

Rock alteration in a hydraulic engineering project in Southwest China

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Abstract Rock alteration is an important problem of engineering rock mechanics to be solved in Southwest China. X-ray diffraction analysis indicates that rock alteration was formed under specific geological conditions with mineral composition of mainly kaolinite altered from feldspar. Besides feldspar kaolinization, major types of alteration also include feldspar chloritization in which chlorite replaces some dark minerals (such as biotite and hornblende) in rocks. Rock alteration in the study area is mainly developed in the unloading zone, where NE- and NW-trending faults are found. The surrounding rock heterogeneity such as mineralization, alteration, and structural fault distribution leads to complexity in groundwater system. The chemical composition of groundwater in the transition from dry seasons to rainy seasons and the distribution of strongly permeable zones should be considered in evaluating whether seepage deformations or other engineering problems occur under the high pressure of water permeation.

Keywords Alteration · Hydraulic engineering · Nujiang Gorge · Kaolinization

Introduction

Rock alteration caused by hydrothermal mineralization often occurs in engineering projects (Ye 1991; Zhai 1999; Eilu et al. 2001; Elumalai et al. 2005; Hürzeler and Abart 2008; Qin et al. 2008; Dwijesh et al. 2009; Pazand et al. 2013; Abbaszadeh and Hezarkhani 2013) and caused many

engineering geological problems (Eilu and Mikucki 1998; Khalokakaie and Naghadehi 2012; Ghanbari et al. 2013; Ozcelik et al. 2013), such as the Yunnan-Tibet Railway (Zhang et al. 2007) and many other hydraulic engineering projects (Zhang and Tu 1994; Qu 1985; Qu et al. 1992, 2004; Chen et al. 2010), especially in Southwest China (Yang et al. 2006; Qin and Xu 2007; Meng et al. 2008).

In this paper, rock alteration in the Maji hydraulic engineering project in Southwest China is investigated, which is located between the Indian plate and the Eurasian plate. Its geological mechanisms of origination are explored by analyzing the distribution of the altered rocks. In addition, the engineering characteristics of the altered rocks are further studied in support of assessing the degree of alteration, resolving geologic issues in engineering and formulating related engineering measures.

Site description

The study area is located in the middle reach of the Nujiang River, about 80 km from the Fugong town, and 45 km from the Gongshan town of Nujiang, Yunnan Province, PR of China (Fig. 1). The river has a natural water level from 1,324.0 to 1,327.0 m above sea level.

The Nujiang Gorge of the study zone is N–S trending, with “V”-shaped valley section. Gorge slope develops ladder-like scarps. The slope on the west (or right) varies between 35° and 50°. The slope on the east (or left) varies between 30° and 45°.

According to geological investigation, the groundwater includes bedrock fissure water and quaternary pore water, which drains from the study area to the Nujiang Valley in the forms of springs and surface runoff. Water pressure tests show that the rock mass has low permeability, and hydraulic-fracturing measurements show that the maximum horizontal stress is in the EW direction.

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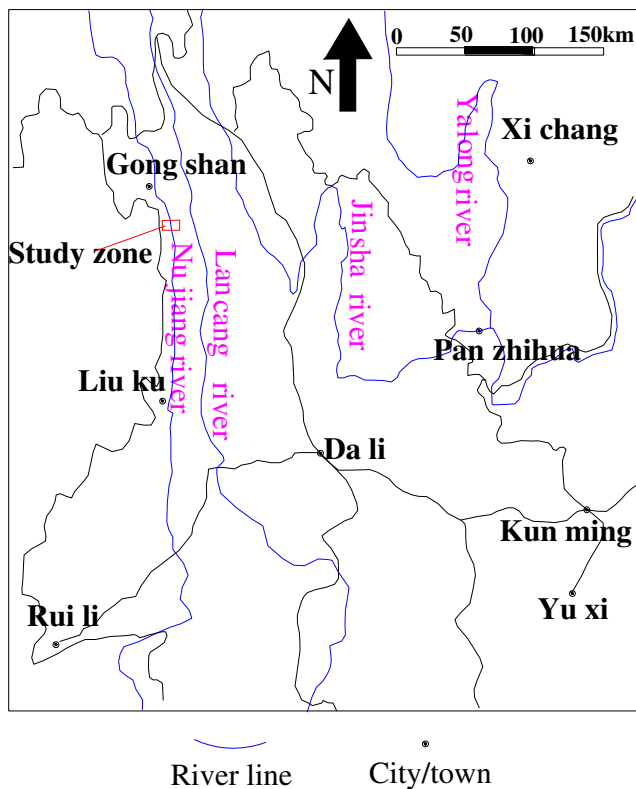


