

# Abundances of chemical elements of the granitoids in different geotectonic units of China and their characteristics

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**Abstract** On the basis of actual analytical data of 767 composited samples collected mainly from about 750 large to middle representative granitoid bodies all over China, the average chemical compositions and element abundances of about 70 chemical elements of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, FeO, MgO, CaO, Na<sub>2</sub>O, K<sub>2</sub>O, H<sub>2</sub>O<sup>+</sup>, CO<sub>2</sub>, TFe<sub>2</sub>O<sub>3</sub>, Ag, As, Au, B, Ba, Be, Bi, Cd, Cl, Co, Cr, Cs, Cu, F, Ga, Ge, Hf, Hg, Li, Mn, Mo, Nb, Ni, P, Pb, Rb, S, Sb, Sc, Se, Sn, Sr, Ta, Th, Ti, Tl, U, V, W, Zn, Zr, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu and Y in alkali feldspar granite, syenogranite and adamellite in 7 geotectonic units in China such as Tianshan–Xing’an orogenic series, Sino–Korean metaplatform, Kunlun–Qilian–Qinling orogenic series, Yunnan–Tibet orogenic series, Yangtze metaplatform, South China–Youjiang orogenic zone and Himalayan orogenic belt, are calculated and presented in this paper. In addition, the characteristics of petrochemical parameters, trace element contents and rare earth element distributions of different rock types of the granitoids in different geotectonic units are also sufficiently discussed.

**Keywords** granitoids, element abundance, geotectonic unit, China

## 1 Introduction

As an important part of the study on element abundances of the earth’s crust, the abundances of chemical elements in granitoids have been the focus across the world. Since Daly (1933) first published the average chemical compositions of major elements in the world’s granitoids, much information and many data about chemical compositions in granitoids

have been obtained by different scholars with different calculating methods (Beus, 1972; Le Maitre, 1976; Li et al., 1998; Li and Yio, 1963; Nockolds, 1954; Shi et al., 2005a, 2005b; Turekian and Wedepohl, 1961; Vinogradov, 1962; Yan and Chi, 1997).

On the basis of the actual analytical data of about 500 granitoid bodies in east China together with some collected major element data of granitoid bodies in west China, Yan and Chi (1997) calculated the average values of 76 elements or components in granite, alkali feldspar granite (syenogranite), adamellite, granodiorite and acid rock population in five geotectonic units of eastern China such as Inner Mongolia Xing’an–Jihei orogenic belt, North China platform, Qinling–Dabieshan orogenic belt, Yangtze platform (East), and South China system of folds. Based on the actual analytical data, Shi et al. (2005a, 2005b) proposed the abundances of about 70 chemical elements and compositions in China’s granitoids, various rock types of granites and granitoids in different tectonics and different ages. Furthermore, many data and much information about the chemical compositions of a single granite body or of the granites (granitoids) in a region have been obtained by different institutes and researchers, such as Guiyang Institute of Geochemistry of Chinese Academy of Sciences (1979), The Science Exploration Team of Qinghai–Tibet Plateau of Chinese Academy of Sciences (1982), Yu et al. (1987), Lu (1987), Wang (1987), Zhang and Sun (1988), Liao (1989), Wang (1989), Zhang (1990), Li and Wang (1991), Zhang et al. (1994), Wang and Zhang (2001), Xu et al. (2001).

Although a lot of researches have been done on the chemical components of different granite bodies in China, it is still short of national and systematical researches on the actual multi-element abundances of different rock types of granitoids in different tectonic units. There are no average values of chemical compositions and element abundances of the different rock types of granitoids in different tectonic units calculated absolutely based on the actual data in China.

About 70 elements for the granitoid samples in eastern China were analyzed with 15 analytical methods relying

Translated from *Acta Geologica Sinica*, 2007, 81(1): 47–59 [译自: 地质学报]

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mainly on instrumental neutron activation analysis (INAA) and X-ray fluorescence spectrometry (XRF) by some experimental laboratories and analyzers. Analytical methods and the pertaining elements for the granitoid samples in western and southeastern China are as follows: non-fire atomic absorption spectrometry (AAN): Au; emission spectrometry (ES): Ag, B, Sn; atomic fluorescence spectrometry (AFS): As, Ge, Hg, Sb, Se; potentiometry (PO): CO<sub>2</sub>; fused disc X-ray fluorescence spectrometry (FU-XRF): SiO<sub>2</sub>, TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, MnO, MgO, CaO, Na<sub>2</sub>O, K<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub>; gravimetry (GR): H<sub>2</sub>O<sup>+</sup>; volumetry (VOL): FeO; inductively coupled plasma masses (ICP-MS): Bi, Cd, Co, Cs, Cu, Ga, Hf, Mo, Ni, Sc, Ta, Tl, U, W, Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Sm, Tb, Tm, Y, Yb; inductively coupled plasma optical emission spectrometry (ICP-OES): Be, Cr, Li; ion selective electrode (ISE): F; pressed disc X-ray fluorescence spectrometry (XRF): Ba, Cl, Mn, Nb, P, Pb, Rb, S, Sr, Th, Ti, V, Zn, Zr. For major elements, it is required that the sum of the contents of compositions lie within the range of 99.00%–100.70%. National preliminary geochemical certified reference materials (CRMs) and confidential duplicates are used to rigidly monitor the analysis quality. The analytical precision was evaluated by the relative deviations (RD) of 35 confidential duplicates. The accuracy of analysis was evaluated by the relative errors (RE) of 98 international accepted confidential CRMs compared with the actual determinations with their certified values (Shi et al., 2005b).

