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Study on the element geochemical charactersitics of the Shazi large-sized anatase ore deposit in Qinglong, Guizhou Province

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Abstract The Shazi anatase ore deposit in Qinglong, Guizhou Province, is a large-sized anatase deposit that has been recently explored. The characteristics of major oxides in the ore are similar to those of modern laterite weathering crust and laterite in the laterite-type gold deposits in the western part of Guizhou Province. Studies on the REE characteristics of basalts and anatase ores in the study region showed that both of them do have extremely strong affinities. There are two groups of trace elements in the ores, i.e., Au-Ag-As-Sb-Hg-Tl association and Sc-TiO_2-Cu-Fe-Mn association, reflecting that the formation of anatase ore is related to the formation of siliceous claystone at the early stage of eruption of the Emeishan basaltic magma. The siliceous claystones are the major country rocks for the formation of laterite-type gold ores and anatase ores. In the region anatase ores are rich in Sc and the basalts enriched in Fe, Mn, Ti and Sc are the material source of metallogenesis.

Key words anatase ore deposit; Emeishan basalt; trace element association; element geochemical characteristic; Qinglong; Guizhou

1 Introduction

The Shazi anatase ore deposit was discovered in 2007 by Profs. Nie Aiguo in Qinglong, Guizhou Province. From 2007 to 2011 a general survey and detailed geological work had been conducted on this deposit. It has been basically verified that the ore reserves of this anatase ore deposit are 2306.09×10^5 ton and the quantity of TiO_2 resource is 102.48×10^5 ton, with an average TiO_2 grade of 4.39%. It is indicated that the Shazi anatase ore deposit belongs to a large-scale eluvial -type anatase ore deposit. Before the discovery of the Shazi anatase ore deposit, there had been found the metasedimentary-type and hydrothermal reworking-type anatase ore deposits only in the Yangtzishan-Moshishan area, Inner Mongolia, China (Zhao et al., 2008, 2006). This is the first discovery of anatase ore in the Emeishan basalt-weathering eluvial soil profile in Guizhou Province, marking the first discovery of a large-sized eluvial-type anatase ore deposit, which makes such a history come into an end that there is no anatase ore resource in Guizhou Province. This discovery is of great practical significance for the reevaluation of ore resources in Southwest Guizhou Province and has also made a certain contribution to exploration of anatase resources and research on their origin both at home and abroad.

Anatase ore is one of the ore types of critical shortage in China and one of the 14 kinds of strategic ore reserves on which China relies seriously (Wu and Zhang, 2006; Cao, 1996; Gao and Wang, 2008). Theoretical research on the newly discovered Shazi anatase ore deposit in Qinglong has just begun and there still exist many blind zones in research. To carry out studies on the geochemical characteristics of this anatase ore deposit will promote deep-going investigations into the rules of transport, enrichment and metallogenesis of anatase ore and also are of great significance in constraining their origins.

Ten ore-exposed drill core assemblage samples were collected randomly from the Shazi anatase ore deposit in Qinglong for bulk oxide analysis, 13 ore-exposed drill core assemblage samples were collected from the same deposit for REE and trace element analysis, and 7 basalt samples were taken from the mining district for REE and trace element analysis. Then, analysis and discussion were conducted on the above analytical results. It is concluded that this anatase ore deposit is rich in Sc and is of great economic significance.

2 Geology of the ore deposit

There have been already explored three anatase orebodies of industrial value, which are arranged in a N-E-S direction and are numbered consecutively: No. 1 anatase orebody, No. 2 anatase orebody and No. 3 anatase orebody (Nie et al., 2011). Through phase analysis it can be seen that the independent minerals of this anatase ore deposit do not occur as commonly observed ilmenite and rutile, but occur in the form of anatase which is not usually observed. The discovered anatase orebodies are distributed in the Quaternary cumulates derived from weathering of basalts in the karst negative-relief fluid bowls on the Maokou Formation limestones at the altitude of 1450–1350 m above sea level, forming eluvial claystone-type ores. Ore minerals are mainly anatase and ilmenite; opague minerals are mainly sericite, chlorite, kaolinite, quartz and secondly are mica, plagioclase and ferrous mud. Ore structures are: as observed by naked eyes, the ores are earthy-yellow, pale brown, grey in color and loosely earthy. The ores exhibit mainly earthy massive structure, secondly massive, faviform, brecciated structures. As observed under microscope, some limonite is distributed as fine veins along ore fissures, thus making the ores exhibiting fine-vein structure either. The ore textures are dominated by muddy texture, micro-scaly texture, blastoporphyritic texture, microcrystalline texture, pseudomorphic texture, alteration intergradular-intersertal texture, fine sand texture, and alteration aleuritic texture. It is primarily considered that this anatase ore deposit belongs to the eluvial slope-type anatase ore deposits associated with Emeishan basaltic magma eruption.