Fig. 1 Location

Rock alteration investigations

Rock types

As the study area lies in the northwest plateau of Yunnan Province southeast of the Tibetan Plateau and in the middle of the Lancang River and Dulong River, geologically, it belongs to the Sanjiang (e.g., Nujiang River, Lancang River, and Jinsha River) orogenic belt between the Indian Plate and the Eurasian Plate. The Sanjiang orogenic belt has undergone strong tectonic magmatism accompanied with magmatic hydrothermal mineralization and hydrothermal alteration (Zhang et al. 2007; Qin et al. 2008). The Sanjiang metallogenic belt, a mountain area between eastern Tibetan and western Sichuan and Yunnan, is an important part in the Himalayan–Sanjiang metallogenic province, one of the most important magmatic hydrothermal metallogenic provinces located at the eastern and the sharp turns of the southern Tethys–Himalayan belt.

Four main alteration belts have been found in the Sanjiang metallogenic belt: the Dali–Jinping basic and ultrabasic rock belt, Jinsha River basic and ultrabasic rock belt, Zhongdian–Lijiang neutral and intermediate-acid porphyry belt, and Lancang River basic and ultrabasic rock belt (Zhang et al. 2007). Survey shows that the intermediate-acid instructive rocks play a dominant role in the study area, with lithology similar to the Zhongdian–Lijiang alteration belt. Furthermore, the study area locates in a relatively large dextral strike-slip shear stress field. Therefore, rock alteration

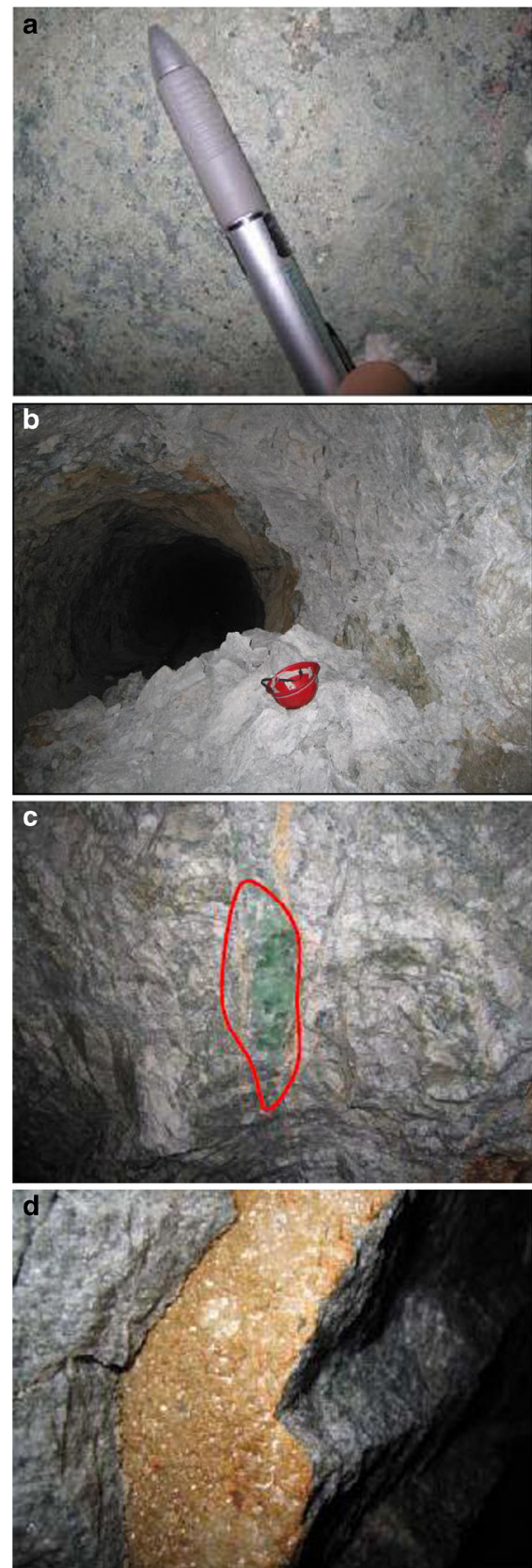


Fig. 2 Photos showing alteration. **a** Alteration of chlorite, **b** collapse of altered rock, **c** fluorite, **d** gypsum crystal

