地理学报(英文版) 2002年第12卷第2期

Chemical element transfer of weathering granite regolith in the Three Gorges Dam region of Yangtze River

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Chemical element transfer of weathering granite regolith in the Three Gorges Dam region of Yangtze River ZHANG Li-ping1, ZHU Da-kui2, YANG Da-yuan2 (1. Institute of Soil and Water Resources and Environment, Zhejiang University, Hangzhou 310029, China; 2. Department of Geo and Ocean Science, Nanjing University, Nanjing 210093, China) Weathering regolith is a product of exposed rock weathered by various exogenic processes. In essence, weathering processes are destruction and transferring processes of rock and weathering regolith. In different natural environment and landforms, the weathering processes differ greatly. So, types of weathering regolith and its development phase also differ. Up to now, researches on the landform processes, distribution law, vertical zonal features and formation of weathering granite regolith have been done and a large number of academic thesis and works have been published (Bao, 1992; Cliff, 1984; Denys, 1979; Gong, 1983; Lu, 1982; Milan, 1984; Smith, 1988; Song et al., 1987; Su, 1988; Wang et al., 1980; Xiong and Feng, 1965; Xu, 1994). But the researches on the chemical element transferring law and chemical weathering distinction in different river valley landforms have hardly been done. Clearing up sediment and regolith on the foundation of the Three Gorges Dam of the Yangtze River in 1999, riverbed were exposed which offered an opportunity to research river valley landforms. In the Three Gorges Dam region, the rock is granite formed in Presinian period (CWRC, 1997), and two sides of the valley slope are weathering granite regolith with different thickness. Through researches, the difference and process and intensity of chemical element transferring in various landforms can be revealed and presented. 1 Sampling collection At 100 m downward the dam foundation, 50 samples were equidistantly collected at a height interval of 1.5 m along a NE 42(trending cross section of the river valley, where 4 different elevations and 6 typical sample columnar sections were identified. The first and second sample sections, with a height of 10 m, were situated at both sides of the riverbed deep trough with a top evaluation of 38 m where 14 samples were collected. The third and fourth sample sections, with a height of 8.5 m, were situated at both sides of the riverbed flood-plain with a top elevation of 53 m where 12 samples were collected. The fifth sample section, with a height of 17.5 m, lies in the left side of Zhong Baodao Island with a top elevation of 72 m where 12 samples were collected (Figure 1). The sixth sample section was located on the left hill slope of the fifth permanent ship lock ranging between 100 to 200 m from Zhiwan to Leipitai. Because of limit of weathering regolith vertical layer development, 12 samples were collected taking the same weathering layer level shift method. The position of the sixth sample columnar section was not marked in Figure 1 for its long distance to the dam site exceeds the range of the figure. Figure 1 Distribution of sampling sites along the cross section of the Three Gorges Dam of the Yangtze River 2 Research method 2.1 Chemical element content and transferring ratio In this research, we adopted X rays fluorescent slice to analyze chemical total composition of weathering granite regolith. Based on the results of analysis, we further calculated chemical element transferring ratio m (Table 1): The figures in Table 1 are average value of two sample columns situated at the same landform positions with the same chemical element in the same layer. In Table 1, the average of sample columns 1 and 2 got riverbed, sample columns 3 and 4 got flood plain column, and sample columns 5 and 6 got valley slope column. Fresh granite chemical total content is the average value of many drill cores data from the Three Gorges Investigation and Research Institute CWRC (CWRC, 1997), and Chinese Geological University (Ren et al., 1998) and Hohai University1, because fresh granite from drill cores differ in chemical total composition. According to change features of figures, we chos e peculiar chemical elements in content change and drew Figure 2. Table 1 Chemical composition and transferring ratio of the weathering granite regolith in the Three Gorges Dam region of the Yangtze River 2.2 Chemical element transferring characteristics value and intensity calculation On the basis of analysis to chemical total composition and transferring, we calculated, in detail, the proper values and intensities of chemical element transferring in various landforms. In the process of calculating, we selected 7 weathering coefficients (Table 2), listing below: Weathering coefficients gave expressions in the absolute weathering intensity and leaching and enrichment of chemical elements in certain vertical sections. It can only be used to analyze comparatively on the same element in different layers of certain weathering sections. There are difficulties in synthetic evaluation on chemical element motion features in different weathering sections and can bring about wrong conclusions. Thus, we recommended a better comprehensive index--weathering intensity I (Table 2) (Huang et al., 1996). where Em is balance index of chemical element and Er is balance index of weathering coefficient where H (s) is information function (Yi, 1995), N is is total calculated number, Pi is probability, i.e. the percentage of each weathering value to the total value and is average leaching coefficient. Figure 2 The changing trend of peculiar chemical content in different granite weathering layer depths in the Three Gorges Dam region of the Yangtze River Table 2 The proper value of chemical element transferring and intensity in all weathering granite regolith sections in the Three Gorges Dam region of Yangtze River where is the oxide weight % transferred from mother rock in the process of weathering, y0 is weight % of oxide in fresh granite, yi is weight % of oxide in different depths. When ≤0, it should be neglected. Weathering intensity index can comprehensively indicate weathering degree in various weathering sections and different layers, and can be used to analyze comparatively various weathering sections in different landforms, and show the features of leaching and enrichment in the development process of weathering granite regolith. 3 Results analysis 3.1 Chemical content and transferring characteristics Table 1 and Figure 2 show that the oxides of Si and Al accounts for 80% of the chemical composition of weathering granite regolith in the Three Gorges Dam region. Chemical element leaching and enriching is vary greatly in different landforms.