Classification and naming of granitoids in the paper is done, followed with the Quartz-Alkalifeldspar-Plagioclase (QAP) triangle diagram according to the scheme recommended by the igneous rock classification committee of International Union of Geological Sciences (IUGS) (Shi, 2003).

Some contents in the paper about the distribution of China's granitoid samples, sample collecting, sample preparing, and calculating method of abundance value have been introduced by Shi (2003) and Shi et al. (2005b). This paper mainly discusses the element abundances and their characteristics in granitoids and in alkalifeldspar granite, syenogranite, and adamellite in seven geotectonic units.

## 2 The element abundances of granitoids in different geotectonic units and different types of rocks

On the basis of the Chinese geotectonic unit partition scheme of Ren et al. (1999) and the granitoid samples distribution (Shi et al., 2005b) related to the paper, the average chemical compositions and element abundances of about 70 chemical elements in alkalifeldspar granite, syenogranite and adamellite in seven geotectonic units of China such as Tianshan–Xing'an orogenic series, Sino–Korean metaplatform, Kunlun–Qilian–Qinling orogenic series, Yunnan–Tibet orogenic series, Yangtze metaplatform, South China–Youjiang orogenic belt and Himalayan orogenic belt are calculated, according to the actual analytical data of samples collected

from about 750 representative granitoid bodies in the Chinese Mainland (Shi, 2003). They are listed in Tables 1 to 4.

## 3 The characteristics of petrochemistry and trace elements

### 3.1 Regional distributions of element abundance of granitoids in different geotectonic units

#### 3.1.1 The characteristics of element abundance of granitoids in different geotectonic units

Compared with the average values of major element contents in China's granitoids (Shi et al., 2005b), Si, Fe and Na are concentrated in granitoids in Tianshan–Xing'an orogenic series, so the granitoid is an enrichment type of Si-Fe-Na; Al, Fe, and Na are concentrated in granitoids in Sino–Korean metaplatform, so the granitoid is an enrichment type of Al-Fe-Na; Al, Fe, Mg, Ca, and Na are concentrated in granitoids in Kunlun–Qilian–Qinling orogenic series, so the granitoids is an enrichment type of Al-Fe-Mg-Ca-Na; Al, Fe, Mg, and Ca are concentrated in granitoids in Yunnan–Tibet orogenic series, so the granitoid is an enrichment type of Al-Fe-Mg-Ca; Si, Fe, and Mg are concentrated in granitoids in Yangtze metaplatform, so the granitoid is an enrichment type of Si-Fe-Mg; Si, Fe, and K are concentrated in granitoids in South China–Youjiang orogenic belt, so the granitoid is an enrichment type of Si-Fe-K; Si, Al, Ca, and Na are concentrated in granitoids in Himalayan orogenic belt, so the granitoid is an enrichment type of Si-Al-Ca-Na (Table 5).

Li et al. (1998) classified the granitoids of China into eastern enrichment type of Si-Fe-Na-K, southwestern enrichment type of Si-Na-K, and western enrichment type of Al-Fe-Mg-Ca. It was also shown that regional petrochemical characters of granitoids in different regions are varied.

#### 3.1.2 Regional distributions of element abundance of granitoids in different geotectonic units

**(1) Lithophile elements:** the contents of Li, U, W, Cs, Ta, Mo, Rb, Be, Th, and Nb evidently increase from Sino–Korean metaplatform → Tianshan–Xing'an orogenic series → Kunlun–Qilian–Qinling orogenic series → Himalayan orogenic belt → Yunnan–Tibet orogenic series → Yangtze metaplatform → South China–Youjiang orogenic belt. They are the lowest in Sino–Korean metaplatform and are the highest in South China–Youjiang orogenic belt. Another outstanding feature is that the contents of these elements of granitoids in South China (Yangtze metaplatform and South China–Youjiang orogenic belt) are commonly higher than those in North China (Sino–Korean metaplatform, Tianshan–Xing'an orogenic series, Kunlun–Qilian–Qinling orogenic series, Himalayan orogenic belt, and Yunnan–Tibet orogenic series). The changing tendency of Sr and Ba is the opposite—the content in North China is lower than that in South China. That means the two element contents of Yangtze metaplatform are lower

**Table 1** The total average chemical compositions and element abundances of granitoids in seven geotectonic units of China