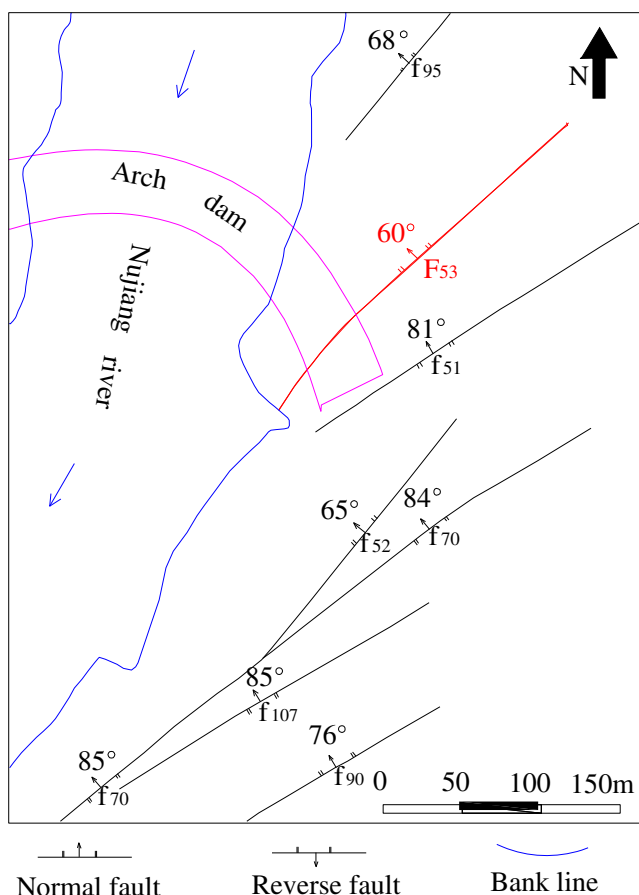


Fig. 3 Simplified engineering geological map within the left bank of hydro-junction area

in the study area is close to that in Zhongdian–Lijiang alteration belt having complex compositions at small scale. The main types of altered rock are diorite porphyrite, granite diorite porphyrite, quartz–monzonite porphyrite, and monzonite–granitic porphyrite, and they are mostly distributed on both sides of regional faults.

Moreover, the mineral composition in the study area mainly consists of quartz, plagioclase, and potash feldspar, with little biotite and hornblende. Therefore, major alteration types are feldspar kaolinization and chloritization in which chlorite replaces some dark minerals (such as biotite and hornblende) in rocks. In addition, fluorite and gypsum are found in some altered rocks, indicating that they are products of low-temperature hydrothermal alteration. Strong alteration and thick alteration zones occur in the study zone, where the remineralization of granite is shown in Fig. 2.

Table 1 Hydrochemical analysis results of fissure–water

Sampling site	pH	Hydrochemical composition (mg L ⁻¹)						Degree of mineralization (mg L ⁻¹)	Hydrochemical type
		HCO ₃ ⁻	SO ₄ ²⁻	Cl ⁻	Ca ²⁺	Mg ²⁺	Na ⁺ /K ⁺		
Dripping of PD201	7.7	54.68	11.86	3.41	14.52	1.36	9.26	95.09	HCO ₃ ⁻ –Ca ²⁺ Na ⁺
Flowing of PD201	7.2	53.98	7.28	2.05	18.41	1.72	0.77	84.21	HCO ₃ ⁻ –Ca ²⁺
Fracture of PD105	7.1	39.55	2.37	1.71	12.87	1.00	0.49	57.99	HCO ₃ ⁻ –Ca ²⁺

Hydrothermal mineralization

Intensive magmatic activities occurred at Sanjiang orogenic belt in northwest Yunnan and southeast Tibet, are famous for the hydrothermal mineralization. Widely distributed clay-altered rocks occur in this region (Zhang et al. 2007) in accordance with the Himalayan–Sanjiang metallogenic formation and mineralization of metallic sulfide deposits. Yanshan and Himalayan granite rocks are often rich in sulfide minerals (pyrite, chalcopyrite, etc.). Regional engineering geological issues, such as diagenesis and remineralization (e.g., kaolinization) associated with low-temperature hydrothermal activity, could not be avoided in the engineering geological evaluation in this area.

