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Distribution and controlling factors of selenium in weathered soil in Kaiyang County, Southwest China

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Abstract Selenium is one of the life-related elements. Survey reveals that selenium enrichment in the studied strata from Kaiyang County is considered to be closely related to the following factors: regional black shale series in Niutitang Formation of Early Cambrian, strong adsorption of organic matter (OM), magmatic hydrothermal migrate along the deep fault, mixing and migration of hydrothermal brine, regional uranium mineralization and presence of a great deal sulfides. For selenium enrichment in its weathered soil and crops, the reason responsible is selenium-enriched bedrock, which provides material sources for weathering profile and is considered as the main controlling factor of selenium content in the soil profile. After leaching and migrates downwards, organic carbon (OC) adsorption, iron-manganese layer adsorption, geochemical barrier role, selenium content in different profiles, there are mainly three types of distribution features: bottom enrichment type, top enrichment type and no significant enrichment type. Comprehensive analyses find that selenium enrichment area is mainly distributed in the Machang, Gaoyun-Fengsan-Guanpo, Baimadong, Chuandong-Hefeng-Shaoshang and Longgang-Gaozhai region, etc. Besides, around the east part of the county, in Huali and Yongxing selenium are relatively scarce.

Key words selenium enrichment; controlling factors; geochemistry; weathered profile; Kaiyang

1 Introduction

Kaiyang County is located in north-central Guizhou Province and subordinate to the capital city Guiyang, between Central Guizhou Economic Circle and Northern Guizhou Economic Belt. The county is 64.5 km long from south to north and 53 km wide from east to west, with the area of 2020.2 km^2.

The emerged strata in Kaiyang County are characterized with Neoproterozoic, Cambrian, Ordovician, Carboniferous, Permian, Triassic, Upper Cretaceous, and Quaternary. The geomorphology belongs to hill-plain-basin region of Central Guizhou, and is situated on second step of the Guizhou Slope of Yunnan-Guizhou Plateau. It features high and rough topography and complicated and various geological structures. During frequent and drastic crustal movements, many deep and big fractures occurred in the region, most of which were NE, NEE, EW, SN, and NW faults. These faults usually mutually intersect to form complex cross-fractures, which may cause significant influence on the control of occurrence and development of geological structures.

In the tectonic setting, Kaiyang County is in the uplifted southeast of central Guizhou on Yangtze Platform. In the tectonic movements in Paleoproterozoic Era, Caledonian, and Hercynian, etc. This region has undergone through uplift, interrupted sedimentation, and denudation for many times. During Ningzhen Orogeny in Yanshanian, this region was fault-folded into mountains. Therefore, the County's strata exposed insufficiency, with a little thickness of sedimentary rocks.

Kaiyang County also features a rich selenium source, with lower development and utilization rates compared with such rates in places nearby (Wang and Zhu, 2003; Li et al., 2004, 2005; Ren et al., 2012a, b). In addition, there are few researches on selenium distribution, enrichment, and control factors. Therefore, this Paper takes some weathered soil profiles from Neoproterozoic age to Permian as research objects to discuss the distribution and enrichment factors of selenium in weathered soil and analyze control factors of enrichment in Kaiyang County.

2 Weathered soil analyses

2.1 Characteristics of weathered red clay profiles

This paper takes strata of Neoproterozoic Yangshui Formation, Dengying Formation, Cambrian, Permian and their weathered soil profiles as research objects to discuss selenium-enriched strata and the distribution and control factors of selenium in weathered soil profiles (Fig. 1).

Fig. 1. Locations of the study region and the sampling points. A. Linjiazhai profile; B. Shaoshang profile; C. Baimadong profile; D. Yanjia Coal Mine profile; E. Dingfang profile; F. Gaoyun profile; G. Hefeng profile; H. Jinzhong profile; I. Yakou profile; J. Huangmu village profile.

Systematic sampling has been conducted on profile H (dolomite and its weathered soil, Yangshui-Dengying Formation, Sinian), profile B, G and I (dolomite and its weathered soil, Dengying Formation), profile C and F (dolomite and weathered soil, Qingxudong Formation, Cambrian), profile A and E (dolomite and weathered soil, Loushanguan Group, Cambrian), profile J (limestone and its weathered soil, Liangshan-Maokou Formation, Permian), profile D (limestone, sandstone and its weathered soil, Maokou-Wujiaping Formation, Permian), with the description on such weathered soil profiles shown as follows:

Profile A is located in Linjiazhai Village, Nanmudu Town, Kaiyang County, which is a weathered soil profile of dolomite in Middle-Upper Loushanguan Group of Cambrian, with the profile thickness of about 5.2 m. The profile is divided into earthy-yellow clay layer, purplish-red and purplish-yellow clay layer, yellow and brownish-yellow clay layer, yellowish-brown clay layer, dark brown clay layer, and dolomite from top to bottom (Fig. 2A).

Profile B is located in Shaoshang Town in southern Kaiyang County. Its bedrock is occurrence-gentle dolomite in Dengying Formation. The weathered profile has a great thickness of 2–7 m. Through the analysis of vertical characteristics of the profile, its strata are similar to those of other red clays profiles, which are dolomite, siltstone, dark purplish-brown clay, purplish-red and purplish-brown clay, and grayish-yellow clay (Fig. 2B).