1) SiO2, Al2O3, Fe2O3. The process of desilication and allitization of weathering granite regolith is not distinct. The rate of desilication is in the order of flood plain (9.7%) > riverbed (7.1%) > valley slope (2.5%). Al2O3 in weathering granite regolith of riverbed does not basically enrich and tends to decrease from bottom to top, but in flood-plain and valley slope, it is obviously enriches respectively at the ratio of 12% and 10.4%. Fe2O3 enriches, from bottom to top, in every weathering granite regolith section respectively at the ratio of 29.1% (riverbed), 22.6% (flood-plain) and 12% (valley slope). 2) Alkaline-earth metal (CaO, MgO). CaO content trends toward leaching in the weathering granite regolith section situated on flood-plain and valley slope. Contrarily, CaO content trends toward enrichment in the weathering granite regolith section of the river, but the greatest content of CaO is in the certain portion under surface layer. At all weathering granite regolith sections, there are CaO enrichment layers ranging 3-5 m under surface layer. General tendency of MgO content is leaching, from bottom to top, in the weathering granite regolith section on the valley slope, but the least MgO content layer appears in the middle of the weathering granite regolith section. MgO content enriches in line, from bottom to top, in the weathering granite regolith section located in riverbed and flood-plain, only there is a bizarre layer in bottom of the flood-plain and at 3.5 m depth of riverbed.

3) Alkaline metal (K2O, Na2O). General tendency of Na2O content is in leaching state, from bottom to top, in the weathering granite regolith section of various landforms, the least content appears in upper layer, but there is an obvious enriching layer in 6.5 m depth of the section, and decreases progressively from 6.5 m depth to both ends of the upper and the lower. K2O content changes complicated. It trends toward leaching, from bottom to top, in the weathering granite regolith section of the riverbed and valley slope. But it enriches with obvious regularity, from bottom to top, in the weathering granite regolith section of the flood-plain. However, there is a least content layer in 6.5 m depth of various weathering granite regolith sections. 3.2 Chemical element transferring intensity analysis Table 2 indicates that weathering granite regolith development differs in various landforms. * SiO2/Al2O3 It decreases gradually, from bottom to top, in various weathering granite regolith sections, the order of decreasing ratio is flood-plain>valley slope>riverbed. * Al2O3/Fe2O3 It also decreases gradually, from bottom to top, in various weathering granite regolith sections, but it can better reflect chemical element transferring law than SiO2 /Al2O3 can. * R2O3/(RO+R2O) It increases gradually, from bottom to top, in various weathering granite regolith sections respectively at the ratio of 2.33% (valley slope), 1.67% (flood-plain) and 0.57% (riverbed). * (RO+R2O)/Al2O3 It tends toward decreasing with a great changing ratio, from bottom to top, in the weathering granite regolith section of valley slope and flood-plain. But, in the weathering granite regolith section of riverbed, it increases progressively from bottom to top. * Weathering intensity. In the weathering granite regolith section of riverbed and flood-plain, weathering intensity increases progressively from bottom to top, but the process of increasing undulates greatly. In the weathering granite rego