Fault fractures

Fault fractures enhance underground thermal water migration, water–rock material exchange, and hydrothermal alteration. Fault structure directly controls the direction, scale, and extent of the development of hydrothermal alteration.

Investigations of regional geological structures show that the study area locates in a relatively large dextral strike-slip shear stress field, and a series of strong strain bands have developed along strata or boundaries of different lithologies. Tectonic stress at the convergent area of the Indian plate and the Eurasian plate is still active.

In the study area, faults are mainly in the NE direction, mostly NE 40°–70°, with relatively long extension and large scale beneficial to the flow of water solution and metasomatic alteration. The fault material is mainly composed of cataclasite. Part of the fault zones is cemented, and alteration appears in some fault zones with a thickness of less than 2.0 cm. In tensional fault zones and its impact zones, seepage, drip, and even water inflow often appear, such as f₅₁, f₅₂, F₅₃, f₇₀, f₉₀, f₉₅, and f₁₀₇, as shown in Fig. 3.

Hydrothermal solution often migrates along extended torsional fault and spreads to secondary fractures on both sides of the faults, so the type and strength zoning of altered rocks are controlled by the structure development.

Groundwater

Field investigation of the adits on both sides of the study area indicates that seepage and water gushing phenomena appear

Table 2 Granulometric analysis results and water content of gouge or fracture filling of left bank adits for F53

Fault gouge sampling site	Moisture content (%)	Particle composition (%)							Remarks
		>2.0 mm	2.0~0.5 mm	0.5~0.25 mm	0.25~0.075 mm	0.075~0.005 mm	<0.005	<0.002	
PD201	20.56	6.20	15.95	6.05	10.75	30.21	30.84	20.68	
PD201	20.97	15.58	29.62	12.45	17.30	17.21	7.74	5.60	
PD203	12.30	15.23	13.91	5.97	11.41	27.38	26.10	20.49	
PD105-1	18.45	7.84	13.29	5.24	10.08	26.13	37.42		
Tan jello of PD105-1	209.89	–	–	–	–	–	–	–	Fe(OH) ₃ and Al(OH) ₃ pH is 5.5

significantly in strongly unloading zones on the shallow surface of adit mouth. Moreover, fracture seepage was found at depths of 100~200 m deep under the cave, especially through the extensional fracture in the NNW direction on the right bank where hydroyps are commonly found at the bottom of the surveyed adits.

The mineralization degree of the groundwater is very low (less than 100 mg L⁻¹), and the hydrochemical type is HCO₃⁻Ca²⁺ with HCO₃⁻ taking of 39.55~54.68 mg L⁻¹. The greater the amount of water seepage, the higher content of HCO₃⁻. For example, the drip water at the depth of 82 m in adit 201 has a HCO₃⁻ content of 54.68 mg L⁻¹ and SO₄²⁻ content of 11.86 mg L⁻¹, while the seepage of f₁₅ at the depth of 125 m in adit 105 has a HCO₃⁻ content of 39.55 mg L⁻¹ and SO₄²⁻ content of 2.37 mg L⁻¹. These data suggests that the recharge, seepage, and excretion conditions of the groundwater in the rocks are good, and the groundwater has significantly direct hydraulic connection with meteoric water (Table 1).