Profile C is located in the east of Kaiyang County and in the left of a highway from Baimadong Village to Kaiyang County, which was excavated when the highway was reconstructed and expanded. The profile is near a fault belt and features distinct broken bedrock. In addition, it displays apparently color layering from top to bottom: gray black clay layer, yellow clay layer, yellowish-brown clay layer, siltstone stratum, and pink dolomite (Fig. 2C).

Profile D is located in a coal mine of Yanjiao Village, Hefeng Town, southwestern Kaiyang County. It is a weathered profile in coal measure stratum of Permian seen from the weathered soil profile of limestone in Maokou Formation, it presents a dark purplish-brown clay layer, yellowish-brown clay layer, and limestone from top to bottom. Seen from the weathered soil profile of sandstone in Wujiaping Formation, the entire profile is divided into one stratum, i.e., piled gravel sand stratum (Fig. 2D).

Profile E is located in southern Kaiyang County and a weathered soil profile of dolomite in middle-upper Loushanguan Group of Cambrian, with the profile thickness of about 2.5 m. The profile exhibits vegetation, yellowish-brown clay layer, earthy-yellow clay layer, and dolomite (bedrock) from top to bottom (Fig. 2E).

Profile F is located next to a highway from Shuangliu to Kaiyang, northwestern Kaiyang County. The profile was excavated during the highway construction, after that the bottom of which was bolt supported and hided, but we could still see the emerged dolomite in Qingxudong Formation of Lower Cambrian. The soil profile features few color changes but great thickness which is mainly related to that the bedrock is argillaceous dolomite and has abundant joints. The soil is observed to be yellowish-brown clay layer, yellow clay layer, and dolomite from top to bottom (Fig. 2F).

Profile G is located in Hefeng Town in southeastern Kaiyang County. Its bedrock is dolomite in Dengying Formation of Sinian. Under the bedrock, there is a stratum of black carbonaceous mudstone of about 50 cm thick. The entire profile also presents distinct stratification from top to bottom: grayish-yellow clay layer, dark purple clay, black carbonaceous mudstone, siliceous dolomite, and dolomite (Fig. 2G).

Profile H is located in a place which is 8 km from Jinzhong Town in the northwest. Its bedrock is phosphoric dolomite in Yangshui-Dengying Formation of Sinian. The dolomite features clear lamina. The entire profile presents distinct color stratification and is divided into dark black clay layer, yellow clay layer (containing Fe and Mn), yellowish-brown clay layer, brown clay layer, and bedrock. We collected a sample in every stratum (Fig. 2H).

Profile I is located beside Yakou Quarry Yard which is on one side of a highway from Jinzhong Town to Kaiyang County. The profile is a weathered soil profile of dolomite in Dengying Formation of Sinian. The profile presents distinct stratification and includes grayish-yellow clay layer, dark purplish-red clay layer, siltstone, and bedrock from top to bottom. We collected a sample in every stratum (Fig. 2I).

Profile J is located in Huangmu Village of Nanmudu Town of northern Kaiyang County. The profile is a weathered profile of dark black thin siliceous dolomite in Middle Permian Maokou Formation. The profile presents vegetation, yellowish-brown clay layer, dark brown clay layer, and bedrock from top to bottom (Fig. 2J).

2.2 Sample collection

We made systematic sampling on profiles from bottom up. During sampling, we eliminate surface strata affected by wind, dust, and rainwater, and take fresh soil. Since the profiles feature distinct color stratification and frequent color changes, we selected a strip-center collection method on the collection direction, i.e., continually selecting samples in centers of every color strips from bottom up, so as to enable every sample to represent general characteristics of color strips.

Samples were dried under a low temperature (< 40℃) and ground to 200 meshes. As in Table 1, ALS Laboratory Group utilized ME-MS41 Aqua regia digestion method and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to determine trace elements (TE); or ME-MS81 melting method and ICP-MS to determine contents of rare-earth elements (REE).

3 Distribution of selenium in rocks, soils and crops

The Kaiyang County has rich selenium resource and the current research is targeted selenium in this region with respect to its distribution and the relation between it and black shale. This paper discusses the distribution and control factors of selenium based on previous researches.

