Rock alteration adjacent to fractures and its effect on reducing capacity in Beishan granite

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Abstract. In order to determine the rock alteration and its effect on reducing capacity in Beishan granite, mineralogy and geochemical analysis of the rock adjacent to fractures have been preliminarily performed during site characterization. The results show that the altered rock takes some specific changes in mineralogy and chemical composition compared with the unaltered rock. The variation of some elements (Na₂O, CaO, Fe, etc.) content in the specific altered rock is mainly related to the changes in mineralogy. The Fe(II)/Fe_total-ratio analysis indicates that the alteration around fractures has little effect on reducing capacity of the bedrock.

1. Introduction

Deep geological disposal is considered as the best way for the safe disposal of high-level radioactive waste (HLW). In the process of R&D for HLW disposal, it is of importance to select an appropriate underground disposal site, which should be suitable for implementing all necessary engineered barriers to prevent or retard the potential movement of radionuclides from the disposal system to the accessible environment[1]. Dissolved oxygen in groundwater can corrode metal canisters containing radioactive waste, and increase the solubility and migration rate of radionuclides (Tc, Np, U etc.) in groundwater[2]. Therefore, one of the tasks during site characterization and safety assessment is to determine how much reducing capacity i.e. Fe(II) possessed in the geological media especially around water conducting fractures[3]. As a result of the influence by hydrothermal fluid during the geological evolution history, the crystalline rock adjacent to the fracture generally occurs different degrees of alteration which may vary its mineralogical, chemical composition and reducing capacity.

Based on the systematic analysis of mineralogical and chemical composition of the rock surrounding fractures, the alteration characteristics of the bedrock and its effect on reducing capacity in Beishan site are preliminarily discussed. This study is one of the tasks to evaluate the suitability of Beishan site, which can provide the key basis to site characterization and safety assessment for HLW disposal.

2. Geological setting

The Beishan site is located in Gansu Province, Northwest China, which is the most potential area for HLW disposal in China. The bedrock of Beishan site is mainly dominated by Hercynian granodiorite and monzonitic granite within the approximately 235–296Ma old[4]. The NE trending faults are relatively developed in the area, under the influence of EW trending ductile shear zones and Altun fault. It is suggested that the bedrock within Beishan site has undergone multiphase hydrothermal or oxidation process, resulting in several types of alteration remained in the wall rock especially around the fractures.

3. Sampling and analyses
Mapping and sampling have been carried out respectively on drill cores from six deep boreholes (BS24–BS27, BS33–BS34) within the vertical depth of 0–1000m in Beishan site, focusing on the altered rock adjacent to fractures. Thirteen rock samples characterized by alteration including red-staining, white-staining and green-staining and nine fresh samples (unaltered) were collected and analyzed. The mineralogical characteristics of samples were obtained by ocular inspection and polarizing microscope observation. The major elements composition of each sample was also determined using X-ray fluorescence method (XRF), containing total iron content (i.e. Fe\textsubscript{total}) and FeO.

4. Results and discussion

4.1. Mineralogy

According to the results of drill core investigation, a number of rocks adjacent to the fracture at different depths of boreholes are altered with various appearances. The main types of rock alteration in Beishan granite include red-staining, white-staining and green-staining, commonly with dissimilar mineral and chemical composition through observation under polarizing microscope. Photographs of drill core and polarizing micrographs for main rock alteration types are shown in figure 1.

In the red-stained rock, alkaline feldspar (perthite, microcline, etc.) are commonly completely replaced by albite or K-feldspar, and part of magnetite are replaced by Fe-oxides (hematite, limonite, etc.). The crystal shape of alkaline feldspar generally remains unchanged in the process of alteration. The red-staining extent is stronger where minute Fe-oxide inclusions exist in rock pores or micro-fractures than metasomatic minerals (albite or K-feldspar). The red-stained rock is normally considered as the result of hydrothermal alteration, and it has likely undergone oxidation process\cite{5}. The white-staining is commonly thought to represent the result of weathering or leaching of groundwater where plagioclase or melanocratic minerals are generally replaced by clay mineral (mainly illite, kaolinite, etc.). The phenomenon of green-staining along the fractures is practically caused by chloritization of biotite and other melanocratic minerals.
Rock alteration is rarely found in Beishan granite as a whole, except in fracture zones and water conducting fractures. Red-staining is widely distributed relatively that almost 3%–5% of the fractures in Beishan site are surrounded by red-stained wall rock (figure 2). The distribution of red-staining alteration has a very close relationship with hydrothermal and oxidation process, and is most extensive within the scope of fracture zones. The white-staining commonly occurs around the fractures near the surface and water conducting fractures, and green-staining is relatively rare (less than 1% of all fractures) especially in the deep of the bedrock.

Figure 2. Variation with depth of red-staining fractures along total fractures in borehole BS33 and BS34 respectively. The distribution of fractures in the depth range of 300–600m for each 10m interval is shown.