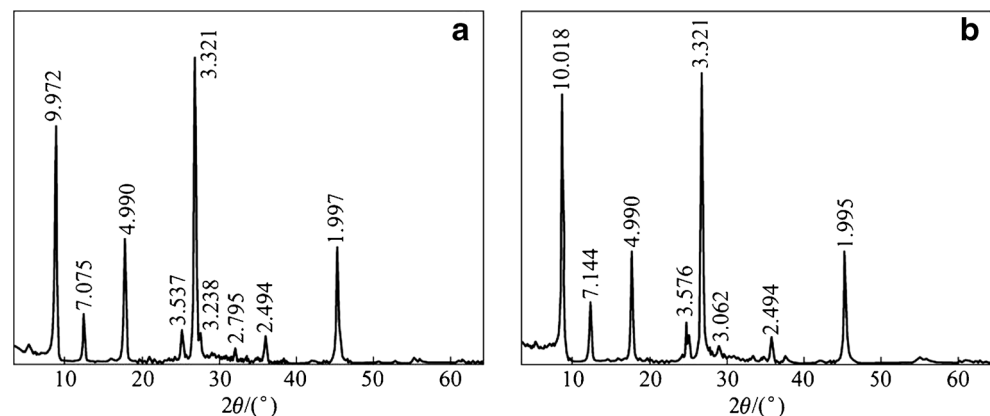
Characteristics of altered rock

Rocks in the study area are granites which are rich in sulfide minerals (pyrite, chalcopyrite, etc.) in Himalayan. The low-temperature hydrothermal alteration in the mineralization period, namely kaolinization and illitization of gneissic granite, converts plagioclase into kaolinite, precipitating Ca²⁺ or Na⁺ (in the meanwhile, Cl⁻ is precipitated in the hydrothermal fluid remains). After the process of diagenesis and fracturing

of rock mass, pyrite(FeS₂) and chalcopyrite (CuFeS₂) generate much brown colloidal precipitation Fe(OH)₃ and anion SO₄²⁻ (4FeS₂+15O₂+14H₂O→8SO₄²⁻+4Fe(OH)₃+16H⁺) in the process of oxidation–hydrolysis. Under the long-term action of acid water, rock kaolinization after diagenesis can also appear. Halloysite can also be produced in the groundwater full of HCO₃⁻, a strong leaching environment with good drainage. Due to the large amount of brown colloidal gel in F53 from PD105-1, the water percent reaches 209.89 % by sampling determination and the pH value is 5.5. Moreover, they are mainly Al(OH)₃ associated with colloid Fe(OH)₃, according to differential thermal analysis (shown in Table 2).

The disintegration experiments of irregular drying rocks after being soaked and the water absorption tests of rocks are effective engineering methods. In the process of clay alteration of igneous rocks, a large number of clay minerals in the rock are formed often accompanying with drying shrinkage, water absorption expansion (laterally constrained), and disintegration (unconstrained). Thus, swelling rocks can be produced. Identification test of swelling powder rocks shows that the altered rock samples are the micro-expansive type with a saturated ratio of water absorption between 10 and 20 %. At the same time, the particles of size less than 5 μm is a mixture of kaolinite and illite, as indicated by the X-ray diffraction (XRD) analysis and thermal analysis (DTA and TGA), as shown in Fig 4. Illite is produced by the alteration of a large number of K-feldspar (orthoclase and feldspar) in granite

Fig. 4 XRD of altered rocks in (a) PD103 and (b) PD113



under the influence of groundwater or hydrothermal mineralization. Kaolinite and illite are clay minerals of lattice expansion, low physical and chemical activity, and low hydrophilicity, so the altered rock has a lower swelling power and the fault gouge formed by them has low water content, liquid limit, and plasticity index. From the perspective of seepage deformation, however, it is more prone to occur in the middle–low activity clay minerals.

Conclusions

Analysis of the alteration phenomena of rock mass in the study area indicates that the structural plane kaolinization of feldspar mainly develops in the unloading zone or weathered zone of slopes and less in slightly weathered zone, usually with the structure surface semi-closed.

Rock alteration has less impact on the strength of the slightly weathered rock. The surrounding rock heterogeneity of mineralization, alteration, and structural fault distribution leads to the complexity in the groundwater system. Groundwater chemical composition in the transition from dry seasons to rainy seasons and the distribution of strong permeable zones should be considered in the future work of evaluating whether seepage deformations or other engineering problems are under the influence of high pressure of water permeation.