Table 1 Selenium content in rocks, soils and crops in Kaiyang County

Sample	Characteristic	Se (mg·kg^{-1})	Sample	Characteristic	Se (mg·kg^{-1})
KMA1	Siltstone stratum	8.00	KY-JZB00	Dolostone	1.00
KMA2	Dark purplish-brown clay	3.10	KY-JZB01	Yellow clay	1.00
KMA3	Purplish-red and purplish-brown clay	2.10	KY-JZB02	Light yellowish-brown clay	1.00
KMA4	Purplish-red and purplish-brown clay	3.30	KY-JZB03	Yellowish-brown clay	1.00
KMA5	Purplish-red and purplish-brown clay	1.20	KY-JZB04	Black clay	1.00
KMA6	Purplish-red and purplish-brown clay	1.30	KY-GY00	Dolostone	2.00
KMA7	Grayish-black clay	1.00	KY-GY01	Yellow clay	1.00
KY-LJZ01	Dolostone	1.00	KY-GY02	Yellow clay	1.00
KY-LJZ02	Dark brown clay	2.00	KY-GY03	Yellow clay	1.00
KY-LJZ03	Light yellowish-brown clay	2.00	KY-GY04	Yellow clay	1.00
KY-LJZ04	Yellow and brown clay	2.00	KY-GY05	Yellow clay	1.00
KY-LJZ05	Yellow and brown clay	2.00	KY-GY06	Yellowish-brown clay	2.00
KY-LJZ06	Yellow and brown clay	2.00	KY-HMC00	Siliceous dolostone	2.00
KY-LJZ07	Yellow and brown clay	2.00	KY-HMC01	Dark brown clay	4.00
KY-LJZ08	Yellow and brown clay	2.00	KY-HMC02	Yellowish-brown clay	5.00
KY-LJZ09	Yellow and brown clay	2.00	KY-HMC03	Plant	2.00
KY-LJZ10	Purplish-red and purplish-yellow clay	2.00	KY-YJ01	Dark purplish-brown clay	3.00
KY-LJZ11	Dusty-grey and earthy-yellow clay	3.00	KY-YJ02	Yellowish-brown clay	4.00
KY-LJZ12	Plant	2.00	KY-YJ03	Piled grvel sand	2.00
KY-bmdt01	Dolostone	2.00	KY-YJ04	Limestone	191.00
KY-bmdt02	Siltstone stratum	2.00	KY-DF01	Dolostone	2.00
KY-bmdt03	Yellowish-brown clay	1.00	KY-DF02	Purplish-red and purplish-yellow clay	2.00
KY-bmdt04	Yellowish-brown clay	1.00	KY-DF03	Yellowish-brown clay	2.00
KY-bmdt05	Yellow clay	1.00	KY-DF04	Plant	2.00
KY-bmdt06	Yellow clay	2.00	KY-DF05	Plant	2.00
KY-bmdt07	Grayish-black clay	2.00	KY-HF01	Sallow clay	5.00
KY-JZ00	Dolostone	1.00	KY-HF02	Dolostone	2.00
KY-JZ01	Siltstone stratum	2.00	KY-HF03	Plant	2.00
KY-JZ02	Purplish-red clay	2.00	KY-HF04	Sallow clay	7.00
KY-JZ03	Yellowish-brown clay	1.00	KY-HF05	Dolostone	4.00
	Custal abundance [a)]	0.08		Chinese average content of soils [b)]	0.23

Note: [a)] Cited from Li, 1976; [b)] cited from Xing et al., 2003.