Through process mineralogical studies it has been found that the contents of anatase (the molecular formula is TiO_2) are about 4.42%. Electron microprobe compositional analysis revealed that anatase contains as much Ti, O and Si as 51.37%, 47.72%, and 0.91%, respectively. Microscopic observation shows that anatase displays yellowish-green, yellowish-brown, adamantine and port oily lusters, and they are cubic dipyramid-shaped and xenomorphic granular. As observed under polarizing microscope, anatase is distributed mainly in seriously altered basalts, it is xenomorphic granular, dentritic and muddy in shape and is of close intergrowth with quartz, feldspar and muddy material and are enclosed in gangue minerals or are distributed in quartz and feldspar fissures. It also intergrows with ferruginous material and is probably derived from the decomposition of melanocratic minerals during the process of rock alteration. Therefore, its grains are fine. In the artificial heavy concentrates an extremely small amount of granular anatase (about 0.15%) can be observed under stereomicroscope, but when observed under polarizing microscope anatase grains which are less than 47.2 mm in size account for 96.35% and the grains which are less than 23.6 mm account for 75.37%. It can be seen that the dissemination extent of anatase is relatively small. This kind of anatase occurs as micro-fine particles in soils derived from weathering of the Emeishan basalts.

3 Major element geochemical characteristics

Oxide bulk analysis was conducted of ten ore-exposed drill-core composite samples from this ore deposit and the analytical results are listed in Table 1. The major characteristics are presented as follows:

(1) The total amount of major oxides such as SiO_2, Al_2O_3, Fe_2O_3 and TiO_2 in the ore is within the range of 81.64%–88.15% and this feature is approximate to that of laterite in the laterite-type gold ores in the western part of Guizhou and also to that of the laterite weathering crust in Guizhou (Wang et al., 2000; Gao et al., 2002), though the content of TiO_2 is relatively high.

(2) Iron in the ores is all present in the form of Fe_2O_3, indicating that the ores were strongly weathered and completely oxidized.

(3) The content of SiO_2 is all less than 55%, indicating that the ores are clayey ores.

(4) There is a positive correlation between TiO_2 and Fe_2O_3 and the correlation coefficient is 91.06%, reflecting that anatase has a relationship of coexistence (association) with Fe-bearing minerals in the protolith.

(5) There is a positive correlation between TiO_2 and Al_2O_3 and the correlation coefficient is 86.21%, reflecting that anatase has a relationship of coexistence (association) with clay minerals in the protolith.

Table 1 Analytical results for the major elements and relevant coefficients of the Shazi anatase ore deposit, Qinglong, Guizhou Province

