РАЗДЕЛ II. ГИДРОТЕРМАЛЬНЫЕ СИСТЕМЫ, ГЕОТЕРМАЛЬНЫЕ И ГИДРОМИНЕРАЛЬНЫЕ РЕСУРСЫ

CHAPTER II. HYDROTHERMAL SYSTEMS, GEOTHERMAL AND HYDROMINERAL RESOURCES

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Экспериментальные измерения растворимости кварца с высоким разрешением в сверхкритических геотермальных условиях

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Кварц – один из самых распространенных минералов в земной коре, состоящий в основном из кремнезема. В сверхкритических геотермальных системах растворение/осаждение кремнезема тесно связано с образованием хрупко/пластичных переходных зон и непроницаемых водоупоров, что существенно влияет на циркуляцию геотермальных флюидов в геотермальной системе. Кроме того, растворение/осаждение кремнезема создает инженерные проблемы для устойчивого производства энергии в сверхкритических геотермальных системах, как, например, прекращение работы исландской скважины IDDP-1 из-за закупорки кремнеземом. Чтобы количественно охарактеризовать эти геохимические процессы, необходимо сначала провести экспериментальные исследования термодинамических и кинетических характеристик растворения кварца в сверхкритических геотермальных условиях.

Ключевые слова: Растворение кварца; сверхкритические геотермальные ресурсы; гидротермальные процессы; поведение ретроградной растворимости; термодинамические данные

High-resolution experimental measurements of quartz solubility under supercritical geothermal conditions

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Quartz is one of the most widely distributed minerals in the Earth's crust, mainly composed of silica. In supercritical geothermal systems, the dissolution/precipitation of silica is closely related to the formation of brittle plastic transition zones and impermeable cover layers, which significantly affects the circulation of geothermal fluids in the geothermal system. In addition, the dissolution/precipitation of silica poses engineering challenges for sustainable energy production in supercritical geothermal systems, such as the abandonment of Iceland's IDDP-1 well due to silica blockage. To quantitatively characterize these geochemical processes, it is necessary to first conduct experimental research on the thermodynamic and kinetic characteristics of quartz dissolution under supercritical geothermal conditions.

Keywords: Quartz dissolution; supercritical geothermal resources; hydrothermal processes; retrograde solubility behavior; thermodynamic data

In order to simulate the high-temperature and high-pressure environment in supercritical geothermal systems, we independently developed a high-temperature and high-pressure experimental system that can monitor resistance in situ, as shown in fig. 1. Compared to commonly used reaction vessels, this experimental system has better heating, temperature control, and insulation performance. Through the connection of electrodes, resistance testers, and display terminals, it can provide intuitive judgment of the equilibrium state of water rock reactions inside the reaction vessel. In addition, in order to improve the accuracy of experimental testing, we independently designed an in-situ separation sampling analysis method, as shown in fig. 2. This sampling and analysis method can minimize the problem of mineral precipitation during the sampling and analysis process. Based on the above experimental system and sampling analysis methods, static reaction thermodynamic experiments and batch reaction kinetics experiments of quartz and pure water were carried out under subcritical (300–374 ℃) to supercritical (374–500 ℃) temperature range and high pressure (25–50 MPa) conditions to obtain the solubility and reaction rate constants of quartz in pure water under different temperature and pressure conditions.