lith section of valley slope, weathering intensity changes insignificantly, and undulates around 44%, but with minor range. Thus, it can be seen that both absolute and relative weathering intensity are in the order of riverbed > flood-plain > valley slope. 4 Conclusions and discussion 4.1 Conclusions 1) In the weathering granite regolith section of riverbed, Al_2O_3 trends toward decreasing, Fe_2O_3 enriches at great ratio, the easy leachable CaO and MgO enriches relatively, but in 3.5 m depth, there are the layer of the greatest CaO content and the layer of the least MgO content. Though K_2O and Na_2O are at leaching state, in 6.5 m depth, K_2O content decreases to the least and Na_2O content reaches the greatest. Because CaO and MgO content enriches relatively, $(CaO+MgO)/Al_2O_3$ trends toward increasing. Further, the leaching ratio of K_2O and Na_2O is less than the enriching ratio of CaO and MgO, and Al_2O_3 trends toward decreasing, so $(RO+R_2O)/Al_2O_3$ trends toward increasing. 2) In the weathering granite regolith section of flood-plain, excluding few peculiar layers, transferring law of all the chemical elements are more obvious, only K_2O and MgO go on enriching. The change laws of increasing and decreasing of weathering coefficients develop regularly, or $R_2O_3/(RO+R_2O)$, $(RO+R_2O)/Al_2O_3$ and R_2O_3/SiO_2 trend to increasing, and the other weathering coefficients trend to decreasing. 3) In the weathering granite regolith section of valley slope, the leaching and enrichment of chemical elements and weathering coefficients change regularly. It shows features of weathering granite regolith in the north subtropics. There is special layer in depth of 6.5 m, where the K_2O and MgO contents decrease to the least and Na_2O content reaches the greatest, and SiO_2 content relatively enriches, and Fe_2O_3 is the layer of relative reduction. 4.2 Discussion 1) Because weathering granite regolith of riverbed is in a flowing water environment for a long time, its chemical reaction (including: hydration, hydrolysis, solution, oxidation, etc.) and transferring ratio of easy soluble minerals are faster than of flood-plain and valley slope. However, under the action of long term erosion and washing by flowing water, loose weathering granite regolith is eroded and can not be dissolved further, so no completely and intensely weathered granite regolith exists (CWRC, 1997). Thus, it only develops in the early period of chemical weathering. In the period, K^+ and Na^+ are displaced with H^+ and are washed away as flowing water, and CaO and MgO are relatively enriching. The other reasons for relative enrichment of CaO are that CO_2 is much leaser and carbonic acidization is weaker in river water than in soil and weathering matter. 2) Flood-plain basically is the sedimentary place. Some easy dissolved material as flowing water temporary deposits on it, so the cardinal number of easy dissolved salt is very great and presents peculiar enriching phenomenon on the surface layer. In flood water season it is inundated with flood, and chemical reaction (including hydration, hydrolysis, solution, oxidation, etc.) are faster than in valley slope. But due to little depth of water and slow flowing velocity, erosion and washing action are weaker than in riverbed. Thus, the weathered granite can remain for some time and go on being weathered, the weathering intensity is greater than in valley slope. 3) In weathering granite regolith section, there are some peculiar layers of leaching element relatively enriched and enrichment element relatively leached. These layers give the facts that chemical element transferring does not develop following the theoretical model of leached element decreasing and enriched element increasing, but with landform and water cycle condition. Chemical element transferring takes vertical movement as dominant way in the upper weathering granite regolith, and begins to enrich gradually in certain depth due to slowdown of water cycle. 4) Weathering intensity change depends on Em, Er and . Table 2 shows that Er and Er change regularly and have no peculiar point, but undulates greatly. Thus, we can infer that the reason for weathering intensity undulation is due to the stability of value. Further, value change is decided by the maximum and minimum weight functions of SiO_2, K^+, Na^+, Ca^+ and Mg^+. In a word, in weathering granite regolith of the Three Gorges Dam region, there still are alkaline-earth and alkaline metal, and the processes of desilification and allitization are not distinct, which show that leaching of easy dissolved salt is not intense and chemical weathering is in the transition phase from early to middle period. In weathering granite regolith of riverbed, there are many peculiar phenomena which require to be researched further, i.e., Al_2O_3 decreases progressively, Fe_2O_3 enriches at faster velocity, there is opposite layer of CaO enrichment and MgO leaching in 3.5 m depth. Further research is also needed as there is opposite layer of K_2O relatively leaching and Na_2O relatively enriching in 6.5 m depth of all weathering granite regolith. References

关键词： Three Gorges Dam; weathering regolith; chemical element; transferring?