overlain by Paleozoic aged recrystallized limestones with angular unconformity. The upper part of the stratigraphic section consists of Miocene aged rhyolitic tuffs, ignimbrite, latitic lavas, and rhyolitic lavas, which are products of calcic volcanism (Şener and Gevrek, 2000). The ignimbrites formed in the last stage of the volcanism in the region are covered by sediments of the Upper Miocene-Pliocene age, consisting of conglomerate, sandstone, limestone, and clayey limestone alternations. The Quaternary-aged Alluvium, located at the top of the stratigraphic section, formed the Tuzla plain. Tuzla geothermal water represents the active thermal regime and is a region associated with hydrothermal activity following Miocene volcanism (Şener and Gevrek, 2000). Miocene-aged volcanic rocks in the study area were affected by faults in the NW-SE direction. Around these faults, which provide the formation of hot water springs, silicified and argillic alterations are clearly observed. Currently, the active thermal regime in TGF is associated with volcanism. Major geological structures in the study area are controlled by N-S and NW-SE trending faults. N-S directional fault systems are located at the boundary of Neogene sediments and Quaternary alluvium (**Fig. 2 and Fig. 3**). There are many springs along with N-S directional fault systems.



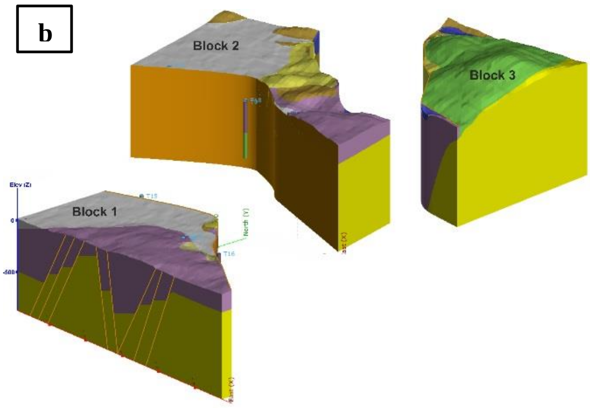


Figure 2: Conceptual model of TGF

a) 3D model of the geothermal site, b) Fault blocks in the TGF

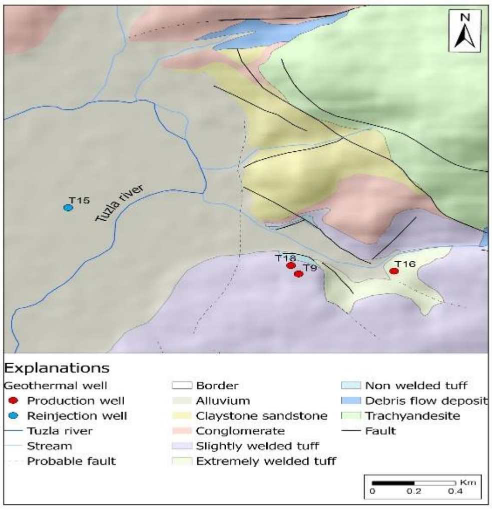


Figure 3: Geology map of the study area

3. METHOD

In order to evaluate the scale types in the TGF, water samples were taken from 4 geothermal wells and surface equipment systems. Collecting samples from high-temperature fluid was provided with a separator. Brine samples were collected for chemical and δ^{18}O-δD isotope, and δ^{34}S and $\delta^{34}S\text{-}SO_4$ / $\delta^{18}O\text{-}SO_4$ analysis with sampling production wells. Anion and cation samples were collected into 1 L containers and silica samples were collected into 250 ml polyethylene bottle. $\delta^{34}S\text{-}SO_4$ / $\delta^{18}O\text{-}SO_4$ isotope samples were collected into steel cylinder. The chemical analysis of TGF water samples was carried out by the laboratories of integrated research centers (TAM) in İzmir Institute of Technology. The following parameters; K^+, Na^+, Ca^{2+}, Mg^{2+}, Li, boron, SiO_2 and As were analyzed by the Inductively Coupled Plasma (ICP) method. A volumetric method was used for HCO_3^- analysis. Anions such as Cl^-, SO_4^{2-} were analyzed using ion chromatography. δ^{18}O-D isotopes were analyzed by isotope ratio mass spectrometer in the State Hydraulic Works (DSİ) (Ankara-Turkey). $\delta^{34}S\text{-}SO_4$ / $\delta^{18}O\text{-}SO_4$ analysis was carried out by the Hydroisotop in Germany.

