Eco-Environmental Geochemistry of Heavy Metal Pollution in Dexing Mining Area *

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Abstract: An eco-environmental geochemical investigation was carried out in and around the Dexing mining area to determine the concentrations of heavy metals in the surface water, sediments, soils and plants. The main objective of this study is to assess the environmental situation and evaluate the transferring of heavy metals from mining activities into the food chain. Some samples of water, sediment, topsoil and plant were collected along the Lean River in the Dexing mining area. The total concentrations of Cu, Pb, Zn, Cd, and As were determined by AAS, and Hg was analyzed by cold-vapor AAS. Some indices such as 'contamination degree', 'geo-accumulation index', and 'biological absorption coefficient' were used to assess eco-environmental quality. The investigation indicated a highly localized distribution pattern closely associated with the two pollution sources along the Le'an River bank: one is strong acidity and a large amount of Cu in the drainage from the Dexing Cu mining area; and the other is the high concentrations of Pb and Zn in the effluents released from many smelters and mining, processing and extracting activities in the riparian zone. Results from the investigated localities indicated, at least in part, that some problems associated with environmental quality deterioration should be solved in the future.

Key words: eco-environmental geochemistry; contamination degree; I_{geo}; BAC; Dexing mining area

1 Introduction

In the planet Earth, metals are ubiquitously exist from the core to the upper atmosphere (Allan, 1997). Metals are a fundamental component of life on the Earth and part of food chain (Allan, 1997). Mining activities and metals in the environment are a sub-area of the broader field of studying metals in the environment (Allan, 1997). Mining activities can have significant environmental impacts including visual intrusions, dust, noise, blasting, traffic and hydrology (Horvath and Gruiz, 1996; Thornton, 1996; Ripley et al., 1996; Kwolek, 1999). The processes of mineral extraction, processing, smelting and refining can never approximate to becoming environmentally neutral, but the areas of impact can be ameliorated (Kwolek, 1999; Klukanova and Rapant, 1999). The regions where mining activity is present for long are the potential candidates for a wide diffusion of pollutant elements in the environment (Allan, 1995, 1997). Hence, these areas are the targets for de-

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tailed environmental geochemical investigations. The distribution of these elements in relation to the exploration and treatment centers, and the designation of the different areas for land use should be both taken into account (Boni et al., 1999).

Environmental geochemistry involves many factors affecting the sources, dispersion and distribution of elements in the environment, their pathways into soils, foodstuffs and water supplies and their influence on plant, animal and human health (Thornton, 1993, 1996). Metals in the contaminated soils and water enter agricultural products and cause various physiological changes in them, thus lowering their biomass (Rulkens et al., 1998; Sponza and Karaoglu, 2002). As humans consume such agricultural products, the metals will enter human bodies, causing various chronic diseases. Environmental geochemists working with environmental assessment teams have diverse missions (Siegel, 1995, 2002; Selinus, 1996; Plant et al., 2001): 1) to predict potential pollution problems that could occur; 2) to solve newly identified or suddenly high profile short- or long-term contamination problems to minimize the impact on the living ecosystem; and 3) to evaluate the remediation that might be proposed in the light of practical and future impacts on the environment. Monitoring of the industrial and mining areas has become an essential facet in the assessment and control of anthropogenic impacts on the ecosystem (Teng Yangguo et al., 2002).

In the past few years, studies of environmental geochemistry in mining areas have been carried out in China. Some examples of China's mining areas are those V-Ti magnetite mining areas (Teng Yanguo et al., 2001, 2002; Ni Shijun et al., 2001), thallium mining areas (Zhang Zhong et al., 2002), coal mining areas (Dang et al., 1997), gold mining areas (Zeng Yongnian et al., 1999), copper mining areas (Ma Zhendong et al., 2002), REE mining areas (Gao Xiaojiang et al., 1999), zinc mining and smelting areas (Wu Pan et al., 2002), and so on.