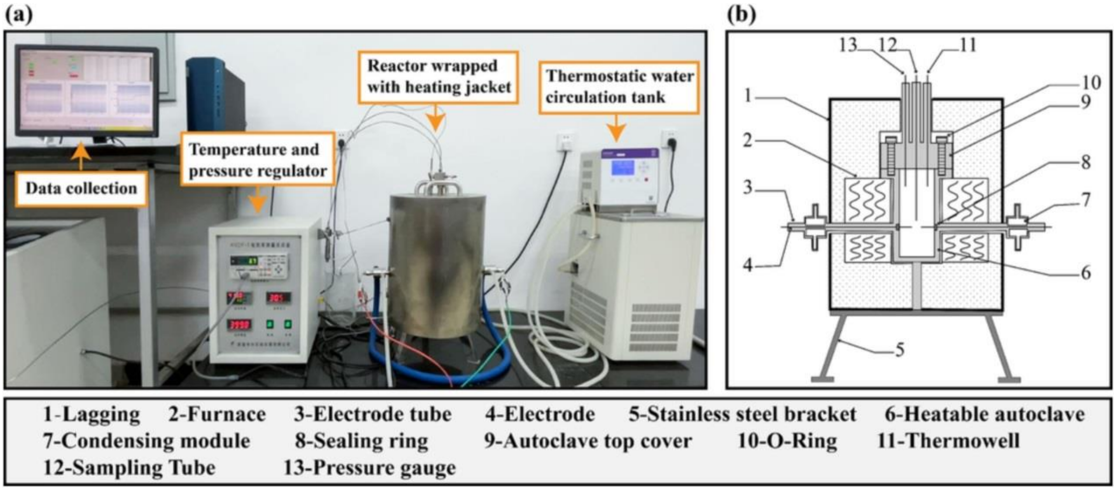

Figure 1 – (a) Experiment system and (b) schematic of the reactor for the quartz dissolution experiment

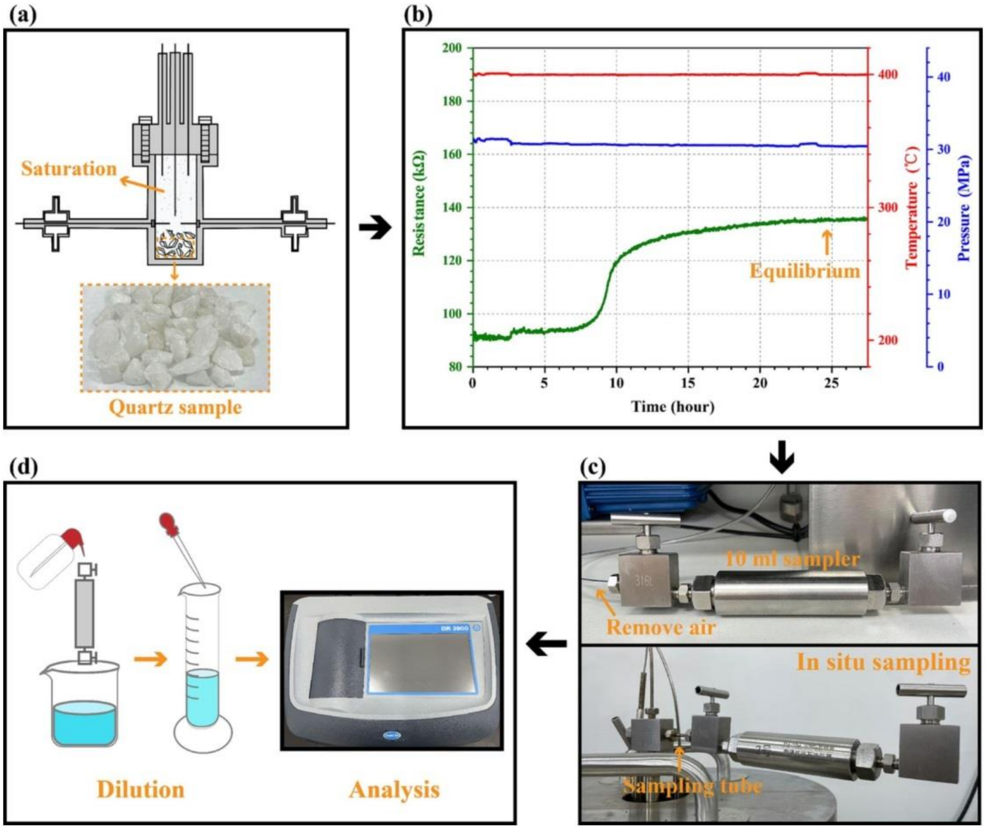

Figure 2 – Experimental procedures: (a) the reactor with pure water and quartz; (b) long time record of temperature, pressure, and resistance; (c) in-situ sampling method; (d) sample analysis