Unit	1	2	3	6	7	8	9	Unit	1	2	3	6	7	8	9
$N_c$	138	196	94	68	89	172	10	Mo	0.43	0.39	0.45	0.37	0.46	0.89	0.35
$N_s$	1 259	1 883	716	343	643	1 220	15	Nb	11.0	13.0	13.0	11.5	14.3	18.2	8.9
SiO <sub>2</sub>	72.73	72.14	70.44	70.89	72.45	73.29	73.60	Ni	4.0	4.2	5.0	4.5	3.5	6.0	2.4
TiO <sub>2</sub>	0.26	0.24	0.35	0.31	0.30	0.27	0.22	P	349	341	517	496	428	413	316
Al <sub>2</sub> O <sub>3</sub>	14.04	14.38	14.92	14.59	14.11	13.62	14.37	Pb	19	23	28	22	27	32	17
Fe <sub>2</sub> O <sub>3</sub>	0.90	1.03	0.85	0.65	0.83	0.77	0.75	Rb	125	131	147	157	197	237	174
FeO	0.89	0.81	1.48	1.55	1.21	1.15	0.94	S	70	70	80	59	84	125	60
MnO	0.04	0.04	0.05	0.05	0.05	0.05	0.05	Sb	0.16	0.11	0.13	0.10	0.13	0.10	0.13
MgO	0.46	0.44	0.79	0.74	0.56	0.46	0.41	Sc	4.7	2.9	5.8	6.3	5.5	6.0	5.5
CaO	1.32	1.31	1.87	2.08	1.34	0.98	2.02	Se	0.020	0.030	0.029	0.006	0.015	0.020	0.004
Na <sub>2</sub> O	3.86	3.90	3.65	3.18	3.16	3.00	3.55	Sn	1.6	1.2	2.6	2.4	3.8	5.3	1.0
K <sub>2</sub> O	4.09	4.27	3.94	4.05	4.31	4.70	4.16	Sr	179	312	257	209	117	97	201
P <sub>2</sub> O <sub>5</sub>	0.07	0.08	0.11	0.10	0.10	0.09	0.06	Ta	0.92	0.90	1.16	1.29	1.60	1.97	1.13
H <sub>2</sub> O <sup>+</sup>	0.65	0.80	0.86	0.54	0.87	0.84	0.36	Th	12.8	13.6	15.8	15.5	19.1	22.3	12.7
CO <sub>2</sub>	0.26	0.16	0.37	0.23	0.23	0.20	0.13	Ti	1 528	1 300	1 890	1 717	1 588	1 497	1 236
TFe <sub>2</sub> O <sub>3</sub>	1.95	1.91	2.49	2.30	2.28	2.16	1.76	Tl	0.62	0.77	0.75	0.72	0.92	1.26	0.64
Ag	51	51	47	45	50	59	33	U	2.13	1.97	2.40	2.63	4.09	5.49	3.79
As	1.3	0.6	1.0	1.2	0.9	1.1	1.4	V	22	19	30	28	27	22	19
Au	0.40	0.30	0.46	0.40	0.29	0.35	0.50	W	0.51	0.30	0.70	0.77	1.20	1.60	0.42
B	4.1	3.0	4.8	5.0	4.1	4.2	8.7	Zn	38	38	46	45	46	47	26
Ba	461	916	711	485	380	422	437	Zr	141	150	158	128	152	149	115
Be	2.4	2.3	2.3	2.2	3.2	3.9	1.8	La	26	35	35	30	39	40	28
Bi	0.10	0.10	0.13	0.10	0.28	0.31	0.05	Ce	52	66	65	53	71	71	46
Cd	60	40	64	44	50	79	30	Pr	5.76	—	7.14	6.15	8.40	8.89	4.78
Cl	57	41	66	108	70	70	76	Nd	21.2	24.7	26.3	21.8	28.2	30.9	16.0
Co	2.9	2.6	4.5	3.6	3.2	2.6	1.8	Sm	3.90	3.80	5.04	4.08	5.50	6.34	3.29
Cr	4.0	5.0	7.6	9.5	6.3	5.0	2.5	Eu	0.72	0.80	0.96	0.80	0.93	0.81	0.71
Cs	3.1	2.0	4.2	6.5	6.6	7.2	6.1	Gd	4.5	4.0	4.5	3.5	5.5	6.0	3.0
Cu	4.6	4.7	6.3	4.8	5.0	6.0	6.3	Tb	0.55	0.42	0.63	0.62	0.91	0.95	0.55
F	287	383	495	430	601	643	234	Dy	3.7	—	3.7	3.4	5.0	5.3	3.0
Ga	18	18	19	17	18	18	15	Ho	0.74	—	0.68	0.70	1.00	1.05	0.58
Ge	1.24	1.10	1.30	1.43	1.54	1.40	1.35	Er	2.18	—	2.03	1.93	2.66	2.85	1.61
Hf	4.7	4.5	5.0	5.0	5.5	5.2	5.0	Tm	0.38	—	0.36	0.35	0.45	0.47	0.29
Hg	5.00	6.00	6.55	4.32	4.71	5.00	3.92	Yb	2.20	1.10	1.87	2.20	2.62	3.01	1.81
Li	16	13	24	32	26	30	21	Lu	0.33	0.19	0.30	0.35	0.40	0.50	0.30
Mn	335	299	388	386	389	388	350	Y	19.0	16.0	19.0	19.4	26.0	30.7	18.2

$N_c$ : number of analyzed composited samples;  $N_s$ : number of collected samples. Content units:  $10^{-9}$  for Au, Ag, Cd, Hg;  $10^{-2}$  for major elements;  $10^{-6}$  for others. Unit: 1) Tianshan–Xing’an orogenic series; 2) Sino–Korean metaplatfrom; 3) Kunlun–Qilian–Qinling orogenic series; 6) Yunnan–Tibet orogenic series; 7) Yangtze metaplatfrom; 8) South China–Youjiang orogenic belt; 9) Himalayan orogenic belt. “—” represents no statistical significance due to insufficiency of number of analyzed data.

than those of Sino–Korean metaplatfrom, and the contents of South China–Youjiang orogenic belt are clearly lower than that of other orogenic series /zones.

**(2) Siderophile elements:** the contents of Mg, V, Ti, Co, and P are the highest in Kunlun–Qilian–Qinling orogenic series; the contents of Cr, Ca, and Sc are the highest in Yunnan–Tibet orogenic series. As a whole, the contents of these elements in geotectonic units of middle region (Yunnan–Tibet orogenic series and Kunlun–Qilian–Qinling orogenic series) are higher than those in other geotectonic units, and there are no evident differences between South and North China.

