

## 土耳其西部 Kızıldere 地熱田與舊有地熱活動相關的蝕變礦物的礦物學和地球化學特徵

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### 摘要

位於土耳其西部的 Kızıldere 地熱場，是最重要的適合發電的地熱儲集層。舊有噴氣孔和變質或礦化帶直接與受南北向延展影響的構造帶有關。與化石地熱活動相關的礦物包括方解石、白雲石、菱錒礦、石英、石膏、硬石膏、天青石、高嶺石、蒙脫石和赤鐵礦，以裂隙填充形式存在於古生代變質岩和中新世-第四紀碎屑岩和碳酸鹽岩中。目前的礦物學組成顯示溫度條件為 100-250°C，接近目前的儲集層溫度。一些具有化石地熱來源的礦物，如方解石、硬石膏、白雲石、天青石、非晶質二氧化矽和石英，與根據礦物平衡模型和井礦物結垢學估計的礦物沉澱物相符。最常見地熱礦物的形成順序被確定為方解石→石膏→硬石膏→石英，顯示先呈鹼性條件，後呈酸性條件。矽質碳酸鹽岩脈中的方解石被石英取代顯示場域中發生了沸騰。地熱礦物分帶顯示由淺至深為硬石膏、白雲石、方解石。礦物分帶的橫向和縱向分佈與地熱水主要受圍岩成分的影響有關。Kızıldere 地熱場中的礦化主要來自熱地熱水的直接沉澱，而非圍岩中礦物的轉化。碳酸鹽和硫酸鹽礦物中矽、鋁、鎂、鉀和鈉的濃度呈正相關，且均來自變質岩。而與這些元素呈負相關的鈣則來自於變質碳酸鹽或石灰岩圍岩。根據目前地熱水的組成，鈣在深部富集，而鎂和硼在靠近盆地邊緣的淺層富集，這顯示礦物沉澱的圍岩成分不同。淺層硼含量相對較高，顯示硼被該層沉澱的礦物保留，導致硼較少被釋放到地表。

**關鍵字：**地熱、熱液蝕變、碳酸鹽和硫酸鹽新生礦物、礦物學、地球化學

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# Geochemistry

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## Mineralogical and geochemical characteristics of alteration minerals related to fossil geothermal activities in the Kızıldere geothermal field, Western Turkey

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### ABSTRACT

The Kızıldere geothermal field, located at the eastern part of the Büyük Menderes graben in Western Turkey, is the most important geothermal reservoir suitable for electricity generation. Fossil fumarole fields and alteration or mineralization zones are directly related to the tectonic zones influenced by N-S directional extension. Associated to fossil geothermal activities, calcite, dolomite, strontianite, quartz, gypsum, anhydrite, celestine, kaolinite, smectite, boehmite and goethite/limonite were occurred in the form of void or crack fill within the Paleozoic metamorphic and Miocene-Quaternary clastic and carbonate host rocks. The current mineralogical composition indicates temperature conditions of 100–250 °C which close to current reservoir temperatures. Some of minerals with fossil geothermal origin, i.e. calcite, anhydrite, dolomite, celestine, amorphous silica and quartz, are compatible for mineral precipitations estimated from mineral equilibrium modeling, and scale mineralogy of wells, as well. The formation order of the most common geothermal minerals is determined as calcite → gypsum → anhydrite → quartz direction indicating that alkaline conditions were followed by acidic conditions. The blade-like/prismatic rhombohedral calcites replaced by quartz occurrences in siliceous-carbonate veins indicate the boiling was occurred in the field. The geothermal mineral zoning determined from drilling samples is anhydrite-dolomite-calcite from shallow to deeper parts. The lateral and vertical distribution of mineral zoning is related to the fact that geothermal waters are mainly affected by host rock compositions, i.e. dissolution from the host rocks and precipitation along the cracks/fractures and bedding planes. Mineralizations in the Kızıldere geothermal field mainly represent the direct precipitations from hot geothermal waters rather than transformations of minerals in the host rocks. Si, Al, Mg, K and Na concentrations in carbonate and sulfate minerals show a positive correlation relationship and are derived from metapelites. Whereas Ca is negatively related to these elements and it is derived from metacarbonate and/or carbonate host rocks. According to the current geothermal water composition, Ca enriches in the deeper parts, while Mg and B enrichment in shallow depths near the basin edge that indicates the different composition of the host rocks where minerals precipitated. The relatively high boron contents at shallow depth indicate that it is retained by the minerals precipitated this level and causes less release to the surface.