Sample No.	Analytical result（10^{-2}）										
	SiO_2	Al_2O_3	TFe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	MnO_2	P_2O_5	LOSS
ZK5501	34.26	21.08	23.10	4.71	0.20	0.32	0.52	0.02	0.29	0.35	12.78
ZK5902	30.26	24.23	23.95	4.97	0.06	0.17	0.35	0.04	0.32	0.49	13.62
ZK21-2	32.16	21.40	23.74	4.71	0.90	1.39	1.30	0.46	0.16	0.27	12.02
ZK903	26.60	24.19	25.82	5.03	0.07	0.13	0.44	0.03	0.25	0.37	14.04
ZK104	41.08	19.70	19.45	3.93	0.26	0.51	0.61	0.01	0.21	0.35	11.80
ZK1103	51.22	16.09	16.94	3.90	0.20	0.34	1.48	0.02	0.07	0.52	7.78
ZK1701	46.10	15.26	18.18	3.42	1.35	1.30	0.87	1.02	0.12	0.47	10.34
ZK23-1	36.96	21.45	20.89	3.80	0.25	0.47	0.67	0.05	0.26	0.39	12.68
ZK5003	29.62	23.38	25.52	5.16	0.08	0.20	0.52	0.04	0.32	0.39	13.74
ZK5401	43.28	18.34	16.31	3.80	0.82	0.92	0.64	0.02	0.22	0.40	12.32
SiO_2	1										
Al_2O_3	-0.9538	1									
TFe_2O_3	-0.9519	0.8915	1								
TiO_2	-0.8732	0.8621	0.9106	1							
CaO	0.4397	-0.6426	-0.4822	-0.5812	1						
MgO	0.3583	-0.5439	-0.4025	-0.5013	0.9518	1					
K_2O	0.5877	-0.6138	-0.4414	-0.3802	0.3961	0.5054	1				
Na_2O	0.2632	-0.4969	-0.1892	-0.3921	0.8563	0.7733	0.3264	1			
MnO_2	-0.7782	0.8309	0.6643	0.6443	-0.5577	-0.5574	-0.8700	-0.4905	1		
P_2O_5	0.4967	-0.3826	-0.4181	-0.3050	-0.0719	-0.2736	0.0773	0.0619	-0.2446	1	
LOSS	-0.8982	0.8727	0.7472	0.6637	-0.3519	-0.3269	-0.8262	-0.3070	0.9062	-0.4715	1
Laterite in the laterite type gold deposits in western Guizhou	51.50	22.39	10.93	1.56	0.22	0.13	0.97	0.16	0.13	0.02	9.50
Laterite weathering crust, Guizhou	52.35	22.02	8.55	1.16	0.20	1.38	1.97	0.10	0.02	0.04	12.07

Note: Laterite in the laterite-type gold deposits in the western part of Guizhou (Wang et al., 2000); laterite weathering crust in Guizhou (Liao et al., 2004).

4 REE geochemical characteristics

Thirteen ore-exposed drill -core composite samples randomly were selected from this deposit for REE analysis, and 7 basalt samples were taken from the mining district for REE analysis. The analytical results are listed in Table 2. The REE patterns of basalt samples and ores in three orebodies in the mining district are established (Figs. 1–2) and their characteristics are described as follows:

(1) The total REE amount (∑REE) of basalts in the mining district is $(183.53–215.86)\times10^{-6}$ and that of basalts in the western part of Guizhou is $(144.73–265.500)\times10^{-6}$ (Mao et al., 1992), and their abundances vary within the range of abundances of basalts in the western part of Guizhou. The chrondrite-normalized REE patterns of basalts in the mining district are of right-inclined type. The LREE values of the samples are $(125.15–144.40)\times10^{-6}$, their HREE values are $(58.38–71.46)\times10^{-6}$, and their LREE/HREE ratios vary within the range of 1.92–2.25, indicative of relative LREE enrichment. Basalts in the western part of Guizhou are sodium-modified basalts, and in the more alkaline media the LREE tend to separate from the HREE, thus leading to relative LREE enrichment.

(2) The total REE amount (∑REE) of ores in the three orebodies in the mining district is relatively high, mostly within the range of $(163.56–370.26)\times10^{-6}$. The total REE amount of some samples is $(402.26–702.67)\times10^{-6}$, indicating REE enrichment to different degrees in the ores. The chondrite-normalized REE patterns of basalts in the mining district are of right-inclined type and most samples have much similarity to the basalts in the mining strict, indicating that both of them have strong affinities (Wang et al., 1989). The LREE values are within the range of $(112.57–529.15)\times10^{-6}$ and the HREE values are within the range of $(35.52–244.26)\times10^{-6}$; the LREE/HREE ratios vary between 1.41 and 4.01 with an average value of 2.71, indicative of LREE enrichment. That is

to say, anatase was formed in a more alkaline environment, thus leading to further separation of LREE from HREE.