**(3) Chalcophile elements:** the changing tendencies of Ag, Cd, Pb, S, Bi, and Sn are identical; the contents of these elements evidently increase from Himalayan orogenic belt→Tianshan–Xing’an orogenic series→Sino–Korean metaplatfrom→Kunlun–Qilian–Qinling orogenic series→Yunnan–Tibet orogenic series→Yangtze metaplatfrom→South China–Youjiang orogenic belt. It is similar to the

changing tendencies of lithophile elements that the contents of these elements in granitoids in South China are higher than those in North China. Meanwhile, the contents of these elements in granitoids in South China–Youjiang orogenic belt are the highest and that in Himalayan orogenic belt are the lowest. Contents of Cu and Au in granitoids in Himalayan orogenic belt and Kunlun–Qilian–Qinling orogenic series are higher, and that in Sino–Korean metaplatfrom are lower. The content of As in granitoids in Tianshan–Xing’an orogenic series, Himalayan orogenic belt and Yunnan–Tibet orogenic series is higher, and that in Sino–Korean metaplatfrom is relatively lower. The content of Zn in granitoids in Yangtze metaplatfrom and South China–Youjiang orogenic belt is higher. Contents of Hg and Se in granitoids in Sino–Korean metaplatfrom and Kunlun–Qilian–Qinling orogenic series are higher than that in other units. The contents of Zn, Hg, and Se in granitoids in Himalayan orogenic belt are lower. The content of Sb in granitoids in Tianshan–Xing’an orogenic series is higher than that in other units.

**Table 2** The total average chemical compositions and element abundances of alkali feldspar granite in six geotectonic units of China

Unit	1	2	3	6	7	8	Unit	1	2	3	6	7	8
$N_c$	30	42	10	3	28	60	Mo	0.56	0.54	0.52	0.33	0.60	0.85
$N_s$	341	397	86	10	231	491	Nb	16.0	20.0	16.0	12.0	21.7	24.0
SiO <sub>2</sub>	75.26	74.49	74.86	76.99	76.34	75.40	Ni	2.7	2.2	1.7	2.2	1.5	4.0
TiO <sub>2</sub>	0.16	0.17	0.12	0.11	0.13	0.15	P	152	169	153	162	118	193
Al <sub>2</sub> O <sub>3</sub>	12.98	13.18	13.50	12.67	12.30	13.13	Pb	22	19	31	51	30	34
Fe <sub>2</sub> O <sub>3</sub>	0.90	0.94	0.65	0.40	0.63	0.68	Rb	161	172	147	259	325	270
FeO	0.46	0.33	0.44	0.87	0.56	0.50	S	80	70	55	59	67	100
MnO	0.03	0.03	0.04	0.04	0.04	0.04	Sb	0.18	0.12	0.08	0.19	0.14	0.09
MgO	0.14	0.17	0.15	0.17	0.13	0.23	Sc	2.6	1.9	3.0	5.3	4.3	4.2
CaO	0.47	0.49	0.51	0.59	0.40	0.40	Se	0.019	0.030	0.035	0.010	0.014	0.019
Na <sub>2</sub> O	3.71	3.67	3.84	2.97	3.15	3.09	Sn	2.3	1.2	1.5	4.0	5.1	6.4
K <sub>2</sub> O	4.64	4.87	4.56	4.78	4.67	4.94	Sr	70	98	58	44	36	45
P <sub>2</sub> O <sub>5</sub>	0.04	0.04	0.04	0.03	0.03	0.04	Ta	1.56	1.32	1.95	2.05	3.33	2.73
H <sub>2</sub> O <sup>+</sup>	0.66	0.73	0.47	0.47	0.67	0.85	Th	16.9	20.1	15.0	21.5	25.7	23.7
CO <sub>2</sub>	0.20	0.12	0.29	0.23	0.25	0.22	Ti	938	944	560	579	778	842
TFe <sub>2</sub> O <sub>3</sub>	1.35	1.58	1.17	1.52	1.38	1.32	Tl	0.70	0.87	0.68	0.91	1.21	1.32
Ag	71	55	58	39	46	62	U	2.74	2.47	2.74	5.89	6.72	6.88
As	1.4	0.7	0.6	2.4	0.8	1.0	V	11	12	8	12	11	13
Au	0.30	0.30	0.30	0.38	0.26	0.22	W	0.79	0.63	0.72	0.96	1.80	1.85
B	2.8	3.8	2.6	4.6	2.3	3.3	Zn	32	27	25	23	37	39
Ba	325	401	428	117	175	154	Zr	161	155	121	94	133	126
Be	4.2	3.2	4.0	6.1	4.8	5.1	La	29	34	27	21	38	35
Bi	0.15	0.10	0.09	0.39	0.42	0.47	Ce	63	61	55	39	71	60
Cd	40	40	50	41	50	72	Pr	—	—	7.00	4.36	5.81	6.35
Cl	47	47	45	41	41	48	Nd	22.1	22.3	24.5	15.4	27.2	24.3
Co	1.2	1.3	0.6	1.8	0.8	1.0	Sm	4.10	3.35	5.70	3.13	6.95	5.30
Cr	2.0	3.4	2.0	1.7	1.9	2.0	Eu	0.40	0.48	0.56	0.35	0.36	0.45
Cs	2.9	1.8	1.6	11.4	7.0	6.8	Gd	5.6	5.8	5.4	3.0	8.6	6.1
Cu	4.3	3.3	3.3	2.9	2.8	4.9	Tb	0.59	0.50	0.58	0.62	1.22	0.91
F	195	362	368	287	621	500	Dy	—	—	7.5	3.8	6.5	6.2
Ga	18	18	19	16	18	18	Ho	—	—	1.55	0.82	1.36	1.33
Ge	1.38	1.20	1.60	1.83	1.80	1.40	Er	—	—	4.44	2.47	3.78	3.87
Hf	5.4	5.1	5.6	3.8	5.5	4.6	Tm	—	—	0.83	0.49	0.68	0.68
Hg	6.0	7.0	6.0	3.9	4.7	5.0	Yb	2.90	1.63	2.55	2.92	6.10	4.00
Li	11	7	6	14	22	26	Lu	0.45	0.31	0.39	0.46	0.82	0.61
Mn	257	225	273	296	289	310	Y	23.0	22.0	21.0	19.3	41.0	34.0