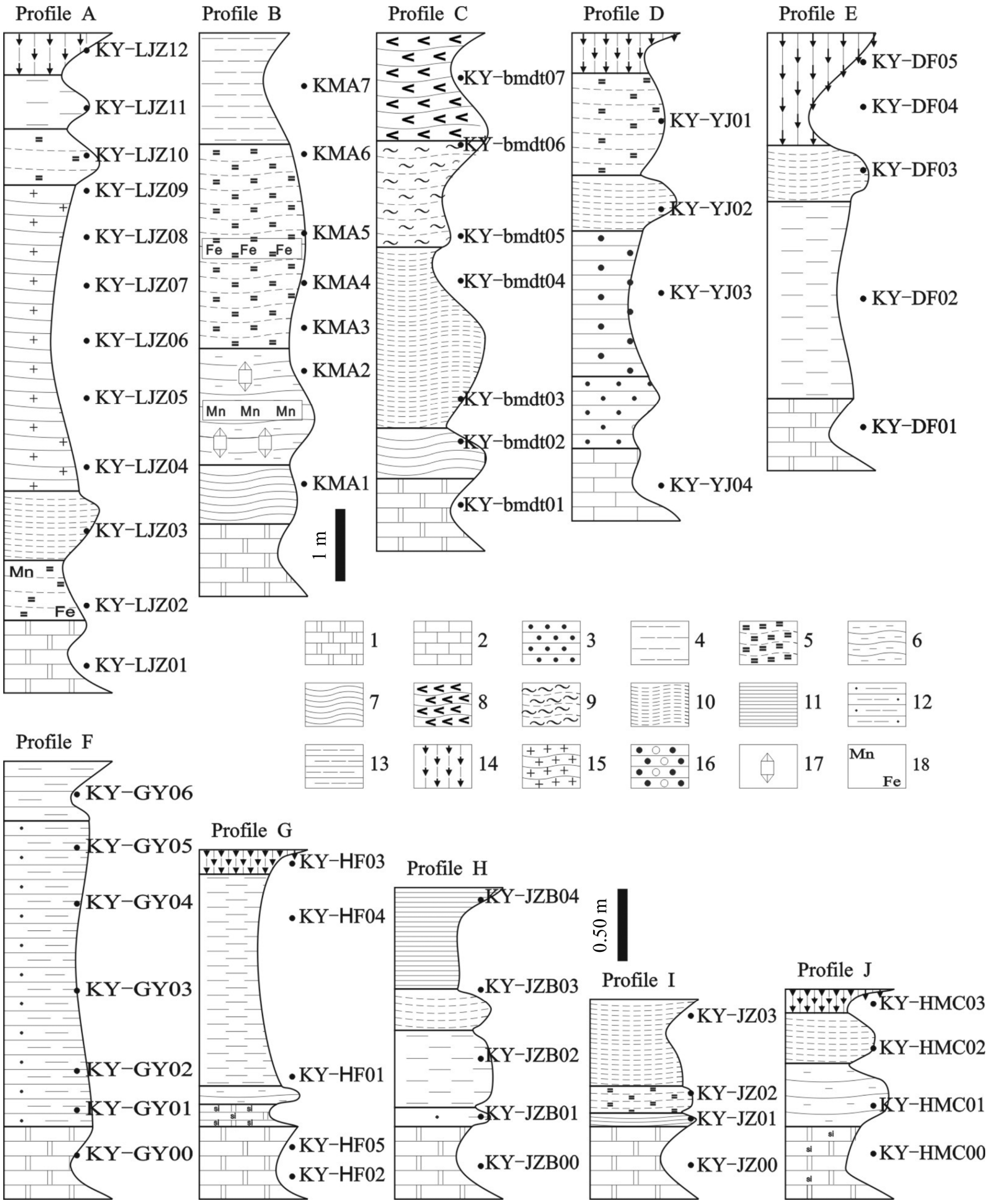


Fig. 2. Map of the weathered soil profile in the study area. 1. Dolostone; 2. limestone; 3. sandstone; 4. dusty-grey and earthy-yellow clay; 5. purplish-red and purplish-brown clay; 6. dark purplish-brown clay; 7. siltstone stratum; 8. grayish-black clay; 9. yellow clay; 10. yellowish-brown clay; 11. black clay; 12. light yellow clay; 13. dark yellowish-brown clay; 14. plant; 15. yellow and brown clay; 16. piled gravel sand; 17. crystal; 18. iron and manganese stratum.

Among ten rock samples in Kaiyang County, except an abnormal sample (with oddly high selenium content of 191 mg·kg^{-1}), the selenium contents in the rest 9 bedrock samples are 1–4 mg·kg^{-1}, with the average content of 1.89 mg·kg^{-1}, 23.63 times more than the content of crustal abundance. On strata, the average content of selenium in dolomite in Dengying Formation of Sinian is 2.0 mg·kg^{-1}, 25 times more than the content of crustal abundance. The average content in dolomite in Middle-Upper Loushanguan Group of Cambrian is 1.5 mg·kg^{-1}, 18.75 times more than the content of crustal abundance; Lower Qingxudong Formation of Cambrian 2 mg·kg^{-1}, 25 times more than the content of crustal abundance. The average in siliceous dolomite in Maokou Formation of Permian is 2 mg·kg^{-1}, 25 times more than the content of crustal abundance. And the average content in limestone in Maokou Formation of Permian is 191 mg·kg^{-1}, 2388 times more than the content of crustal abundance. In addition, the black shale in Early Cambrian in Kaiyang County is rich in selenium, with the average content of 5.2 mg·kg^{-1}, 65 times more than the content crustal abundance (Ren et al., 2012a).

The average content of selenium in five rape samples in Kaiyang County is 2 mg·kg^{-1}.

The average content of selenium in 45 soil samples in Kaiyang County is 2.22 mg·kg^{-1}, 9.66 times more than the average selenium content in China's soil. Seen from Fig. 3, the selenium distribution includes in the following enrichment and distribution forms: bottom-enriched, top-enriched, and a little differentiated types. Profiles in a top-enriched type include the profile in Linjiazha Village, Huangmu Village, Hefeng Town, Gaoyun Village, and Bamadong Village; profiles in a bottom-enriched type include the profile in Shaoshang Town and Yakou Village; profiles in a little differentiated type include the profile in Yanjiao Village, Dingfang Village, and Jinzhong Town.

From the profile A in Linjiazhai Village to The profile D in Yanjiao Coal Mine, selenium features bedrock inheriting enrichment and weathering enrichment as well as distinct top enrichment.

In Profile E in Dingfang Village and Profile J in Jinzhong Town, selenium concentrations in all strata of the profile are 2.0 and 1.0 mg·kg^{-1}, respectively without difference in the various parts of the profile.

According to researches, the coal measure strata in Permian and black shale strata in Lower Cambrian in Kaiyang County have the two highest selenium content (Wang and Li, 2001; Ren et al., 2012a), and in Dengying Formation of Sinian and Qingxudong Formation of Cambrian, its value are higher than average, but in Loushanguan Group of Cambrian, it is a little lower than the average value. Accordingly, we may deduce the limestone in Maokou Formation of Permian and black shale strata in Lower Cambrian have the two highest selenium contents, followed by the weathered soil profiles of Dengying and Qingxudong formations, and Loushanguan Group.

From the investigation result of geochemistry in several target regions of Guiyang City, we found the selenium in the surface soil in emerged areas of black shale strata and coal measure strata of Permian features distinct enrichment in the surface soil, which also occurs in the surface soil near the deep fracture of Bamadong Village, but the selenium content in surface soil of the emerged stratum in Banxi Group and Qingshuijiang Formation in the Cretaceous is low (Fig. 4).

Meanwhile, the distribution of selenium is closely related to the distribution of organic carbon in the surface and deep soil. Regions with high organic carbon contents such as Yongwen-Fengsan-Zhaiji region, Longgang-Gaozhai region, are rich in selenium in the surface soil. In Hualin with low organic carbon content, the selenium content in the surface soil is low (Fig. 4).

4 Controlling factors of selenium enrichment in weathered soil profiles

In the research area, the distribution of selenium in soil is apparently spatially different between (on region) and within the same profiles (in points). In different weathered soil profiles, selenium is differently distributed because of soil parents. Between different strata of the same profile, during soil formation, selenium in the weathered soil profile is continually migrated and lost because of leaching, and enriched under the influence of surface geological activities and human activities, which leads to different distribution forms of element in soil profiles.