(3) The δEu values of basalts in the mining district are 0.86–0.95, all less than unity, and the basalts show weak negative Eu anomalies. Their δCe values are 0.92–0.97, all less than unity, indicating that the major minerals plagioclase and pyroxene in the basalts simutaneously crystallized in proportion. The δEu values of ores in the three orebodies are 0.79–0.93, all less than unity, indicative of weak negative Eu anomalies. Their δCe values are 0.48–1.44，mostly within the range of 0.48–0.88 and a few are within the range of 1.01–1.44. It can be seen that the values vary over a relatively wide range. It is indicated that ore-forming materials of the deposit sourced from basalts, but in the process of metallogenesis, the decomposition of pyroxene took place in the low-temperature and low-pressure weakly alkaline waterbody (Winchell, 1953; Doucet and Synthese, 1967) and in the process of weathering the depletion extent is different very obviously.

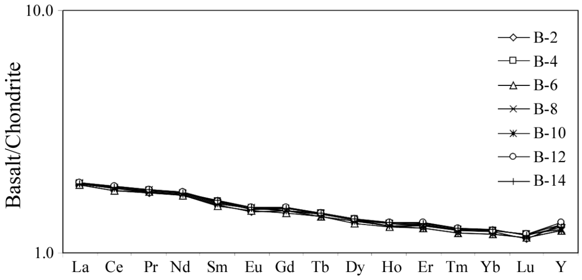

Fig. 1. REE distribution patterns of basalts in the Shazi anatase ore-field, Qinglong.

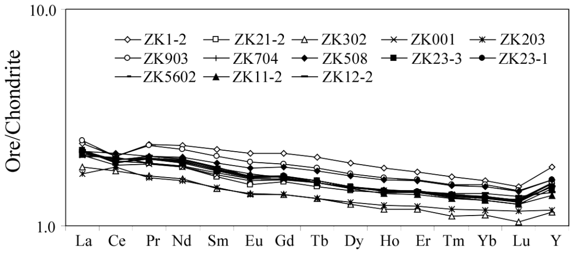

Fig. 2. REE distribution patterns of ores from the Shazi anatase ore deposit, Qinglong.

5 Trace element geochemical characteristics

Trace element analysis was carried out on 13 ore-exposed drill-core samples which had been selected randomly from the ore deposit and the analytical results are listed in Table 3. The average trace element values were statistically calculated, compared with those of the continental upper crust to work out the element concentration clark values. By comparison of 24 trace elements, Au, Ag, As, Hg, Sb, Tl, V, Ti, Fe, Mn, Sc, Th, Cu, Cr and Co are obviously enriched. Correlation analysis was conducted of those obviously enriched trace elements in the ores. Their correlativities are listed in Table 4.

As viewed from the above statistical results, it can be seen that anatase ores have the following essential characteristics:

(1) Coherent elements such as Au, Ag, As, Hg, Sb, Tl, V, U, Pb, Fe, Mn, Th, Cu, Cr and Co are relatively enriched in the ores, but are not enriched to such an extent that they can be comprehensively utilized.

(2) According to the results of correlativity analysis for trace elements in the ores (*N*=13), with the correlation coefficient of 0.6 at the positive correlation level, the coherent elements can obviously be divided into two groups:

Group I: Au-Ag-As-Sb-Hg-Tl association. This element association is the same as the trace element association in the laterite-type gold ores in the southwestern part of Guizhou Province, reflecting that the formation of anatase is consistent with that of the siliceous claystones vastly distributed at the top of the Maokou Formation limestones at the early stage of eruption of regional-background Emeishan basaltic magmas. Those siliceous claystones are the major country rocks for the formation of the laterite-type gold ores and anatase ores.