$N_c$ : number of analyzed composited samples;  $N_s$ : number of collected samples. Content units:  $10^{-9}$  for Au, Ag, Cd, Hg;  $10^{-2}$  for major elements;  $10^{-6}$  for others. Unit: 1) Tianshan–Xing’an orogenic series; 2) Sino–Korean metaplatfom; 3) Kunlun–Qilian–Qinling orogenic series; 6) Yunnan–Tibet orogenic series; 7) Yangtze metaplatfom; 8) South China–Youjiang orogenic belt. “—” represents no statistical significance due to insufficiency of number of analyzed data.

**(4) Rare earth elements (REE):** Light rare earth elements (LREE) contents are evidently enriched in the granitoids of Yangtze metaplatfom and South China–Youjiang orogenic belt, but they are lower in the granitoids of Himalayan orogenic belt and Tianshan–Xing’an orogenic series. As to the heavy rare earth elements (HREE), they show enrichment in the granitoids of Yangtze metaplatfom and South China–Youjiang orogenic belt. The contents of Dy, Ho, Er and Tm in the granitoids of Sino–Korean metaplatfom are much higher. One of the obvious features of REE contents is that REE contents in the granitoids of Himalayan orogenic belt are the lowest.

Therefore, element abundances of the granitoids in different geotectonic units are very different. Different geotectonic units have different features of element abundances. It shows that element abundance of granitoids has some regional features. This is because genesis, source, and magmatic activity of granitoids in different geotectonic units are different.

### 3.1.3 Element abundances of different rock types of granitoids in different geotectonic units

**Alkali feldspar granite:** it can be seen in Table 2 that the contents of siderophile elements in granitoids are a little higher in Tianshan–Xing’an orogenic series and Sino–Korean metaplatfom (Fig. 1), while the contents of Mn and Sc are higher in Yunnan–Tibet orogenic series, Yangtze metaplatfom and South China–Youjiang orogenic belt. Contents of lithophile elements of Li, Be, Si, Rb, Nb, Cs, Ta, W, Mo, Th, U and value of K/Na in Yunnan–Tibet orogenic series, Yangtze metaplatfom and South China–Youjiang orogenic belt are obviously higher than that in Tianshan–Xing’an orogenic series, Sino–Korean metaplatfom and Kunlun–Qilian–Qinling orogenic series. However, Sr and Ba contents in Tianshan–Xing’an orogenic series, Sino–Korean metaplatfom, and Kunlun–Qilian–Qinling orogenic series are higher than that in Yunnan–Tibet orogenic series, Yangtze metaplatfom, and South China–Youjiang orogenic belt.

**Table 3** The total average chemical compositions and element abundances of syenogranite in seven geotectonic units of China