Jiangxi Province is a famous base of nonferrous mineral resources in China, and the Dexing copper mine is the largest copper mine in China. In and around the Dexing area, there are some large-sized deposits such as the Tongkuangshan copper deposit, the Jinshan gold deposit, the Yinshan silver deposit, and so on. The Lean River is located in Jiangxi Province, China. It receives a large amount of acidic mine drainage (pH 2-3) and waste effluents containing Cu, Pb and Zn discharged from the neighboring Dexing copper mine (ore production of $\times 10^5$ tons per day) and from many smelters and mining/panning activities along the banks of trunk stream and tributaries (Liu Wenxin et al., 2003). Great input of heavy metals and distribution in different bound phases have led to a severe deterioration in the surrounding environments. Some preliminary studies have focused on individual aspects (He Mengchang et al., 1997, 1998; Liu Wenxin et al., 1999a, b, 2003). In the past few years, studies of ecological risk and environmental pollution have been carried out in this area; the CERP (Collaboration Ecological Research Program) project sponsored by UNESCO is the most important one of these studies. The CERP project mainly discussed: 1) aquatic ecological risk of the Lean River and Boyang Lake; 2) effects of heavy metal pollution on aquatic fauna and planktons; and 3) problems of AMD (Acid Mine Drainage). In addition, research on land remediation and ecological reconstruction has been carried out under the program sponsored by the Ministry of Science and Technology of China.

Supported by the Ministry of Land and Mineral Resources, an eco-environmental geochemical investigation was carried out in and around the Dexing mining area to determine the concentrations of heavy metals in the surface water, sediments, soils and plants. The main objective of this study is to assess environmental situation and evaluate the transferring of heavy metals from the mining environment into the food-chain.

2 Methodology

The samples of water, stream sediments, topsoils (0 – 20 cm) and plants were collected along the Le'an River (the waste water from the mine flows into the Le'an River) in October, 2002 (Fig. 1).

Soil and stream sediment samples were dried at 35℃ and sieved to obtain the <0.063 mm fractions. The plant seeds were collected in 2002 and the samples were kept at 110℃ in a hot air oven for 8 h to eliminate moisture (Nagaraju and Karimulla, 2002). The total contents of Cu, Pb, Zn, Cd, and As were measured by Atomic Absorption Spectrometry, and the total contents of Hg by Cold Vapor-Atomic Absorption Spectrometry. The measurement was accomplished at the Center of Analysis and Determination, Jiangxi Bureau of Geology and Mineral Resources. The results are presented in Table 1.

Table 1. Analytical results of the samples

Sample No.	pH	Cu	Pb	Zn	Cd	As	Hg
Surface water, heavy metal concentration unit: μg/L							
1	7.06	3.19	0.78	4.35	0.08	1.15	0.074
2	8.72	2.65	0.56	3.60	0.04	1.24	0.021
3	2.43	1923.00	4.73	498.00	2.02	0.58	0.022
4	6.10	112.00	0.37	25.15	0.34	0.48	0.067
5	6.57	156.00	0.70	11.95	0.57	0.41	0.056
6	7.15	83.00	0.45	6.40	0.26	1.32	0.049
7	7.42	118.00	1.42	362.00	0.86	1.58	0.047
8	7.70	33.27	3.77	199.00	0.60	0.88	0.043
Stream sediment, heavy metal concentration unit: mg/kg							
1		17.6	27.9	155	0.23	7.9	0.033
2		136	30.9	198	0.35	10.1	0.04
3		2126	32.4	125	0.21	37.4	0.094
4		751	24.9	106	0.13	40.2	0.18
6		229	24.9	84.9	0.14	9.77	0.015
7		1708	55.1	337	0.29	156	0.12
8		1603	110	626	1.41	79.4	0.092
Topsoil, heavy metal concentration unit: mg/kg							
1		84.9	29.4	131	0.25	12.1	0.042
2		55.7	43	119	0.21	14.9	0.036
3		249	43	126	0.13	17.6	0.055
4		41.4	30.9	94	0.12	10.7	0.032
5		64.4	46	152	0.15	11.5	0.061
6		57	41.5	113	0.28	8.51	0.043
7		27.1	33.9	90.5	0.26	9.68	0.026
Plant, heavy metal concentration unit: mg/kg							
1	Corn	0.28	0.16	8.3	0.008	0.004	0.001
2	Rice	1.52	0.35	23.6	0.021	0.001	0.002
3	Rice	1.52	0.19	3.9	0.004	0.004	0.002
4	Corn	10.30	0.16	78.6	0.100	0.002	0.001
5	Rice	4.87	0.88	19.6	0.280	0.001	0.002
6	Rice	8.22	0.88	23.1	0.210	0.008	0.003
7	Rice	1.34	0.17	3.5	0.006	0.003	0.001