Group II: Sc-TiO_2-Cu-Fe-Mn association, reflecting the characteristic geochemical environment of a confined waterbody under regional background condition, i.e., the confined waterbody in the strong oxidation environment on the earth's surface, basaltic eruptive material rich in Fe, Mn, Sc and Ti fell into the waterbody and hydrolyzed to form a low-temperature and low-pressure and weakly alkaline water environment (Nie, 2008; Chen et al., 2003; Cao, 1991). Ferrous iron in the original basalts was oxidized as trivalent iron to form limonite, divalent manganese in the original basalts was oxidized as traivalent or tetravalent manganese to form psilomelane, and titanium was involved in the formation of anatase under sufficient oxygen supply and low-temperature and low-pressures conditions (Jackson et a1., 2006; Chen and Ji, 1985).

6 The element (Sc) in the ores

The element Sc is obviously enriched in the ores of the three orebodies and its contents vary over a range of $(24.7–53.8)\times10^{-6}$,with an average value of 40.3×10^{-6}, 3.7 times those of the continental upper crust (Table 4). The atomic number of Sc is 21 and its outer electronic configuration is $3d^1 4s^2$. In nature Sc

Table 2 Results of REE analysis and characteristic parameters for anatase ore and basalt in the Shazi anatase ore deposit, Qinglong ($\times10^{-6}$)

Sample No.		Analytical result																							
		La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y	∑REE	LREE	HREE	LREE /HREE	δEu	δCe	$(La/Yb)_N$	$(La/Ce)_N$	$(La/Sm)_N$	$(Gd/Yb)_N$
No.1 orebody	ZK1-2	78.35	103.00	28.60	136.00	35.70	10.70	38.00	5.56	28.70	5.08	12.60	1.54	8.67	1.11	143.00	636.61	392.35	244.26	1.61	0.88	0.52	6.09	1.98	1.38	3.54
	ZK21-2	46.71	79.23	10.88	44.95	9.60	2.57	10.31	1.55	9.02	1.88	5.54	0.75	4.59	0.69	74.20	302.48	193.94	108.54	1.79	0.79	0.82	6.86	1.54	3.06	1.81
No.2 orebody	ZK302	22.97	50.96	6.13	26.43	6.01	1.89	6.51	1.02	5.79	1.12	3.26	0.42	2.78	0.37	27.88	163.56	114.40	49.16	2.33	0.92	1.01	5.57	1.17	2.41	1.89
	ZK001	40.47	63.91	10.52	44.56	10.32	3.05	11.23	1.79	10.06	2.06	5.67	0.79	4.63	0.65	65.76	275.48	172.84	102.64	1.68	0.86	0.73	5.89	1.65	2.47	1.96
	ZK203	17.16	59.18	5.62	24.63	6.27	1.81	6.38	1.03	6.18	1.25	3.60	0.51	3.19	0.49	29.54	166.84	114.67	52.17	2.20	0.87	1.44	3.63	0.76	1.72	1.62