4.1 Evidence on selenium from bedrock in the red clay profile

Bedrock is the material source of weathered soil profile and the main controlling factors of element content in soil (Wang et al., 1999). It is proved by a research on the inheritance between the selenium content and the bedrock in soil of Kaiyang County, which indicates that they are in significant positive correlation (Li et al., 2004). The similar REE distribution curves in bedrock and soil illustrates selenium in soil comes from bedrock, and thus the selenium content in bedrock is the key control factor of the selenium enrichment degree in soil (Ren et al., 2012b). In addition, the selenium enrichment in bedrock is closely related to the participation of black shale and magmatic hydrothermal (Chen, 1990; Chen and Zhang, 1993).

4.1.1 Influence of black shale in the region

Kaiyang in Lower Cambrian is located in the Yangtze Shelf, Pangaea Break-up. Because Yangtze and Cathaysia Landmass subside in acceleration under the strong tension, in addition to sea level rise caused by transgression and tectonic subsidence, another significant anoxic event occurred in South China in Early Cambrian, causing massive sedimentary formation and leading to that the set of black shale is rich in Mo, As, Se, Cd, Sb, U, Ba, Co, Li, Ni, Pb, Re, Th, Tl, V, W, Zn, platinum group element (PGE), and REE, etc. (Li and Gao, 1995; Chen et al., 2006; Yang et al., 2005, 2006; Feng et al., 2010).

In the research area, black shale strata in the Early Cambrian mainly presents hypothermal deposit under a low temperature and hypoxia reducing conditions, and rich in Ni, Mo, Se, V, PEG, and REE etc. Therefore, black shale in the area forms a selenium enriched stratum under hydrothermal process. The selenium enrichment area is controlled by the black shale distribution enriched with multiple metals.

After the comparison and analysis of microelement data, Mo, As, U, Ni, and V etc were found. The black shale strata in research area is very high in the content of Mo: 5.18–1550, As: 16–4490; U: 3.49–419; Ni: 11.8–1505; V: 16–2370; and Se 2–76 mg·kg^{-1} (Ren et al., 2012a), indicating it is closely related to Se enrichment and could be the source bed of selenium enrichment in the area.

4.1.2 Participation of magmatic hydrothermal

The analyzed cause of formation of uranium ore in Bamadong Village indicates that selenium is rich in not only the overlying strata of black shale strata in Niutitang Formation, but also its underlying strata, suggesting that the strata is not the only source bed of selenium enrichment in the area. The uranium mineralization horizon (rocks) in Dengying Formation, Baimadong Village are rich in U, As, Se, PGE, V, Mo, Ni, and other ore-forming elements, of which the enrichment is related to participation of the migration of magmatic hydrothermal along the regional big fracture (Chen, 1990; Li et al., 2003). In combination with the research on the geological map and the selenium distribution diagram in the surface soil, the big fracture in Bamadong Village is surrounded with rich selenium.