Unit	1	2	3	6	7	8	9	Unit	1	2	3	6	7	8	9
$N_c$	67	129	52	36	40	101	5	Mo	0.47	0.36	0.52	0.37	0.46	0.84	0.37
$N_s$	539	1 237	386	227	287	664	8	Nb	11.6	12.0	15.0	12.8	14.0	15.8	10.3
SiO <sub>2</sub>	73.17	71.91	71.21	73.33	71.94	72.10	75.04	Ni	3.5	4.2	4.5	3.0	4.3	6.1	2.6
TiO <sub>2</sub>	0.23	0.25	0.30	0.22	0.35	0.32	0.20	P	306	362	460	349	576	475	230
Al <sub>2</sub> O <sub>3</sub>	14.03	14.47	14.62	13.92	14.12	13.74	13.82	Pb	22	26	28	31	27	31	25
Fe <sub>2</sub> O <sub>3</sub>	0.88	1.02	0.76	0.43	0.86	0.80	0.52	Rb	141	132	164	185	199	219	291
FeO	0.86	0.88	1.26	1.21	1.41	1.50	0.83	S	64	70	70	59	83	134	68
MnO	0.04	0.04	0.05	0.04	0.05	0.05	0.04	Sb	0.14	0.11	0.13	0.10	0.13	0.13	0.07
MgO	0.36	0.49	0.61	0.38	0.69	0.66	0.27	Sc	4.5	2.9	5.3	5.5	5.9	6.7	5.5
CaO	1.28	1.43	1.60	1.34	1.49	1.46	1.04	Se	0.019	0.030	0.029	0.006	0.012	0.020	0.004
Na <sub>2</sub> O	3.87	3.90	3.71	3.25	3.01	2.91	3.48	Sn	1.6	1.2	3.0	3.9	4.5	5.3	2.8
K <sub>2</sub> O	4.22	4.20	4.35	4.49	4.33	4.57	4.88	Sr	162	363	248	131	136	138	87
P <sub>2</sub> O <sub>5</sub>	0.07	0.08	0.10	0.07	0.12	0.10	0.05	Ta	1.11	0.85	1.51	1.57	1.71	1.73	1.36
H <sub>2</sub> O <sup>+</sup>	0.60	0.79	0.79	0.45	0.92	0.82	0.33	Th	13.5	14.1	17.9	18.7	22.9	22.5	30.4
CO <sub>2</sub>	0.26	0.17	0.37	0.25	0.20	0.17	0.10	Ti	1 277	1 351	1 670	1 288	1 979	1 782	1 094
TFe <sub>2</sub> O <sub>3</sub>	1.77	1.91	2.18	1.91	2.69	2.51	1.47	Tl	0.77	0.79	0.86	0.93	1.01	1.30	1.21
Ag	50	48	43	41	54	56	27	U	2.21	1.96	3.06	2.96	4.43	5.16	5.32
As	1.2	0.6	1.0	1.0	1.0	1.2	1.0	V	19	20	23	20	35	28	14
Au	0.40	0.30	0.48	0.34	0.31	0.40	0.42	W	0.52	0.26	0.88	0.75	1.32	1.55	1.57
B	4.0	2.9	4.6	4.6	6.6	4.3	8.4	Zn	33	39	43	40	47	47	22
Ba	512	1040	744	514	526	505	415	Zr	132	150	160	133	159	158	150
Be	2.5	2.4	2.7	3.0	3.4	3.6	4.0	La	26	36	37	30	38	42	33
Bi	0.10	0.10	0.19	0.19	0.21	0.30	0.12	Ce	51	70	70	54	72	78	61
Cd	60	40	68	45	53	80	30	Pr	5.74	—	7.06	6.60	8.04	9.45	7.71
Cl	52	37	62	79	72	77	76	Nd	20.9	26.5	28.2	22.8	28.9	33.4	27.1
Co	2.1	2.9	3.4	2.4	4.1	3.6	1.5	Sm	3.90	3.90	5.26	4.02	5.62	6.92	4.93
Cr	3.1	5.0	5.7	4.5	7.0	7.6	1.8	Eu	0.59	0.82	0.92	0.72	0.98	0.90	0.70
Cs	3.0	2.2	5.1	7.7	6.9	7.9	8.3	Gd	4.8	4.0	4.6	3.3	5.2	6.0	4.2
Cu	4.0	5.0	6.3	3.7	6.0	6.3	4.4	Tb	0.53	0.40	0.69	0.61	0.93	0.97	0.73
F	283	379	529	430	615	680	328	Dy	4.3	—	3.6	3.4	5.0	5.2	3.8
Ga	18	18	19	18	18	18	15	Ho	0.89	—	0.64	0.67	1.01	1.04	0.77
Ge	1.30	1.10	1.30	1.45	1.45	1.42	1.58	Er	2.61	—	1.93	1.77	2.70	2.76	2.16
Hf	4.4	4.5	5.0	4.6	6.2	5.3	5.7	Tm	0.44	—	0.30	0.31	0.46	0.46	0.41
Hg	5.0	5.0	6.5	4.6	4.4	5.0	4.2	Yb	2.39	1.07	1.87	1.92	2.60	2.86	2.41
Li	16	15	27	42	26	33	32	Lu	0.34	0.17	0.31	0.30	0.39	0.47	0.37
Mn	329	297	357	329	387	413	274	Y	19.1	15.0	19.0	18.4	26.0	29.3	22.3

$N_c$ : number of analyzed composited samples;  $N_s$ : number of collected samples. Content units:  $10^{-9}$  for Au, Ag, Cd, Hg;  $10^{-2}$  for major elements;  $10^{-6}$  for others. Unit: 1) Tianshan–Xing’an orogenic series; 2) Sino–Korean metaplatfom; 3) Kunlun–Qilian–Qinling orogenic series; 6) Yunnan–Tibet orogenic series; 7) Yangtze metaplatfom; 8) South China–Youjiang orogenic belt; 9) Himalayan orogenic belt. “—” represents no statistical significance due to insufficiency of number of analyzed data.

Contents of chalcophile elements of Pb, Bi, Sn and Ge in Yunnan–Tibet orogenic series, Yangtze metaplatfom and South China–Youjiang orogenic belt are obviously higher than that in Tianshan–Xing’an orogenic series, Sino–Korean metaplatfom and Kunlun–Qilian–Qinling orogenic series, while the changing of other elements’ content is not clear. HREE and LREE of La, Nd and Sm in Yangtze metaplatfom and South China–Youjiang orogenic belt are higher than that in other units.

**Syenogranite:** from Table 3, it is found out that, for lithophile elements, content of Ba in granitoids is relatively higher in Tianshan–Xing’an orogenic series, Sino–Korean metaplatfom, and Kunlun–Qilian–Qinling orogenic series. Contents of Li, Be, B, Nb, Cs, Hf, Ta, W, Mo, Th, U, and values of K/Na and Rb/Sr are relatively higher in Yangtze metaplatfom, South China–Youjiang orogenic belt, and Himalayan orogenic belt (Fig. 2). Contents of siderophile elements appear to increase from Himalayan orogenic belt, Tianshan–Xing’an orogenic series, Yunnan–Tibet orogenic series, Sino–Korean

metaplatfom, Kunlun–Qilian–Qinling orogenic series, Yangtze metaplatfom to South China–Youjiang orogenic belt (Fig. 2). They are the highest in South China–Youjiang orogenic belt and the lowest in Himalayan orogenic belt. Contents of chalcophile elements of Ge, Pb, Bi, and Sn are higher in Yunnan–Tibet orogenic series, Yangtze metaplatfom, South China–Youjiang orogenic belt and Himalayan orogenic belt, and the changing of other elements’ content is not clear. REE in Yangtze metaplatfom and South China–Youjiang orogenic belt are higher than that in other units.