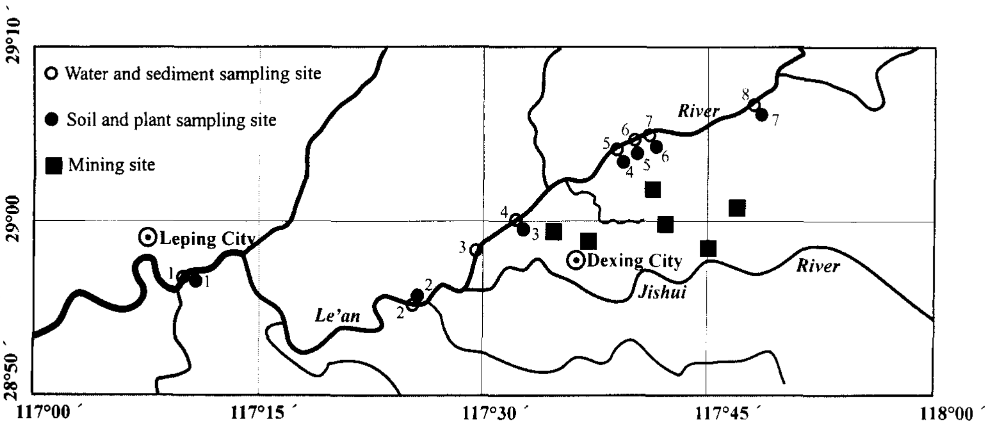

Fig. 1. Location of the sampling sites.

3 Results and discussion

We selected the contamination degree (C_d) to assess heavy metal pollution in the surface water, soils and plants, applied the geoaccumulation index (I_{geo}) to assess heavy metal pollution in the stream sediments, and used the biological absorption coefficient (BAC) to study bioaccumulation effects of heavy metals.

3.1 Heavy metals in the water

The contamination degree (C_d) (Rapant et al. , 1997) is used to determine the excessive values of monitored elements, and the expression is presented as follows (Rapant et al. , 1999) :

$$C_d = \sum_{i=1}^{n} C_{f,i}$$

where $C_{f,i} = \frac{C_{a,i}}{C_{n,i}} - 1$ = contamination factor for the i-th component, $C_{A,i}$ = analytical value of the i-th element (component) , and $C_{N,i}$ = upper permissible limits (normative values). The norm for the upper permissible limits of surface water in China is based on GBZB 1-1999. Here, we selected grade III (pH = 6.5 – 8.5) of GBZB 1-1999 as the normative value, and the calculated results are presented in Table 2. The pH and Cd of heavy metals in the water varying along the Lean River are shown in Fig. 2 and Fig. 3 , respectively.

Table 2. C_d of heavy metals in the surface water

Sample No.	$C_{f,Cu}$	$C_{f,Pb}$	$C_{f,Zn}$	$C_{f,Cd}$	$C_{f,As}$	$C_{f,Hg}$	C_d
1	2.19	14.60	3.35	15.00	22.00	739.00	796.14
2	1.65	10.20	2.60	7.00	23.80	209.00	254.25
3	1922.00	93.60	497.00	403.00	10.60	219.00	3145.20
4	111.00	6.40	24.15	67.00	8.60	669.00	886.15
5	155.00	13.00	10.95	113.00	7.20	559.00	858.15
6	82.00	8.00	5.40	51.00	25.40	489.00	660.80
7	117.00	27.40	361.00	171.00	30.60	469.00	1176.00
8	32.27	74.40	198.00	119.00	16.60	429.00	869.27

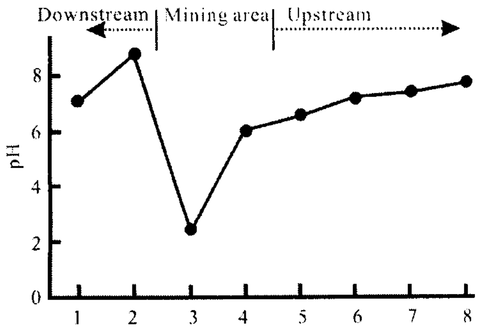

Fig. 2. pH varies along the Le' an River.