4. RESULTS

4.1 Water chemistry of the TGF

In geothermal water samples from the TGF, the average pH and EC values range from 5.6 to 7.65 and from 83.2 to 86.2 mS/cm, respectively. The pH value in the system is changing continuously. The water from the wells is acidic due to an excess of free CO_2 (free mineral acidity) which is the result of the high partial pressure of this gas in the well. The temperature of geothermal fluid in well T9, T16 and T18 in Tuzla geothermal site is 164.47 °C, 166.3 °C and 168.6 °C respectively. According to the Piper and Schoeller diagrams, Na^+ and Cl^- are the dominant ions in the geothermal brine of the TGF (**Fig. 4 and Fig. 5**). NaCl water composition indicates a marine origin and also water-rock interactions. This type of water is called brine. The fact that the geothermal waters in the TGF are NaCl type is an indicator of hydrothermal activity. Active seismicity and hydrothermal activity in the region facilitate the uplift of geothermal fluid from deep. The rising geothermal water cools to some extent and is diluted by mixing with groundwater. When the pH change graphs of geothermal waters are evaluated, it is seen that there is no significant change. However, it is seen that the pH value of the geothermal water slightly increased after the separator (**Fig. 6**). There is no significant change in EC values (**Fig. 7**). Some metals were analyzed in geothermal fluid in the TGF. The concentrations of these minor components B, Al, Li, Fe, Mn, and Ba range from 24.4 to 26.3; from 4.61 to 4.78; from 20.8 to 22.6; from 5.49 to 6.48; from 3.84 to 4.73; from 6.21 to 6.82 ppm, respectively of the geothermal waters. Sr concentrations in geothermal fluids range from 131.5 to 142.5 ppm. High Sr concentrations in the geothermal waters are associated with volcanic rocks. Silica values of the TGF range from 189 to 197 mg/l.