4.2. Rock chemistry
The results of major elements analysis of the altered rock and fresh rock (with no alteration) are shown in table 1. The rock type of samples analyzed primarily includes granodiorite and monzonitic granite. The chemical composition of samples is mainly controlled by the type of protolith, and also affected by the process of alteration to some extent. The variation in concentrations of different elements during the alteration is mainly due to the changes in mineralogy (e.g. growth of secondary minerals)[3].
| Sample       | Rock type              | Alteration type | SiO₂ (wt.% | Al₂O₃ (wt.% | CaO (wt.% | MnO (wt.% | P₂O₅ (wt.% | Ė(FeO⁺)/Fetotal |
|--------------|------------------------|-----------------|------------|------------|------------|------------|-------------|----------------|
| BS24-LX03   | Granodiorite           | Red-staining    | 69.67      | 12.48      | 3.71       | 0.548      | 0.048       | 4.27          |
| BS25-LX03   | Granodiorite           | Red-staining    | 70.68      | 14.42      | 2.61       | 0.09       | 0.062       | 1.95          |
| BS27-LX01   | Granodiorite           | Red-staining    | 70.19      | 14.02      | 2.47       | 0.048      | 0.069       | 2.02          |
| BS28-LX02   | Granodiorite           | Red-staining    | 69.78      | 16.74      | 4.39       | 0.049      | 0.064       | 2.25          |
| BS29-LX03   | Granodiorite           | Red-staining    | 70.68      | 14.42      | 2.61       | 0.09       | 0.062       | 1.95          |

The total iron in each sample.

**M-granite** refers to monzonitic granite.
The enrichment of Na$_2$O in the altered rock (especially in the red-stained rock) is mainly due to albisation of plagioclase rather than potash feldspathization (K$_2$O almost unchanged). K$_2$O-content in the green-stained rock is moderately depleted as a result of chloritization of biotite. CaO is slightly enriched mainly in the white-stained rock compared with the fresh rock, which is attributed to carbonation of wall rock and formation of a few epidotes. The total contents of iron (Fe$_{\text{total}}$) are commonly increased in altered samples because of the growth of Fe-bearing secondary minerals (hematite, goethite, etc.). It is suggested that the enrichment of Fe during the alteration is mainly due to redistributed within the rock instead of obtained from hydrothermal fluid[5]. Compare with the fresh rock, the altered rock generally have higher Loss on Ignition (LOI) as a result of occurrence of secondary minerals rich in crystal-bound water (including hydroxyl group). SiO$_2$, Al$_2$O$_3$, MgO, MnO, TiO$_2$ commonly show no changes or very slight changes between the altered rock and fresh rock. This may indicate that secondary minerals rich in these elements rarely formed along with alteration process, or these elements are fixed in some minerals resistant to alteration[3].

4.3. Reducing capacity

Fe(II) is an important inorganic redox buffer which can provide enough reducing capacity to the bedrock. It is necessary to determine how much Fe(II) is remained in the bedrock especially along the fracture. The values of Fe$_{\text{total}}$-content, Fe(II)-content and Fe(II)/Fe$_{\text{total}}$-ratios of the altered rock and unaltered rock are presented in Table 1. The Fe(II)/Fe$_{\text{total}}$-ratio variation between the red-stained rock and unaltered rock in two main rocks is shown in figure 3.

![Figure 3](image_url)

Figure 3. Box chart of Fe(II)/Fe$_{\text{total}}$-ratios for granodiorite and monzonitic granite including red-staining and no alteration samples. The box represents the interquartile that represents 50% of the values. The dotted lines refer to the average value.

In the granodiorite samples, the average Fe(II)/Fe$_{\text{total}}$-ratio is only 0.035 lower in the red-stained rock, 0.059 lower in the green-stained rock and 0.085 lower in the white-stained rock than in the fresh rock respectively. In the monzonitic granite samples, the value is 0.045 lower in the red-stained rock than in the fresh rock. The slight depletion of Fe(II) in the altered rock is related to metasomatism during the alteration process, e.g. the replacement of magnetite by hematite. The variation degree of reducing capacity between the altered rock and fresh rock is generally very small and even negligible especially for red-staining alteration.
5. Conclusions
Compared with the unaltered rock, the altered rock adjacent to fractures takes some specific changes in terms of mineralogy, chemical composition and reducing capacity. The main types of rock alteration around fractures include albitization (red-staining), illitized (white-staining) and chloritization (green-staining), and all of them are rarely found as a whole in Beishan granite. The enrichment of Na₂O, CaO, Fe, LOI in the specific altered rock is mainly due to the changes in mineralogy, while other major elements show no changes or very slight changes. The variation degree of reducing capacity i.e. Fe(II) between the altered rock and fresh rock is generally very small.

References
[1] International Atomic Energy Agency 1994 A safety guide: Siting of geological disposal facilities (Vienna: International Atomic Energy Agency)
[2] Drake H Tullborg E-L and MacKenzie A B 2009 Detecting the near surface redox front in crystalline bedrock using fracture mineral distribution, geochemistry and U-series disequilibrium Applied Geochemistry vol 24 pp 1023–1039
[3] Drake H and Tullborg E-L 2008 Fracture mineralogy Laxemar: Site descriptive modelling, SDM-Site Laxemar (Stockholm: Swedish Nuclear Fuel and Waste Management Company)
[4] Wang J Chen L Su R 2018 The Beishan underground research laboratory for geological disposal of high-level radioactive waste in China: Planning, site selection, site characterization and in situ tests Journal of Rock Mechanics and Geotechnical Engineering vol 10 pp 411–435
[5] Drake H Tullborg E-L and Annersten H 2008 Red-staining of the wall rock and its influence on the reducing capacity around water conducting fractures Applied Geochemistry vol 23 pp 1898–1920