	ZK903	94.12	102.19	26.81	110.49	23.85	6.80	21.65	3.35	17.61	3.27	8.89	1.13	7.27	0.95	84.74	513.12	364.26	148.86	2.45	0.90	0.48	8.73	2.40	2.48	2.40
	ZK704	53.66	75.26	12.95	54.07	12.17	3.47	12.56	1.97	10.75	2.09	5.86	0.78	4.80	0.68	70.69	321.74	211.58	110.16	1.92	0.85	0.67	7.54	1.86	2.77	2.11
	ZK508	48.73	117.29	15.46	69.77	17.14	5.17	18.98	2.88	16.29	3.11	8.55	1.11	6.83	0.91	85.24	417.46	273.56	143.90	1.90	0.87	1.02	4.81	1.08	1.79	2.24
No.3 orebody	ZK23-3	51.46	70.07	13.91	58.18	12.77	3.51	12.59	1.94	10.59	2.01	5.66	0.73	4.23	0.61	60.26	308.50	209.89	98.61	2.13	0.84	0.62	8.21	1.91	2.54	2.40
	ZK23-1	47.44	87.04	12.95	56.87	13.26	3.75	12.81	1.97	10.74	2.08	5.86	0.80	4.84	0.69	64.22	325.31	221.31	104.00	2.13	0.87	0.83	6.60	1.42	2.25	2.13
	ZK5602	53.88	83.78	14.94	63.33	14.30	3.61	12.79	1.82	10.22	2.05	5.92	0.77	4.63	0.67	63.68	336.39	233.84	102.55	2.28	0.80	0.70	7.84	1.68	2.37	2.23
	ZK11-2	43.38	87.34	13.91	61.86	14.01	3.96	12.12	1.81	10.03	1.88	5.20	0.71	4.32	0.59	46.84	307.96	224.46	83.49	2.69	0.91	0.85	6.77	1.29	1.95	2.26
	ZK12-2	38.78	94.07	11.02	46.98	11.24	3.26	11.46	1.78	10.22	2.06	5.84	0.84	5.35	0.77	52.68	296.37	205.36	91.02	2.26	0.87	1.08	4.89	1.07	2.17	1.73
Basalt	B-2	25.30	52.10	7.19	32.30	7.34	2.22	8.15	1.31	7.42	1.42	4.11	0.56	3.45	0.46	39.10	192.41	126.45	65.96	1.92	0.87	0.92	4.94	1.27	2.17	1.91
	B-4	26.60	55.60	7.82	34.40	8.26	2.42	8.76	1.36	7.84	1.52	4.29	0.57	3.61	0.52	40.30	203.79	135.06	68.74	1.96	0.86	0.92	4.97	1.25	2.02	1.96
	B-6	24.70	52.40	7.33	31.40	7.05	2.28	7.54	1.22	6.74	1.34	3.81	0.52	3.29	0.48	33.50	183.53	125.15	58.38	2.14	0.95	0.93	5.07	1.23	2.21	1.85
	B-8	27.90	58.50	8.02	34.30	8.12	2.54	8.08	1.35	7.53	1.49	4.08	0.57	3.57	0.51	34.70	201.38	139.50	61.89	2.25	0.95	0.93	5.28	1.24	2.17	1.83
	B-10	26.20	56.60	7.51	32.50	7.67	2.43	7.94	1.24	7.10	1.41	3.88	0.52	3.26	0.48	33.30	192.07	132.96	59.11	2.25	0.95	0.96	5.42	1.21	2.15	1.97
	B-12	28.10	61.30	8.07	36.20	8.25	2.53	8.90	1.38	7.85	1.58	4.55	0.59	3.60	0.53	42.50	215.86	144.40	71.46	2.02	0.90	0.97	5.26	1.19	2.14	1.99
	B-14	26.50	58.70	8.04	34.80	8.61	2.58	8.62	1.39	7.75	1.56	4.42	0.59	3.67	0.51	36.80	204.52	139.16	65.36	2.13	0.91	0.96	4.87	1.18	1.94	1.89