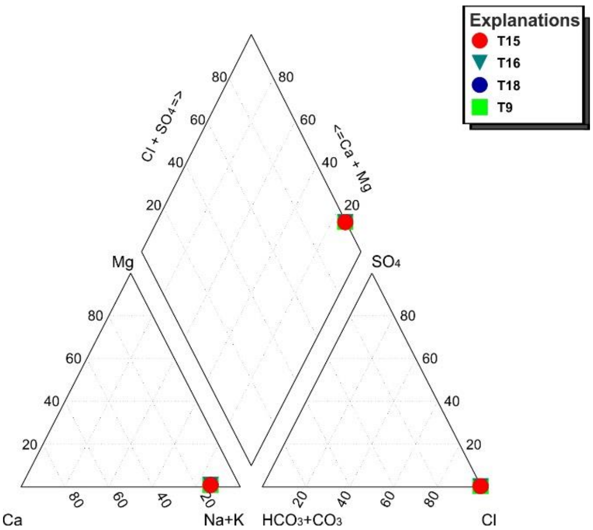


Figure 4: Piper diagram of the geothermal waters in the TGF

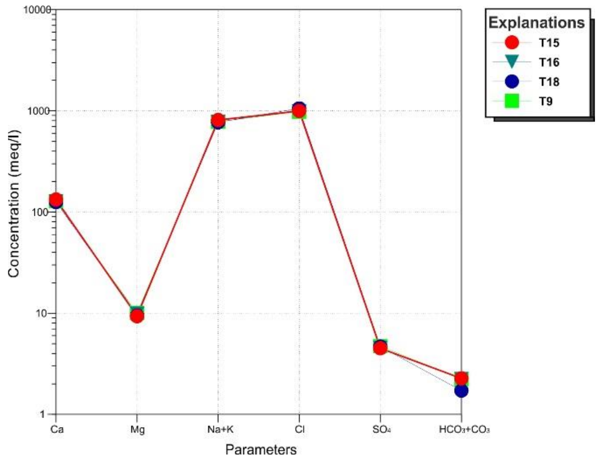


Figure 5: Schoeller diagram of the geothermal waters in the TGF

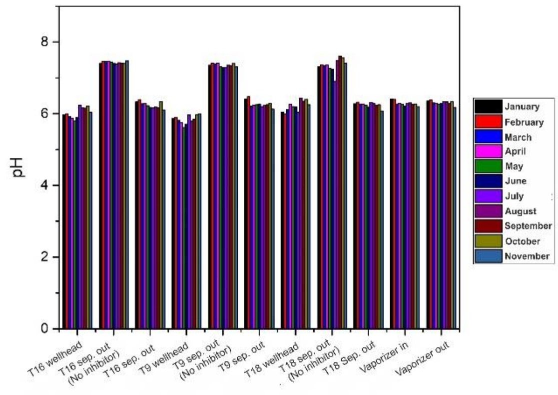


Figure 6: pH change in the geothermal wells

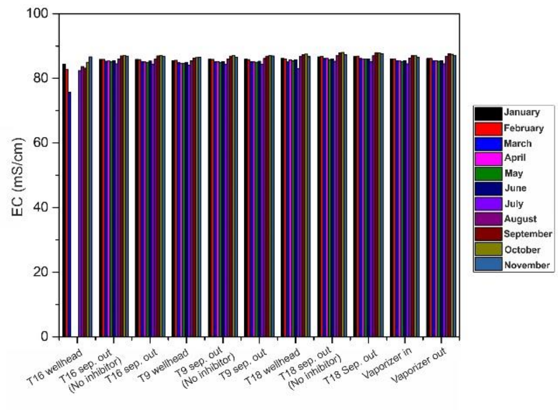


Figure 7: EC change in the geothermal wells

4.2 Isotope Evaluation of the TGF

Stable isotopes provide important information on the origins of thermal waters and underground processes in geothermal reservoirs. Oxygen and hydrogen isotope studies were carried out to understand the evolution of geothermal waters in the TGF. The $\delta^{18}O$ isotope values vary between -0.5‰ and -1.15‰, and the δD isotope values vary between -14.41‰ and -15.79‰ in the thermal waters (**Fig. 8**). The $\delta^{18}O$ content of geothermal brine is enriched up to -0.5, while δD is depleted to -15.79 indicating a high $\delta^{18}O$ shift, which is due to rock-water interaction at higher temperatures. The stable isotope results show that geothermal waters have a meteoric origin in the TGF. Also, in this study $\delta^{34}S$ analysis was performed on TGF geothermal samples. ^{34}S isotopes have been used to investigate the origin of sulfur however, sulfur is highly fractionated due to biological effects and the $\delta^{18}O$ ratio of sulfate is an important tracer in understanding of the origin of sulfur (Clark and Fritz, 1997). In the TGF, $\delta^{34}S$ values vary between 17.9 and 18‰ and $\delta^{18}O$‰ (SO_4) isotope analysis show around 7.7‰ in the reservoir (**Fig. 9**). To better understand the origin of the sulfur, SO_4^{2-} concentration versus $\delta^{34}S$ graph is given **Fig. 10**. Based on the graph; the source of sulfate is from evaporitic rocks in Tuzla thermal waters.

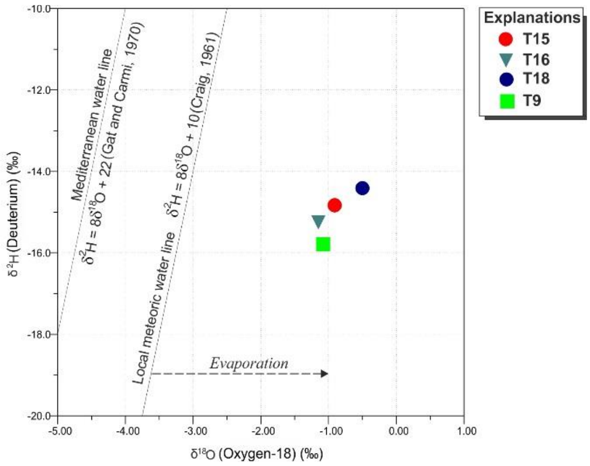


Figure 8: Isotope evaluation of the Tuzla geothermal waters

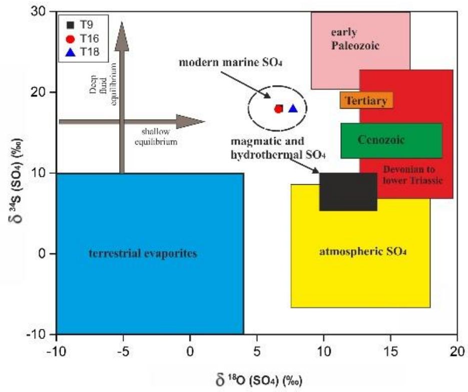


Figure 9: $\delta^{34}S$ versus $\delta^{18}O$-SO_4 for the TGF Systems (modified after Özgür, 2002)