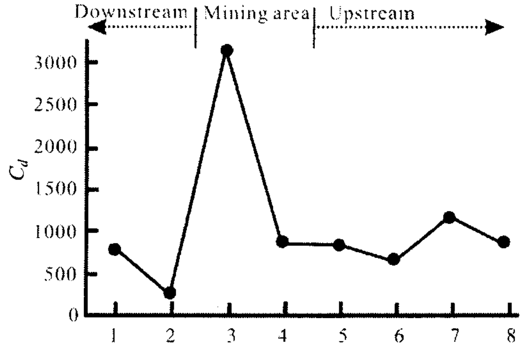

Fig. 3. C_d of water varies along the Le' an River.

The pH is very low in the mining area, which resulted from acid mine drainage which pored into the Dawu River. But after the Jishui River flows into the Le' an River, the pH of water is enhanced, which resulted from alkaline water that was discharged during ore processing and extracting of the Yinshan Ag-Pb-Zn mine.

In the water, all the six elements Cu, Pb, Zn, Cd, As and Hg exceed grade III of the national standards. Variations of C_d showed that the most serious pollution of heavy metals in the Le' an River is seen in the mining area, which resulted from tailings and other solid wastes left behind mining activities.

3.2 Heavy metals in the sediments

Müller (1979) assessed the degree of metal pollution by means of seven different classes based on the numerical values of the index of geoaccumulation (I_{geo}):

$$I_{geo} = \lg_2 C_n / 1.5 B_n$$

where C_n is the measured concentration of element n in the sediment or size fraction, and B_n is the element's content in 'average shale' (Turekian and Wedepohl, 1961), either directly measured in texturally equivalent uncontaminated sediments or size fractions or taken from the literature. The factor 1.5 is introduced to include possible differences in the background values due to lithological variations.

The following descriptive classification is given to the indices of geoaccumulation by Förstner et al. (1990): <0: practically unpolluted; 0 – 1: unpolluted to moderately polluted; 1 – 2: moderately polluted; 2 – 3: moderately to strongly polluted; 3 – 4: strongly polluted; 4 – 5: strongly to very strongly polluted; and >5: very strongly polluted.

The calculated results of I_{geo} are given in Table 3. In the stream sediments, Cu pollution is very serious, especially in the mining area, the contamination level reached grade V (very strongly polluted). In the sediments no Hg pollution is recognized, pollution caused by Pb, Zn and Cd is moderate. In the mining area, the pollution caused by As is moderate to strong.

The regionally environmental geochemical map of copper pollution is shown in Fig. 4.

The distribution of I_{geo}-copper showed that the pollution level is 0 – 4 and the seriously polluted area is located in the Dexing copper mining area and Yinshan silver-lead-zinc mining area.

Table 3. I_{geo} of Le' an River sediments

Samples No.	Cu	Pb	Zn	Cd	As	Hg
1	0	0	1	0	0	0
2	1	1	1	0	0	0
3	5	1	0	0	1	0
4	4	0	0	0	2	0
6	2	0	0	0	0	0
7	5	1	2	0	4	0
8	5	2	3	2	3	0

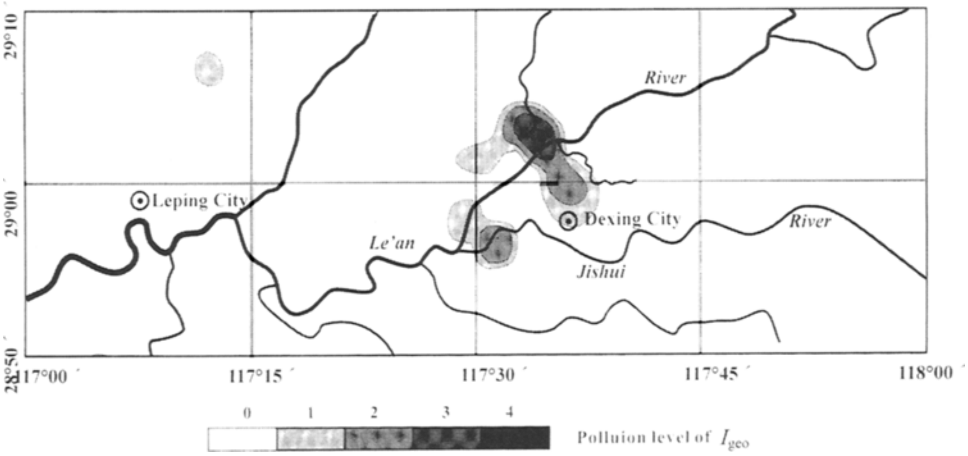

Fig. 4. I_{geo} of Cu distribution in the Dexing area (data from Jiangxi Bureau of Geology and Mineral Resources).