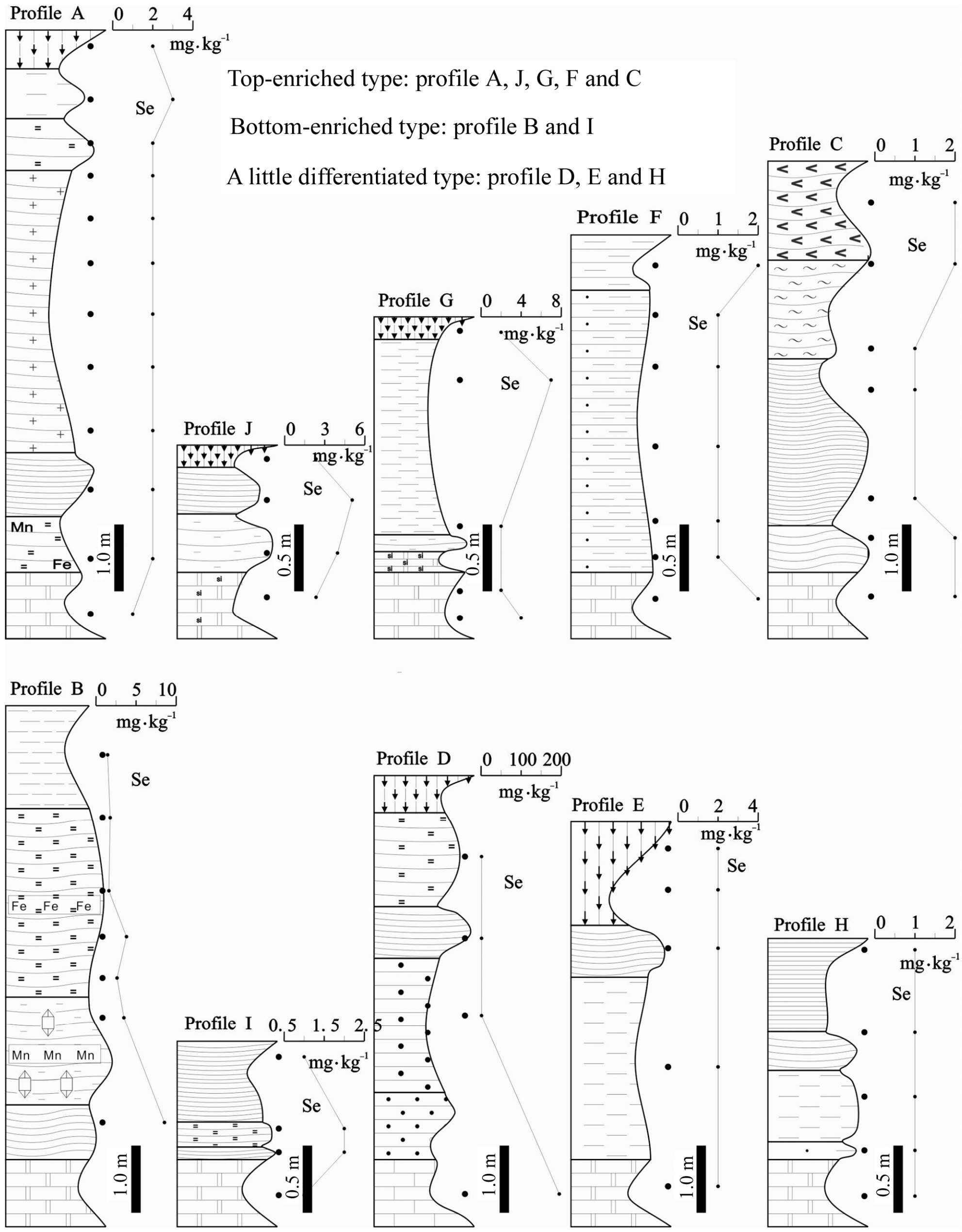
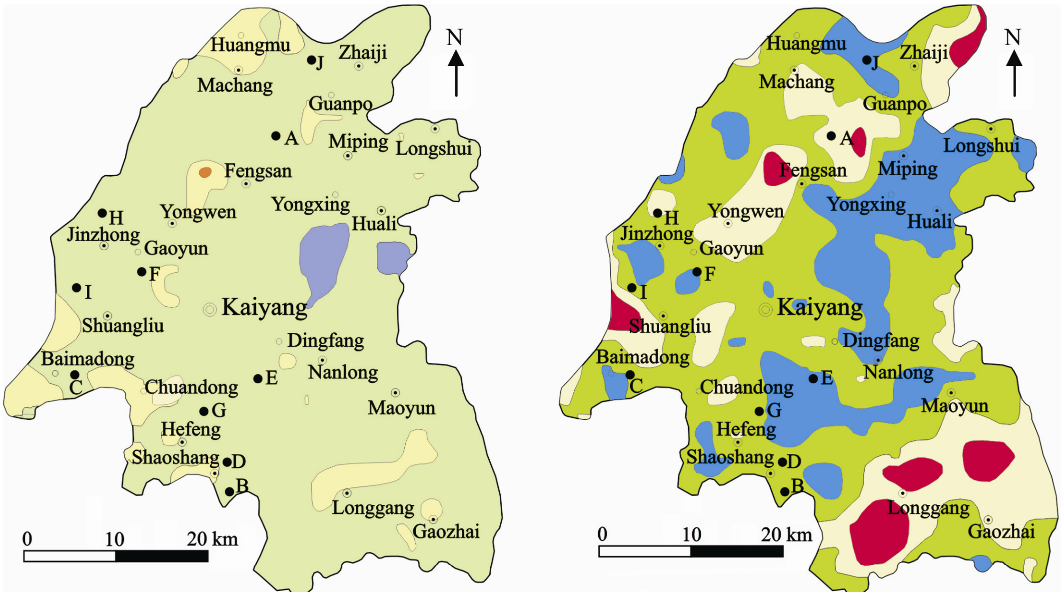


Fig. 3. Distribution types of selenium in the weathered soil profile. A. Linjiazhai profile; B. Shaoshang profile; C. Baimadong profile; D. Yanjia Coal Mine profile; E. Dingfang profile; F. Gaoyun profile; G. Hefeng profile; H. Jinzhong profile; I. Yakou profile; J. Huangmu village profile.



A. Contents of selenium in the surface soil

Color				
Content (mg·kg⁻¹)	>1. 6	0. 8–1. 6	0. 4–0. 8	<0. 4
Percentage (%)	0. 37	26. 07	69 73	3. 83

B. Distribution of organic carbon in the soil

Color				
Content (10 kt)	>12. 61	10. 48–12. 61	8. 78–10. 48	<8. 78
Percentage (%)	0. 37	26. 07	69. 73	3. 83

Fig. 4. Map of surface selenium content and organic carbon distribution in Kaiyang.

In addition, Se, Mo, and V are bioactive elements. Their enrichment indicates the formation of rock in research area is related to biological activities (Tu et al., 2004). Wang et al. (2004) deemed that during the acceleration of sedimentation effect in the Early Cambrian and bedding lateral migration of hydrothermal brine under extrusion in the basin of Caledon miogeosyncline in South Rim of Yangtze Craton, rich Ni, Mo, V, PEG, and other ore-forming elements are drawn from surrounding environment, and formed hydrothermal solution for mineralization that features very high salinity and migrates upward along the deep fracture and mixes with sea water, leading to great enrichment of U, Ba, Ni, Mo, V, and Se, etc. Therefore, the hydrothermal deposit is an important factor causing supernormal enrichment of U, Ba, Ni, Mo, V, and Se.