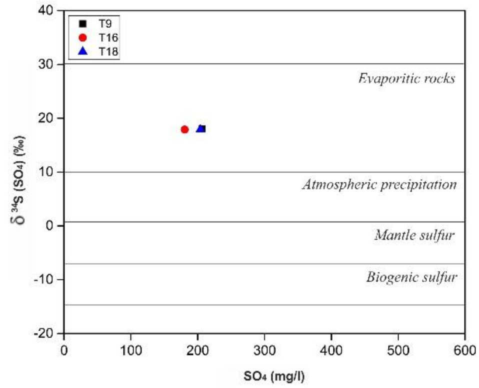


Figure 10: $\delta^{34}S$ values for the TGF (modified after Hoefs, 1997)

4.3 Scale samples of the TGF

The black colour of scale with high Mg, Pb, Fe, Si, and traces of other element content is attributed to the dissolution of ferromagnesium minerals. These are associated with Miocene volcanic rocks which consist of trachyte, andesite, and trachyte andesite. These volcanic rocks which include quartz, K-feldspar, biotite, amphibole, sanidine, chalcopyrite, pyrite and hematite are reservoir rocks of the TGF. The density of the scale sample is between 2.18 and 2.88 g/cm^3 (Demir et al., 2014). As can be seen in **Fig. 10,** scale in the well is mainly composed of PbS (galena) and $CaCO_3$. The scales collected from different depths were subjected to elemental analysis using XRF. As can be seen from the XRF results, the scale sample contains high concentrations of Fe, Pb, Ca, Na, Mg and Si (**Fig. 11**). The concentrations of these elements changes with depth. The concentration of Pb decreases as the depth decreases while the concentration of Fe increases with decreasing depth.

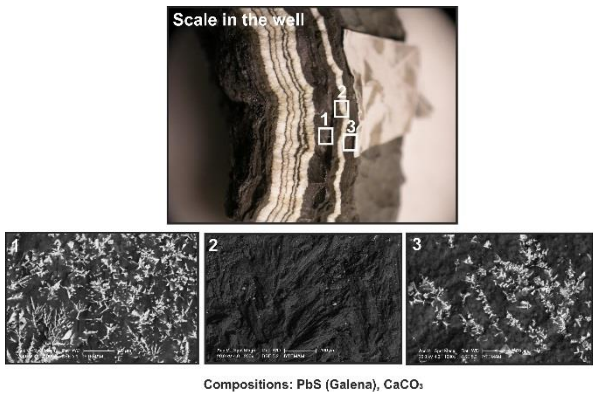


Figure 10: SEM analysis of the scale sample

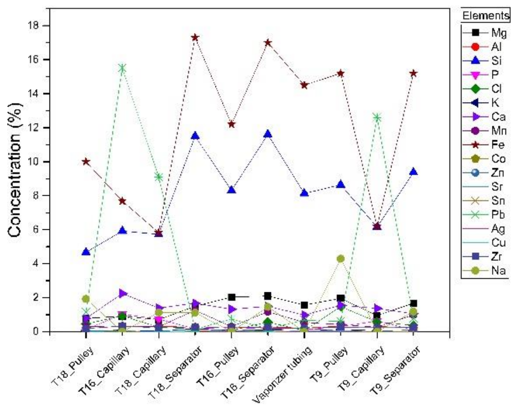
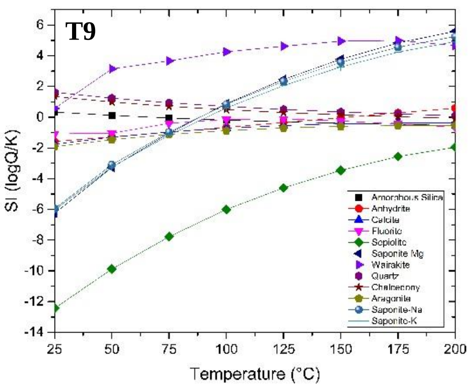
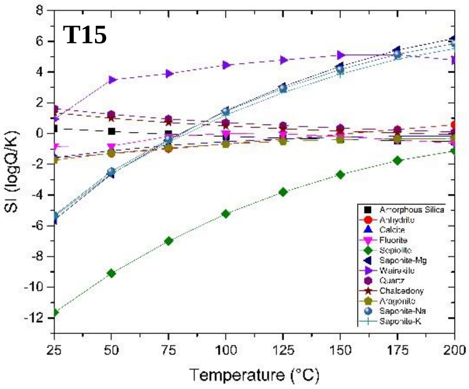