3.3 Heavy metals in the soils

Here, we selected grade I (natural background) of GB 15618 - 1995 as the normative value, and the results of contamination degree are given in Table 4.

The concentrations of heavy metals in the topsoil are far higher than those in the natural background. Cu is a polluting element in the study area and the polluted region is located in the mining area (Fig. 5). In the downstream and upstream of the mining area, the contamination degree is very low, approaching the natural background.

Table 4. C_d of heavy metals in the soils

Sample No.	$C_{f,Cu}$	$C_{f,Pb}$	$C_{f,Zn}$	$C_{f,Cd}$	$C_{f,As}$	$C_{f,Hg}$	C_d
1	1.43	-0.16	0.31	.25	-0.19	-0.72]0.91	
2	0.59	0.23	0.19	0.05	-0.01	-0.76	0.29
3	6.11	0.23	0.26	-0.35	0.17	-0.63	5.79
4	0.18	-0.12	-0.06	-0.40	-0.29	-0.79	-1.47
5	0.84	0.31	0.52	-0.25	-0.23	-0.59	0.60
6	0.63	0.19	0.13	0.40	-0.43	-0.71	0.20
7	-0.23	-0.03	-0.10	0.30	-0.35	-0.83	-1.23

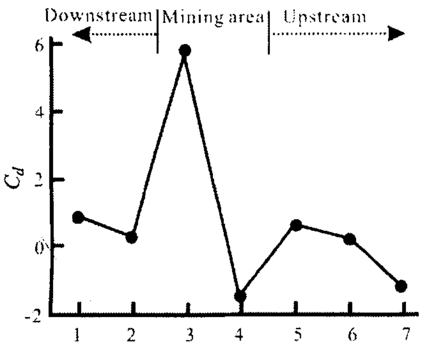

Fig. 5. C_d of soils varying along the Le'an River.

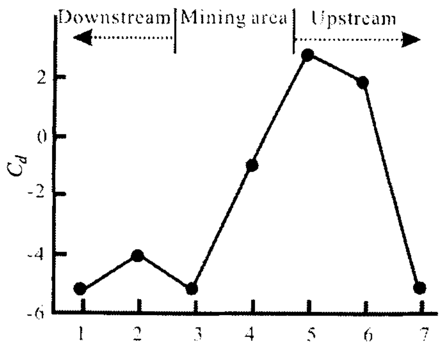

Fig. 6. C_d of plants varying along the Le'an River.

3.4 Heavy metals in the plant seeds

The contamination degree of heavy metals in the plant seeds is based on: the tolerance limit of mercury in food GB2762 - 1994; tolerance limit of arsenic in food GB 4810 - 1994; tolerance limit of copper in food GB 15199 - 1994; tolerance limit of lead in food GB 14935 - 1994; tolerance limit of zinc in food GB 13106 - 1991; and tolerance limit of cadmium in food GB 15201 - 1994. The calculated results are given in Table 5 and shown in Fig. 6.

Table 5. C_d of heavy metals in the plants

Sample No.	$C_{f,Cu}$	$C_{f,Pb}$	$C_{f,Zn}$	$C_{f,Cd}$	$C_{f,As}$	$C_{f,Hg}$	C_d
1	-0.97	-0.60	-0.83	-0.84	-0.99	-0.95	-5.19
2	-0.85	-0.13	-0.53	-0.58	-1.00	-0.90	-3.98
3	-0.85	-0.53	-0.92	-0.92	-0.99	-0.90	-5.11
4	0.03	-0.60	0.57	1.00	-1.00	-0.95	-0.95
5	-0.51	1.20	-0.61	4.60	-1.00	-0.90	2.78
6	-0.18	1.20	-0.54	3.20	-0.99	-0.85	1.85
7	-0.87	-0.58	-0.93	-0.88	-1.00	-0.95	-5.20

In the seeds of corn and rice, the concentrations of Pb exceed the tolerance limit in site Nos. 5 and 6; the concentrations of Cd exceed the tolerance limit in site Nos. 4, 5 and 6; the concentrations of Zn and Cu exceed the tolerance limit in site No. 4; the concentrations of As and Hg do not exceed tolerance limit. The total contamination degree in the plant seeds is high in site Nos. 5 and 6, which resulted from cadmium pollution (Fig. 6).