The experimental results indicate that using real-time monitoring of solution resistance and in-situ separation sampling analysis methods can accurately and reliably estimate the solubility of quartz near the supercritical point and under low density conditions Under subcritical and supercritical conditions, the solubility and reaction rate constant of quartz in pure water are significantly affected by temperature and pressure, while under isothermal conditions, there is a positive correlation with pressure (fig. 3). In addition, the solubility and reaction rate constants of quartz exhibit retrograde behavior under transcritical conditions (fig. 3), which may be related to the drastic changes in water density, dielectric constant, ion product, and hydrogen bonding under transcritical conditions. The above results indicate that the influence of pressure on the thermodynamic and kinetic behavior of quartz dissolution is seriously underestimated. Under supercritical geothermal conditions or in areas with abnormally high compressibility of fluids, the decrease in pressure may become the main factor in the deposition of hydrothermal minerals. By combining the results of this experiment with high-quality data in the literature, thermodynamic and kinetic density models for quartz dissolution were established, which can be used to estimate the solubility and dissolution rate constants of silica in aqueous fluids under normal temperature and pressure to supercritical conditions (fig. 4).

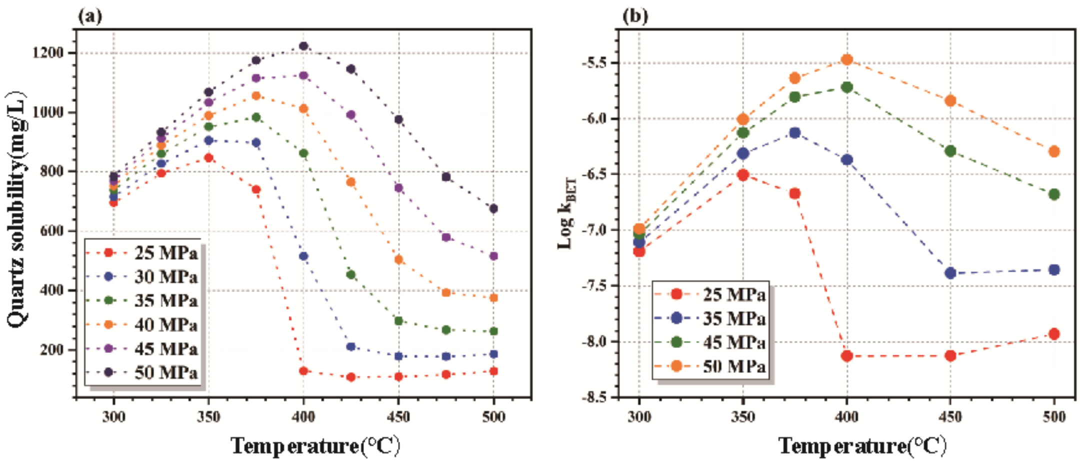

Figure 3 – Temperature dependent curves of (a) solubility and (b) reaction rate constant of quartz under different pressure conditions

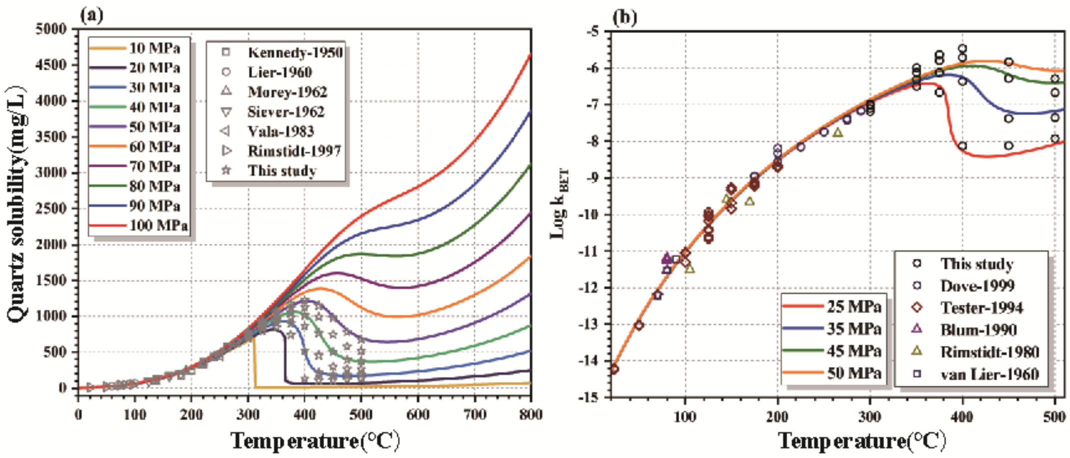

Figure 4 – Quartz solubility(a) and reaction rate (b) constant calculated based on density model