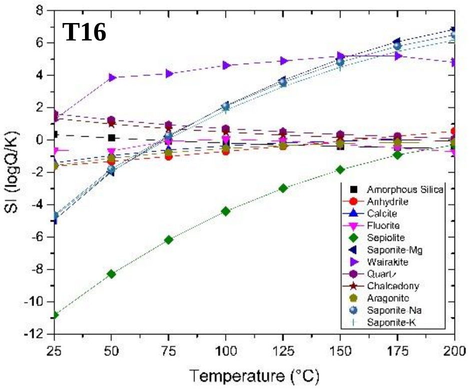
Figure 11: Elemental compositions of the scale sample

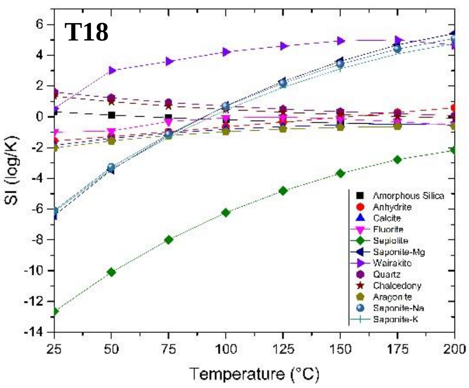
4.4 Saturation indices for the geothermal wells

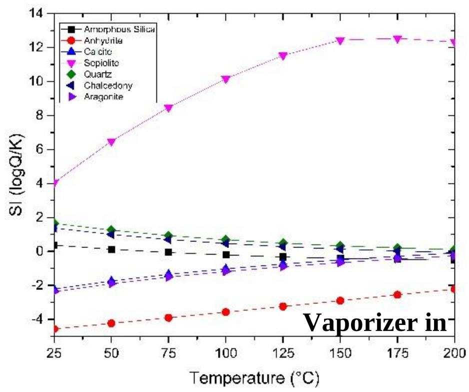
Saturation index diagrams at different temperatures were prepared by using PhreeqC (Parkhurst and Appelo, 1999) and WATCH (Bjarnason, 1994) programs in order to evaluate the silica-based mineral precipitations occurring in the geothermal wells of the TGF. As can be seen from the saturation index diagrams, geothermal wells are supersaturated with the Wairakite mineral at all temperatures. On the other hand, geothermal waters are supersaturated with Saponite minerals above 75 °C. Tuzla geothermal waters are undersaturation with sepiolite mineral at all temperature values. Therefore, there is no risk of sepiolite precipitation in the geothermal wells. However, the geothermal waters at the inlet and outlet of the surface equipment system (vaporizer) are saturated with the sepiolite mineral at all temperature values. Geothermal waters are saturated with amorphous silica mineral below 100 °C (**Fig. 12**).











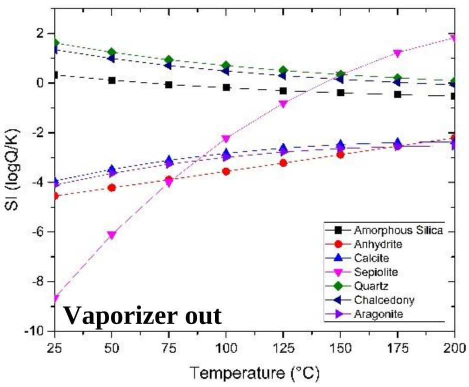


Figure 12: Mineral saturation-temperature diagrams for the downholes and surface equipment system in the TGF

5. CONCLUSIONS

In this study, the scales observed in the TGF were examined. PbS (galena) and $CaCO_3$ were detected in the downhole of the TGF. These precipitations are associated with mainly saponite minerals in the reservoir rock. Currently, a systematic study to develop new methods/new numerical models for the minimization of the scale formation in the TGF is underway.

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Acknowledgements

The authors are grateful for the funding received from the European Union's Horizon 2020 research and innovation program under grant agreement No. 850626 (REFLECT).