4.2 Influence of leaching migration and alkaline barrier

In the weathered profiles, element contents and distributions differ greatly, which is comprehensively caused by the supergene geochemical action and human activities. Kaiyang County belongs to the subtropical humid climate with plentiful rainfall. Se migrates downwards through leaching. Therefore, Se is lost and enriched in different parts of the red clay profiles.

The enrichment in the iron layer and manganese layer is usually a character of soil under a humid environment, which usually occurs in South China and is a product of strong leaching illuviation. In the purplish-brown clay layer of Linzhong profile in Shaoshang Town, distinct iron layer enrichment appears, and in the bottom dark purplish-brown clay layer, manganese layer enrichment appears. It is widely believed that change of pH value is the main reason of iron and manganese enrichment. The red clay profile shows pH value increases with increasing depth. This is because that soil is cultivated for the humus in surface layer, and become faintly acid for the large amount of CO_2 plant root systems absorbed from the air. After intensive leaching, fluid in the surface soil permeates downwards and combines with basic cations in the lower stratum. Therefore, the acidity is gradually neutralized and pH is gradually increased. In addition, since the hydrolyzation of feldspar minerals which are not totally weathered surrounding the siltstone stratum consumes a lot of H^+, pH value is high in the entire bottom of red clay weathered profile.

Iron and manganese are very active under the acid reduction condition but, under the basic oxidation environment, they are oxidized to be highly-charged ions which easily react with hydroxyl ion in the soil solution to form ferric hydroxide and manganese hydroxide colloids. Such compounds are sedimentated and, during infiltration process, absorb massive microelements, rare-earth elements, and metal cations in the surface soil, which is also one reason of bottom enrichment of TE and REE.

The ferric hydroxide and manganese hydroxide colloids have different sensitiveness on pH. During the sedimentation and enrichment in different strata, generally the ferric hydroxide colloid may firstly and then manganese hydroxide colloid deposits to a deeper position that ferric hydroxide colloid. Accordingly, it is known that ferric hydroxide and manganese hydroxide colloids have different absorption capacities on elements. The iron layer has strong absorption capacity on Li, Se, Cd, and REE but presents loss on other elements, especially U, As, Ni, and Pb, with low contents. In the manganese layer, Se, Pb, Te, Zn, V, Hg, Cu, Cr, As, and REE are greatly enriched but with very low U and Co contents. The manganese layer has a strong capacity to absorb TE and REE, which is also a reason that elements are enriched in its bottom.

4.3 Influence of organic matters

The bottom of red clay profile contains a lot of organic matters (OM) (Yang, 2008). In addition to the slow decomposition, OM are distinctly accumulated. The main compositions of organic matters are colloidal particles with negative charges. Fe, Mn, and other cations react with these OM to form insoluble complexes to be tied to clay particles. Main selenium in the soil is absorbed to these colloids. On the hydrated ferric oxide and manganese oxide surfaces with rich humus, they combine with selenium to form insoluble ferrum selenite. Other organic compounds may also form insoluble organic selenides with selenium and they go through slow decomposition at the bottom of the red clay. Therefore, the supernormal enrichment of selenium is formed over a long time.

According to the geochemical investigation result in several target regions of Guiyang City (He, 2011), the surface soil in Guiyang contains high contents of Se, S, N, F, Mo, B, Cu, Mn, Zn, Fe_2O_3, and also a high content of OC, which coincides with the selenium enrichment, indicating OC has a strong absorption capacity on selenium. Therefore, the absorption of OM is an important control factor of regional selenium enrichment and later selenium migration and enrichment.

5 Conclusions

This paper takes strata and weathered soil of Kaiyang County, Guizhou Province as the research object to systematically analyze many classic weathered soil profiles and obtain the distribution of selenium in profiles. In combination with the geochemical investigation on multiple target regions in Guiyang City, this paper discusses the distribution law and control factor of selenium in the weathered soil profiles in Kaiyang County. After the analysis and summary on data, we get the following results:

The bedrock in the research area is generally enriched with selenium, therefore, it is a material source of the weathered soil profiles and a key control factor of element contents in them. The selenium enrichment in the bedrock is closely related to wide distribution of the black shale strata in Early Cambrian and coal measure strata in Permian, and the upward migration of magmatic hydrothermal and hydrothermal brine along the deep fracture, and they are deemed as the source beds of regional selenium enrichment.

The weathered soil profiles in the research area is distinctly enriched with selenium, with the average content of 2.22 $mg{\cdot}kg^{-1}$, far higher than average selenium content in China's soil of 0.23 $mg{\cdot}kg^{-1}$ (Xing and Zhu, 2003). The weathered soil profiles feature bedrock inheriting enrichment and later weathering enrichment, etc. Selenium enrichment is divided into bottom enrichment, top enrichment, and a little differentiated enrichment. In the entire county, the selenium enrichment regions coincide with the distribution scopes of black shale strata, coal-bearing strata, and the organic matters in surface soil. The selenium enrichment regions include Machang-Gaoyun-Fengsan-Guanpo, Baimadong region, Chuandong-Hefeng-Shaoshang region and Longgang-Gaozhai region, etc. Besides, around the east part of the county, in Huali and Yongxing selenium are relatively low.

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References

Chen Lan, Zhong Hong, Hu Ruizhong, Xiao Jiafei, and Zou Yanrong (2006) Early Cambrian oceanic anoxic event in northern Guizhou: Biomarkers and organic carbon isotope [J]. *Acta Petrologica Sinica*. **9**, 2413–2423 (in Chinese with English abstract).