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References

- Abbaszadeh M, Hezarkhani A (2013) Enhancement of hydrothermal alteration zones using the spectral feature fitting method in Rabor area, Kerman, Iran. *Arab J Geosci* 6:1957–1964
- Chen DYQ, Yang T, Xu CY (2010) Hydrologic alteration along the Middle and Upper East River (Dongjiang) basin, South China: a visually enhanced mining on the results of RVA method. *Stoch Environ Res Risk Assess* 24(1):9–18
- Dwijesh R, Catherine M, Ranadip B (2009) Hydrothermal alteration studies of gabbros from Northern Central Indian Ridge and their geodynamic implications. *J Earth Syst Sci* 118(6):659–676
- Eilu P, Mikucki EJ (1998) Alteration and primary geochemical dispersion associated with the Bulletin lode-gold deposit, Wiluna, Western Australia. *J Geotech Explor* 63(2):73–103
- Eilu P, Edward J, Mikucki AL (2001) Alteration zoning and primary geochemical dispersion at the Bronzewing lode-gold deposit, Western Australia. *Miner Deposita* 36(1):13–31
- Elumalai M, Antunes C, Guilhermino L (2005) Alterations of reproductive parameters in the crab *Carcinus maenas* after exposure to metals. *Water Air Soil Pol* 160:245–258
- Ghanbari Y, Ramazi HR, Pazand K, Madani N (2013) Investigation of rock quality of Shirinrud dam site by engineering seismology. *Arab J Geosci* 6:177–185
- Hürzeler JP, Abart R (2008) Fluid flow and rock alteration along the Glarus thrust. *Swiss J Geosci* 101(2):251–268
- Khalokakaie R, Naghadehi MZ (2012) Ranking the rock slope instability potential using the Interaction Matrix (IM) technique; a case study in Iran. *Arab J Geosci* 5:263–273
- Meng GT, Xu WY, Yang SQ (2008) Genesis mechanism and engineering characteristics analysis of G23 mylonitization and fractured belt in dam foundation of a hydropower station. *Rock Soil Mech* 29(6):1691–1696 (in Chinese)
- Ozcelik Y, Bayram F, Yasitli NE (2013) Prediction of engineering properties of rocks from microscopic data. *Arab J Geosci* 6:3651–3668
- Pazand K, Hezarkhani A, Ataei M (2013) The application of litho-geochemical and alteration index for copper mineralization in the Sonajil area, NW Iran. *Arab J Geosci* 6:1447–1456
- Qin LM, Xu M (2007) Chloritized alteration rock mass and the engineering countermeasures in a hydropower station dam site in southwest China. *Chin J Geol Hazard Control* 18(1):68–72 (in Chinese)
- Qin KZ, Li GM, Zhao JX (2008) Discovery of sharing large-scale porphyry molybdenum deposit, the first single Mo deposit in Tibet and its significance. *Geol China* 35(6):1101–1112 (in Chinese)
- Qu YX (1985) The engineering geological problems of swelling rock in underground construction. *Engineering geomechanics problems of rockmass* (no. 5). Science, Beijing, in Chinese
- Qu YX (2004) Soft rock and soft interlayer. *Century achievements of China Geological engineering*. Geologic Publishing House, Beijing, in Chinese
- Qu YX, Xu XL, Wu ZL (1992) Engineering geological research on cementation of mud-rock from eastern China. *Annual report 1992 of engineering geomechanics laboratory institute of geology of Chinese academy of sciences*. Seismological, Beijing, pp 1–18, in Chinese
- Yang GL, Huang RQ, Wang JZ (2006) Study on the pore characteristics and the weakness of altered-rock for a project. *J Miner Petrol* 26(4):111–115, in Chinese
- Ye TQ (1991) Research on the characteristic of Pb-Zn mine ore and the metallogenesis system in Nujiang–Lancangjiang–Jinshajiang region. Beijing Press of Science and Technology, Beijing, in Chinese
- Zhai YS (1999) Regional metallogeny. Geological Publishing House, Beijing, in Chinese
- Zhang FG, Tu XX (1994) Engineering geological characteristics of clay alteration granite. *Guangdong Geol* 9(3):25–34 (in Chinese)
- Zhang YS, Qu YX, Liu JR (2007) Engineering geological research on altered rocks in the area of NW Yunnan along Yunnan-Tibet Railway line. *China J Geotech Eng* 29(4):531–536, in Chinese