Table 3 Statistical results of relevant trace elements in ores in the Shazi anatase ore deposit, Qinglong

Sample No. and characteristic value	Analytical result														
	Ag (10^{-6})	Sb (10^{-6})	Hg (10^{-6})	As (10^{-6})	Co (10^{-6})	Cr (10^{-6})	Cu (10^{-6})	Au (10^{-6})	Pb (10^{-6})	TFe (10^{-2})	Mn (10^{-6})	Sc (10^{-6})	Tl (10^{-6})	V (10^{-6})	TiO_2 (10^{-6})
ZK1-2	0.145	15.700	0.325	1805.000	47.000	122.000	276.000	0.050	12.790	10.140	1608.000	34.300	0.445	401.000	1.840
ZK21-2	0.052	13.760	0.544	75.000	45.400	212.000	164.000	0.085	17.110	8.140	512.000	27.200	0.503	352.000	1.695
ZK302	0.558	7.425	0.287	73.000	62.800	117.000	296.000	0.029	7.650	12.950	1475.000	41.900	0.414	506.000	3.842
ZK001	0.116	24.090	0.310	113.400	69.800	126.000	373.000	0.070	7.470	11.020	1765.000	39.100	1.335	468.000	3.890
ZK203	0.182	12.000	0.254	121.000	102.000	127.000	525.000	0.043	8.020	12.930	2266.000	48.100	0.468	553.000	4.813
ZK903	0.167	29.370	0.338	69.000	172.600	147.000	601.000	0.093	8.800	12.520	2722.000	42.500	0.490	565.000	4.773
ZK704	0.222	19.470	0.330	163.000	57.800	149.000	286.000	0.063	8.605	10.600	1216.000	33.300	0.868	465.000	3.832
ZK508	0.097	6.500	0.169	38.000	114.800	128.000	405.000	0.010	14.720	13.270	2319.000	43.500	0.457	505.000	4.471
ZK23-3	0.074	16.400	0.386	32.000	87.700	136.000	295.000	0.063	10.750	10.990	1035.000	37.800	0.343	454.000	3.783
ZK23-1	0.105	11.870	0.357	23.000	74.800	192.000	362.000	0.050	11.330	13.340	1628.000	45.700	0.300	535.000	4.630
ZK5602	0.332	29.370	4.320	3753.000	29.600	165.000	307.000	0.360	14.180	7.630	624.000	24.700	5.377	611.000	4.760
ZK11-2	0.124	0.990	0.154	4.600	84.400	129.000	396.000	0.085	8.395	14.490	1922.000	51.900	0.191	591.000	5.001
ZK12-2	0.170	1.060	0.126	128.000	92.300	151.000	608.000	0.077	5.731	16.920	1902.000	53.800	0.138	585.000	5.530
Average value	0.180	14.460	0.610	492.200	80.100	146.000	376.000	0.083	10.430	11.920	1615.130	40.300	0.870	507.000	4.070
Average abundance value of continental upper crust	0.050	0.200	0.012	1.500	10.000	35.000	25.000	0.002	20.000	4.500	800.000	11.000	0.750	60.000	0.650
Concentrated clark value	3.610	72.310	49.410	328.120	8.010	4.180	15.060	46.070	0.520	2.650	2.020	3.700	1.160	8.450	6.260

Table 4 Correlativities of trace elements in ores from the Shazi anatase ore deposit, Qinglong

	Au	Ag	Hg	As	Sb	Tl	V	Ti	U	Pb	Fe	Mn	Sc	Th	Cu	Cr	Co
Au	1	0.8208	0.9198	0.8208	0.2918	0.8868	0.3934	0.1529	0.3137	0.1815	0.1121	0.2196	0.1133	0.2576	0.0170	0.2220	0.2279
Ag		1	0.3189	0.3016	0.0531	0.3257	0.2706	0.1807	0.0315	0.1350	0.0580	0.0530	0.0990	0.1365	0.0199	0.1715	0.1112
Hg			1	0.8999	0.2875	0.9737	0.2388	0.0361	0.1871	0.2380	0.5125	1.0000	0.3539	0.2975	0.1812	0.1913	0.3535
As				1	0.3002	0.8958	0.1300	0.1807	0.6339	0.2370	0.5213	0.3179	0.5109	0.3238	0.1912	0.0766	0.1059
Sb					1	0.3257	0.0910	0.3186	0.1937	0.1265	0.7237	0.1931	0.7102	0.1019	0.1609	0.1555	0.2126
Tl						1	0.2097	0.0220	0.5252	0.2323	0.5276	0.3555	0.5540	0.2574	0.1875	0.1589	0.3812
V							1	0.7958	0.3022	0.2485	0.3632	0.3642	0.3872	0.2842	0.6355	0.0764	0.3658
Ti								1	0.5789	0.4254	0.6480	0.5012	0.6568	0.3814	0.6763	0.1609	0.5272
U									1	0.5412	0.6631	0.4320	0.7276	0.3934	0.3569	0.2969	0.3035
Pb										1	0.5364	0.5791	0.6350	0.9603	0.5598	0.6974	0.4257
Fe											1	0.6631	0.9155	0.3736	0.6238	0.4258	0.5682
Mn												1	0.7268	0.4448	0.6580	0.5945	0.7416
Sc													1	0.4657	0.6736	0.5226	0.6004
Th														1	0.5543	0.5615	0.4387
Cu															1	0.3677	0.7605
Cr																1	0.3302
Co																	1