Chen Luming (1990) Discussion on the origin of uranium deposit No. 504 [J]. *Uranium Geology*. **3**, 135–145 (in Chinese with English abstract).

Chen Luming and Zhang Qifa (1993) The distribution features of Ni-Se-Re-Tl in Uranium-Mercury-Molybdenum deposit No. 504 [J]. *Guizhou Science*. **4**, 57–62 (in Chinese with English abstract).

Feng Caixia, Liu Shen, Hu Ruizhong, Liu Jiajun, Luo Taiyi, Chi Guoxiang, and Qi Youqiang (2010) Geochemistry of Lower Cambrian Se-Rich black rock series in Zunyi, Guizhou Province, Southwest China: The petrogenesis and enrichment mechanism of selenium [J]. *Earth Science—Journal China University of Geosciences*. **6**, 947–958 (in Chinese with English abstract).

He Shaolin (2011) Committed livelihood projects—Guiyang multi-target regional geochemical survey results Introduction [J]. *Guizhou Geology*. **4**, 318–314 (in Chinese)..

Li Chaoyang, Liu Yuping, Ye Lin, and Pi Daohui (2003) Discussion on

Some Problems in the Study of Mineralization in Guizhou [J]. *Bulletin of Mineralogy, Petrology and Geochemistry*. **4**, 350–355 (in Chinese with English abstract).

Li Juan, Long Jian, and Wang Jingren (2004) Geochemical characteristics of selenium in soils of Kaiyang region, Guizhou Province [J]. *Chinese Journal of Soil Science*. **5**, 579–582 (in Chinese with English abstract).

Li Juan, Long Jian, and Wang Jingren (2005) Se content of paddy soil in the middle region of Guizhou Province and its effect on Se content of rice [J]. *Chinese Journal of Soil Science*. **4**, 571–574 (in Chinese with English abstract).

Li Shengrong and Gao Zhenmin (1995) REE characteristics of black rock series of the lower Cambrian Niutitang Formation in Hunan-Guizhou provinces, China, with a discussion on the REE patterns in marine hydrothermal sediments [J]. *Acta Mineralogica Sinica*. **2**, 221–229 (in Chinese with English abstract).

Li Tung (1976) Chemical element abundances in the earth and it's major shells [J]. *Geochimica*. **3**, 167–174 (in Chinese with English abstract).

Ren Haili, Gao Junbo, Long Jie, Yang Ruidong, and Bi Kun (2012a) Geochemical characteristics of selenium-rich strata and weathered soil from Kaiyang County, Guizhou Province [J]. *Earth and Environment*. **2**, 161–170 (in Chinese with English abstract).

Ren Haili, Long Jie, Han Xiaotong, Kong Fancui, and Yang Ruidong (2012b) The geochemical characteristics of trace element of the red clay profiles weathered from Neoproterozoic Dengying Fm. Dolomite in Kaiyang County, Guizhou Province [J]. *Chinese Journal of Soil Science*. **5**, 1086–1093 (in Chinese with English abstract).

Tu Guangchi, Gao Zhenmin, Hu Ruizhong, Zhang Qiang, Li Chaoyang, Zhao Zhenhua, and Zhang Baogui (2004) *Dispersing Element Geochemistry and Metallogenic Mechanism* [M]. China Geological Publishing House, Beijing (in Chinese).

Wang Ganlu and Zhu Xiaoqing (2003) A study on the selenium background level in the soils in Guizhou [J]. *Research of Environmental Science*. **1**, 23–26 (in Chinese with English abstract).

Wang Shijie, Ji Hongbing, Ouyang Ziyuan, Zhou Dequan, Zheng Leping, and Li Tingyu (1999) Preliminary studies on weathered soil from carbonate [J]. *Science in China* (Series D). **5**, 441–449 (in Chinese).

Wang Min, Sun Xiaoming, and Ma Mingyang (2004) Rare-earth elements geochemistry and genesis of Xinhua large-size phosphorite deposit in western Guizhou [J]. *Mineral Deposits*. **4**, 484–493 (in Chinese with English abstract).

Wang Jingren and Li Tinghui (2001) *Development and Utilization of Selenium Resources in Kaiyang County* [M]. Guizhou Science and Technology Press, Guiyang (in Chinses).

Xing Guangxi and Zhu Jianguo (2003) *Chemistry of Trace Element and Rare-Earth Element in Soil* [M]. Science Press, Beijing (in Chinese).

Yang Ruidong (2008) The distribution of rare-earth elements and trace elements in latecritic profile: Implication for karst environment [J]. *Geological Review*. **3**, 409–418 (in Chinese with English abstract).

Yang Ruidong, Zhang Chuanlin, Luo Xingrong, Tian Jingquan, Bao Yafan, and Song Guoqi (2006) Geochemical characteristics of Early Cambrian cherts in Quruqtagh, Xinjiang, West China [J]. *Acta Geologica Sinica*. **4**, 598–605 (in Chinese with English abstract).

Yang Ruidong, Zhu Lijun, Gao Hui, Zhang Weihua, Jiang Lijun, Wang Qiang, and Bao Miao (2005) A study on characteristics of the hydrothermal vent and relating biota at the cambrian bottom in Songlin, Zunyi County, Guizhou Province [J]. *Geological Review*. **5**, 481–492 (in Chinese with English abstract).