3.5 Bioaccumulation of heavy metals

The biological absorption coefficient (BAC) is used to characterize the intensity of absorption of chemical elements by plants from their substrate (Nagaraju and Karimulla, 2002). Kovalevskii (1969) has defined the biological absorption coefficient as follows:

$$\mathrm{BAC} = C_p/C_s$$

Where C_p is the concentration of an element in plant ash and C_s is the concentration of the same element in the substrate. The BAC values varies widely from 0.001 to 100 (Nagaraju and Karimulla, 2002). The BAC is also named the vegetable/soil concentration factor (CF) (Panagiotopoulos et al., 1976; Fytianos et al., 2001). Sabinin (1955) was one of the earlier workers to discuss these parameters and to investigate their significance. Alloway et al. (1988) defined it as biological accumulation coefficient and focused their attention on the fact that the plant uptake can be evaluated by using this simple index. The BAC can be classified into five groups (Perelman, 1966): "intensive absorption" (BAC 10 - 100); "strong absorption" (BAC 1 - 10); "intermediate absorption" (BAC 0.1 - 1); "weak absorption" (BAC 0.01 - 0.1); and "very weak absorption" (BAC 0.001 - 0.01).

The BAC values of plants in the Dexing mining area were calculated (Table 6).

Table 6. BAC values in the Dexing mining area

Sample No.	Plant	Cu	Pb	Zn	Cd	As	Hg
1	Corn	0.0033	0.0054	0.0634	0.0320	0.0003	0.0238
2	Rice	0.0273	0.0081	0.1983	0.1000	0.0001	0.0556
3	Rice	0.0061	0.0044	0.0310	0.0308	0.0002	0.0364
4	Corn	0.2488	0.0052	0.8362	0.8333	0.0002	0.0313
5	Rice	0.0756	0.0191	0.1289	1.8667	0.0001	0.0328
6	Rice	0.1442	0.0212	0.2044	0.7500	0.0009	0.0698
7	Rice	0.0494	0.0050	0.0385	0.0231	0.0003	0.0385

In the study area, the BAC of As is lowest, marking 'very weak absorption'; Hg caused 'weak absorption'; Cu, Cd and Zn, 'weak absorption' to 'moderate absorption'. Cd in the rice has the highest BAC in site No. 5, which is 1.8667. In summary, the BAC of rice is higher than that of corn.

3.6 Ecological risk of the mining area

The quantitative indices, integrating chemical, toxicological and ecological responses from different components in the Le'an River ecosystem, including overlying water, surface sediment and floodplain topsoil, indicated a highly localized distribution pattern closely associated with the pollution sources along the bank (Liu Wenxin et al., 2003). Based on the combined indices, deterioration of regionally environmental quality was induced mainly by two factors. One is the strong acidity and a large amount of Cu in the drainage from the Dexing copper mine. The other is the high concentrations of Pb and Zn in the effluents released from many smelters and mining/panning activities in the riparian zone (Liu Wenxin et al., 2003).

4 Conclusions

Long-term mining activities adversely influence the environment in the Dexing area. The eco-environmental geochemical investigation of water, sediments, topsoils and plants indicated a highly localized distribution pattern closely associated with the pollution sources along the Le'an River bank; water, soils, sediments and plants were polluted by heavy metals released in response to mining activities. In the study area, two main pollution sources are proposed as follows: one is the strong acidity and a large amount of Cu in the drainage from the Dexing copper mine; and the other is the high concentrations of Pb and Zn in the effluents, released from many smelters and mining, and processing and extracting activities in the riparian zone. The results of investigations indicated, at least in part, that some problems associated with environmental quality deterioration should be solved in the future.

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