**Adamellite:** from Table 4, it is found out that, for lithophile elements, contents of Li, Nb, Cs, Hf, Ta, Mo, Th, U, and values of K/Na and Rb/Sr in granitoids are relatively higher in Yangtze metaplatfom and South China–Youjiang orogenic belt. Contents of siderophile elements appear to increase from Himalayan orogenic belt, Tianshan–Xing’an orogenic series, Yunnan–Tibet orogenic series, Sino–Korean metaplatfom, Kunlun–Qilian–Qinling orogenic series,

**Table 4** The total average chemical compositions and element abundances of adamellite in seven geotectonic units of China

Unit	1	2	3	6	7	8	9	Unit	1	2	3	6	7	8	9
$N_c$	35	25	29	21	20	9	5	Mo	0.36	0.31	0.37	0.39	0.46	0.94	0.34
$N_s$	312	249	218	93	122	39	7	Nb	8.0	9.0	10.0	10.6	11.0	14.0	7.2
SiO <sub>2</sub>	68.55	66.82	66.89	67.20	67.51	65.58	71.50	Ni	7.0	10.4	7.2	7.5	6.3	10.5	2.4
TiO <sub>2</sub>	0.41	0.48	0.47	0.50	0.53	0.60	0.32	P	546	748	542	622	701	675	393
Al <sub>2</sub> O <sub>3</sub>	15.59	15.39	15.84	15.90	15.45	15.36	15.16	Pb	16	18	25	19	22	22	11
Fe <sub>2</sub> O <sub>3</sub>	1.03	1.40	1.00	0.92	1.38	2.02	0.81	Rb	85	88	101	115	111	170	59
FeO	1.62	1.53	2.30	2.62	2.25	2.52	1.42	S	70	80	92	59	85	130	51
MnO	0.07	0.06	0.06	0.07	0.07	0.09	0.07	Sb	0.16	0.13	0.14	0.10	0.09	0.14	0.18
MgO	1.07	1.33	1.67	1.50	1.54	1.88	0.69	Sc	7.4	5.7	9.0	10.3	9.2	10.8	7.0
CaO	2.82	2.95	3.27	3.92	2.96	3.89	2.86	Se	0.020	0.027	0.016	0.006	0.022	0.030	0.012
Na <sub>2</sub> O	4.02	4.32	3.41	3.08	3.40	3.11	3.84	Sn	1.4	1.2	1.8	1.8	2.7	2.0	0.5
K <sub>2</sub> O	2.69	3.05	2.76	2.99	3.09	3.60	2.43	Sr	309	532	312	318	277	345	300
P <sub>2</sub> O <sub>5</sub>	0.12	0.17	0.12	0.12	0.15	0.15	0.08	Ta	0.60	0.58	0.97	1.16	0.96	1.10	0.61
H <sub>2</sub> O <sup>+</sup>	0.86	1.01	1.04	0.77	1.06	0.87	0.49	Th	9.0	8.3	10.1	11.3	12.8	18.7	7.6
CO <sub>2</sub>	0.30	0.18	0.38	0.22	0.20	0.22	0.30	Ti	2 395	2 584	2 739	3 027	2 980	3 356	1 871
TFe <sub>2</sub> O <sub>3</sub>	3.15	3.55	3.67	4.11	3.84	4.55	2.38	Tl	0.49	0.56	0.60	0.49	0.55	0.89	0.32
Ag	41	56	52	53	52	55	44	U	1.72	1.66	1.46	2.27	2.24	3.69	1.07
As	1.5	0.7	1.2	1.1	0.8	1.0	2.2	V	44	47	54	67	57	70	34
Au	0.40	0.30	0.42	0.43	0.21	0.40	0.62	W	0.31	0.26	0.35	0.57	0.62	0.50	0.32
B	5.2	3.3	6.5	5.8	4.9	2.7	11.2	Zn	50	55	53	50	52	59	38
Ba	527	1 002	670	496	579	669	500	Zr	148	151	154	128	157	158	105
Be	1.8	1.1	1.6	1.8	1.7	1.0	1.0	La	23	33	32	30	41	37	19
Bi	0.10	0.10	0.09	0.06	0.16	0.20	0.04	Ce	46	60	59	53	78	70	33
Cd	60	40	60	41	50	70	30	Pr	5.68	—	6.89	6.15	10.00	8.08	3.64
Cl	78	49	99	198	87	148	127	Nd	19.3	24.5	24.0	22.6	28.4	30.9	13.2
Co	6.7	7.3	9.1	8.8	8.3	12.3	3.8	Sm	3.60	3.80	4.35	4.33	5.40	6.10	2.61
Cr	13.8	11.0	23.2	24.7	17.8	15.6	6.8	Eu	0.96	1.01	1.03	0.96	1.17	0.98	0.71
Cs	3.5	2.5	4.1	4.4	4.7	5.8	3.6	Gd	3.4	3.7	3.6	3.8	4.6	5.4	2.5
Cu	7.9	7.3	7.5	8.0	10.3	10.5	8.2	Tb	0.54	0.46	0.54	0.68	0.72	0.80	0.44
F	349	446	496	450	538	678	209	Dy	2.9	—	3.5	3.7	4.5	5.8	2.5
Ga	17	20	19	17	18	18	15	Ho	0.51	—	0.69	0.75	0.80	1.22	0.52
Ge	1.17	1.00	1.15	1.27	1.39	1.20	1.34	Er	1.52	—	2.10	2.12	2.12	3.12	1.53
Hf	5.0	4.4	5.2	5.4	5.0	5.6	5.0	Tm	0.26	—	0.37	0.38	0.36	0.53	0.28
Hg	5.1	6.5	6.0	4.2	5.0	4.6	3.9	Yb	1.89	1.05	1.70	2.34	1.67	2.21	1.70
Li	21	14	25	27	30	30	16	Lu	0.31	0.17	0.29	0.37	0.25	0.38	0.28
Mn	539	462	491	557	492	674	553	Y	17.0	13.0	16.3	20.0	18.0	25.0	16.2