is present stably in the form of Sc^{3+} (Liu et al., 1984). Mainly unequivalently replacing $Fe^{2+}$and Mg^{2+}, Sc^{3+} is present in pyroxene, hornblende and olivine (Lü et al., 1992). In the mining district Sc^{3+} is present mainly in pyroxene minerals in basalts and coexists isomorphically with Fe, Mn and Ti. When the eruptive materials of basaltic magmas fell into the waterbody, Sc^{3+} would be released from rocks along with the weathering and disintegration of pyroxene and other minerals, forming $Sc(OH)_3$ or Sc_2O_3 which would be adsorbed on colloidal clay minerals. That is why anatase in the mining district is enriched in Sc. As Fe, Mn, Ti and Sc are derived from the same basalt, the correlativities between Sc and Ti, Fe and Mn are relatively high. The coefficient of correlation between Sc and Fe is +0.9155, that between Sc and Mn is +0.7268, and that between Sc and Ti is +0.6568.

The nature of Sc is very close to that of REE. As compared to La and Y, the ionic radius of Sc is particularly small. The alkalinity of hyroxides is extremely weak. Therefore, when hydroxides are mixed with REE, it is possible to isolate Sc from ores by using the ammonia grading precipitation method or the nitrate grading decomposition method. Sc can play a fantastic role in metallurgical, electronic, chemical and optical power and other material industries and it has become a new star in the field of material science. Sc is very expensive. Sophisticated Sc-purification technologies are now available both at home and abroad. A great success has been achieved on an experimental basis in extracting Sc from specimens with a Sc content of 0.0017% (Feng and Zhang, 2005).The total REE amount of this anatase ore deposit does not reach the industrial grade of the weathering-crust ion absorption-type REE ores, but the total REE amount of some samples reaches $(402.26–702.67)\times10^{-6}$, indicative of a certain degree of mineralization. So Sc is relatively high and can be comprehensively utilized. With the development of anatase ores and the comprehensive untilization of Sc, the economic value of Sc is different to estimate.

7 Conclusions

The following conclusions have been drawn from the REE and trace element geochemical studies of oxides in ores from the Shazi anatase ore deposit in Qinglong.

(1) The total amount of major oxides SiO_2, Al_2O_3, Fe_2O_3 and TiO_2 in the ores is close to that of oxides in laterite in the laterite-type gold deposits in the western part of Guizhou and in laterite weathering crust in Guizhou, though the content of TiO_2 is relatively high. The ores are strongly weathered and completely oxidized. There is a positive correlation between TiO_2 and Fe_2O_3 and the correlation coefficients are 86.21%, respectively, reflecting that anatase is associated (coexists) with clay minerals in the protolith.

(2) According to the correlation analysis of trace elements in the ores, the correlative elements can be divided into two groups: Group I: Au-Ag-As-Sb-Hg-Tl association. This element association is identical to the trace element association in the laterite-type gold ores in the southwestern part of Guizhou, reflecting that the formation of anatase is consistent with the formation of siliceous claystones vastly developed at the top of the Maokou Formation limestones during the early stage of regional- background Emeishan basaltic magmas. Siliceous claystones of this type are the major country rocks for the formation of laterite-type gold ores and anatase ores. Group II: Sc-TiO_2-Cu-Fe-Mn association, reflecting the characteristic geochemical environment of the confined waterbody under regional background condition, i.e., in the confined waterbody in the strongly oxidized zone on the Earth’s surface, eruptive materials from basalt magmas enriched in Fe, Mn and Ti fell into the waterbody, followed by hydrolysis, thus creating a low-temperature and low-pressure weakly alkaline water environment. Ferrous iron in the original basalts was oxidized as trivalent iron to form limonite, and divalent manganese in the original basalts was oxidized as trivalent or tetravalent manganese to form psilomelane. The formation of anatase took place in the low-temperature and low-pressure weakly alkaline water environment where oxygen gas supply is sufficient.

(3) Research on the REE geochemical characteristics of basalts and ores in the three orebodies in the study region indicate that both basalts and ores have extremely strong affinities. The ore-forming materials of the deposit come from basalts. In the study region the anatase ore deposit is enriched in Sc. Fe, Mn, Ti and Sc which all sourced from the same type of basalts, mainly from decomposition of pyroxenes in the basalts. Therefore, Sc possesses a very strong correlativity with Ti, Fe and Mn.

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