Characteristics and genesis of carbonate rocks’ hydrothermal dissolution in Laiwu Basin, Shandong Province, China

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Abstract. Through analysing the chemical composition of rock samples, investigating of hydrogeological points and hydrothermal dissolution geological points, the characteristics and mechanism of hydrothermal dissolution in Laiwu Basin were studied. The results show that the high temperature and high pressure magma intrusions resulted in hydrothermal metamorphic marbling of carbonate rocks in the contact zone. Hydrothermal fluids migrating along permeable faults, fractures can cause acidic hydrothermal dissolution and mixed dissolution in carbonate formation and formed dissolution cavities of different scales. The cavities are constituting groundwater enrichment space at present.

1. Introduction
Hydrothermal fluid refers to any relevant water more than 5°C higher than the surrounding environment. It can be a variety of single or mixed sources, including: post magmatic hydrothermal solution, interlayer water heated by magma, heated infiltration atmospheric fresh water[1-2]. Previous studies have shown that hydrothermal fluids related to magmatic activities are usually rich in acidic volatile components such as CO₂, H₂S and SO₂, which migrate to carbonate strata along permeable fractures, rents and unconformities, and it can produce significant dissolution to carbonate rocks[3-4]. In recent years, with the discovery of hydrothermal caves in the United States, Hungary and other countries, more and more attention has been paid to the deep karst and hydrothermal karst[5-6].

This paper discusses the characteristics and genesis of hydrothermal karst in Laiwu basin by means of field outcrop observation of hydrothermal activity and sampling of chemical components of carbonate rocks.

2. Geological background

2.1. Structural characteristics
Laiwu Basin is located in the mountainous area of central Shandong Province (Fig. 1a). The NW trending fault system and Dawenkou Basin and Laiwu Basin have been formed in the structural movement of western Shandong uplift terrain since late Mesozoic[7]. The north and south sides of Laiwu Basin are bounded by faults. A large area of Archean metamorphic granites are widely distributed in the periphery of the basin; the interior of the basin is a North dipping monocline structure composed of Cambrian and Ordovician carbonate rocks, and the upper part is covered with a thick Paleogene clastic rock stratum (Fig. 1b). Four large-scale diorite bodies, such as Kuangshan,
Jiaoyu and Jinniushan Rock were formed in Yanshanian period in the periphery and interior of the basin. There are many iron ores and karst water sources around the rock bodies (Fig. 2).

Figure 1. Geographic location and regional geological settings of Laiwu Basin. a: the location of Laiwu Basin in China; b: the geological characteristics of Laiwu Basin

Figure 2. Diorite intrusive bodies in Laiwu Basin. a: Kuangshan Rock; b: Jiaoyu Rock; c: Jinniushan Rock

2.2. Lithological characteristics
The surrounding strata of each Yanshanian rock bodies are Ordovician carbonate rocks, including Wuyangshan Formation(O2w), Gezhuang Formation(O2g) and Badou Formation(O2-3b). The soluble components are the main body and material basis of karst development. In order to quantitatively analyse the content of soluble components in carbonate rocks around diorite, sampling and analysis of carbonate rocks are carried out around the Kuangshan Rock. The test results show that the proportion of CaCO3 and MgCO3 in the carbonate aquifer of O2w, O2g and O2-3b formation are 96.20%, 94.94% and 92.97% respectively (Table 1). It can provide a material basis for dissolution and marble mineralization.

Table 1. Chemical component content(%) test data of carbonate rocks surrounding Kuangshan Rock

| Location | Sample number | CaO  | MgO  | Al2O3 | SiO2 | CaCO3 | MgCO3 | Soluble constituent | Stratum and lithology |
|----------|---------------|------|------|-------|------|-------|-------|---------------------|-----------------------|
| ZJW      | 12            | 46.50| 7.14 | 0.26  | 1.49 | 83.03 | 14.99 | 98.02               |                       |
| GJT      | 36            | 46.57| 5.66 | 0.63  | 3.74 | 83.16 | 11.89 | 95.05               | Limestone of O2w      |
| SZH      | 5             | 51.64| 3.30 | 0.63  | 3.61 | 92.21 | 6.93  | 99.14               |                       |
| CC       | 6             | 48.44| 4.63 | 0.49  | 4.33 | 86.50 | 9.72  | 96.22               |                       |
| ZJW      | 32            | 43.15| 8.64 | 0.73  | 3.63 | 77.05 | 18.14 | 95.19               | Dolomite of O2g       |
| GJT      | 8             | 36.47| 13.73| 1.80  | 6.85 | 65.13 | 28.83 | 93.96               |                       |
3. Characteristics and genesis of hydrothermal dissolution

3.1. Characteristics
Taking Jinniushan Rock as an example, the large scale NW trending fault distributed in the carbonate area in the north of the rock body (Fig. 3a). It can be used as a water conducting and permeable fault to make the cold atmospheric precipitation infiltrate and mixed with the rising hydrothermal solution rich in CO₂, H₂S and other acidic substances. The dense distribution of ferruginous calcite veins in the vertical fractures of carbonate rocks directly confirms the upwelling of hydrothermal fluids (Fig. 3b). Hydrothermal solution caves can be seen around the NW trending fault. There may be dissolution breccia in the cave, and the chemical fillings are mainly calcite and travertine. Mineral deposits or metasomatism can be seen along the fissures or caves (Fig. 3c).

3.2. Acid fluids dissolution
The hydrothermal solution from the deep crust is rich in CO₂ and H₂S due to the metamorphism of carbonate rocks or magmatism, which makes the fluid remain corrosive. The composition of the acid fluid causes the dissolution of the hydrothermal fluid in the carbonate rocks when it is upwelling along the deep and large faults.

3.3. Mixed dissolution
When two fluids that are saturated with carbonate rock mix can produce fluids that are not saturated with carbonate rock[8]. Magmatic hydrothermal fluids usually have higher temperature, salinity and CO₂ partial pressure, which are different from the infiltration of fresh water and carbonate groundwater. When two kinds of fluids moved and mixed, there are variety of mixed dissolution occurred in carbonate area.

3.4. Hydrothermal marble process
The contact thermal metamorphism of carbonate rock near diorite body forms marble with different grain size. The results of drilling in GJT iron ore show that under the same conditions, the coarse marble is more prone to dissolution compared with unmodified carbonate rocks. The marble karst caves in GJT iron ore are mainly distributed in the place less than 250m away from the ore body, and the closer they are to the rock body, the more caves there are (Fig. 4).

| ZJW  | 17  | 42.24 | 7.77 | 1.61 | 5.19 | 75.43 | 16.32 | 91.75 | Dolomite of O₂₃b |
|------|-----|-------|------|------|------|-------|-------|-------|-----------------|
| GJT  | 5   | 49.57 | 4.39 | 0.46 | 1.68 | 88.52 | 9.22  | 97.74 |                |

Figure 3. Hydrothermal activity and carbonate dissolution characteristics in Jinniushan Rock. a: Permeable fault; b: Hydrothermal calcite veins; c. Mixed solution caves

Figure 4. Marble karst caves in GJT iron ore.
Figure 4. Relation diagram of distance between marble karst caves and ore deposits in GJT ore field

4. Conclusions
During the Yanshanian period, the magmatic hydrothermal fluid rich in CO₂ and H₂S flowed up along the seepage fractures and faults. With the participation of the acid dissolution components, the dissolution of acid fluid, mixed dissolution and contact metamorphism of marble have taken place between hydrothermal fluid and carbonate rocks.

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