$N_c$ : number of analyzed composited samples;  $N_s$ : number of collected samples. Content units: 10<sup>-9</sup> for Au, Ag, Cd, Hg; 10<sup>-2</sup> for major elements; 10<sup>-6</sup> for others. Unit: 1) Tianshan–Xing’an orogenic series; 2) Sino–Korean metaplatform; 3) Kunlun–Qilian–Qinling orogenic series; 6) Yunnan–Tibet orogenic series; 7) Yangtze metaplatform; 8) South China–Youjiang orogenic belt, 9) Himalayan orogenic belt. “—” represents no statistical significance due to insufficiency of number of analyzed data.

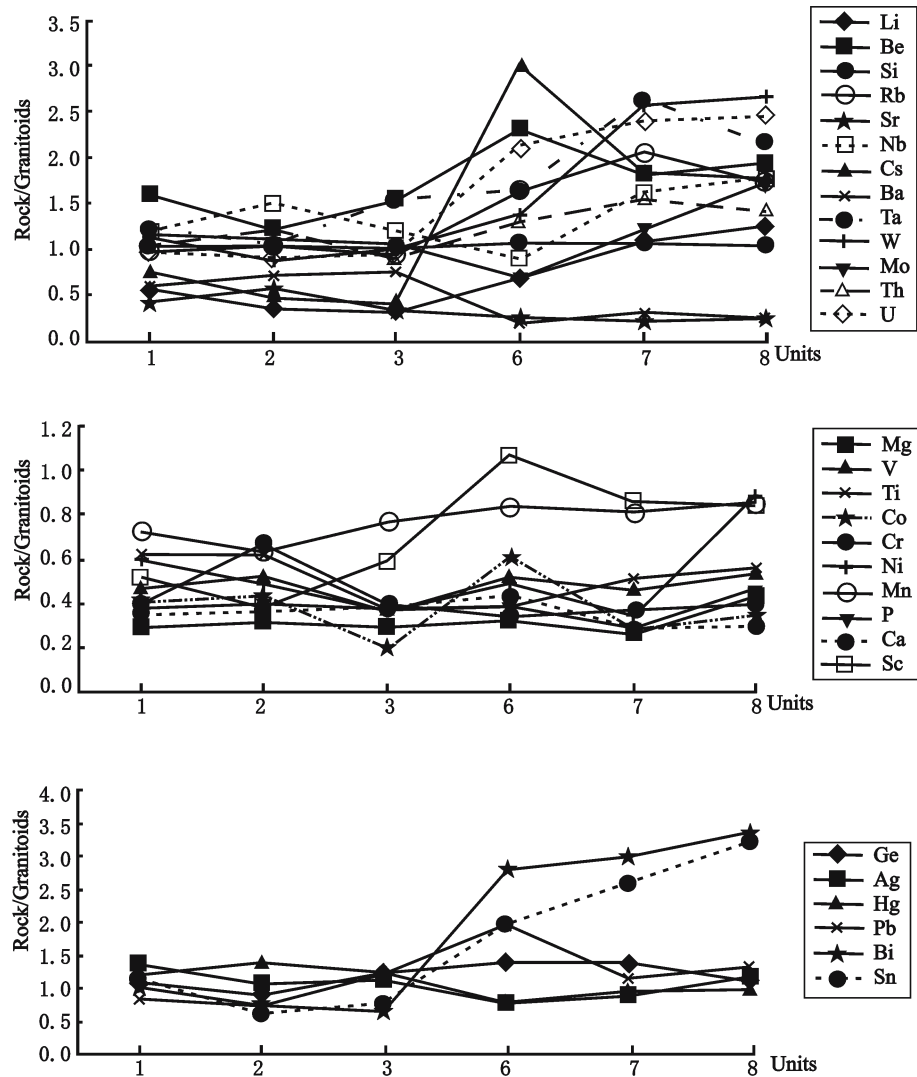
**Table 5** Enrichment degree of major elements for granitoids in seven geotectonic units of China and the regional distribution types

Geotectonic unit	1	2	3	6	7	8	9
SiO <sub>2</sub>	<b>1.01</b>	1.00	0.98	0.98	<b>1.00</b>	<b>1.02</b>	<b>1.02</b>
Al <sub>2</sub> O <sub>3</sub>	0.99	<b>1.01</b>	<b>1.05</b>	<b>1.03</b>	0.99	0.96	<b>1.01</b>
Fe <sub>2</sub> O <sub>3</sub>	<b>1.02</b>	<b>1.17</b>	0.97	0.74	0.94	0.88	0.85
FeO	0.85	0.77	<b>1.41</b>	<b>1.48</b>	<b>1.15</b>	<b>1.10</b>	0.90
MgO	0.89	0.85	<b>1.52</b>	<b>1.42</b>	<b>1.08</b>	0.89	0.79
CaO	0.98	0.97	<b>1.39</b>	<b>1.54</b>	0.99	0.73	<b>1.50</b>
Na <sub>2</sub> O	<b>1.09</b>	<b>1.10</b>	<b>1.03</b>	0.90	0.89	0.85	<b>1.00</b>
K <sub>2</sub> O	0.95	0.99	0.91	0.94	1.00	<b>1.09</b>	0.96
P <sub>2</sub> O <sub>5</sub>	0.78	0.89	1.22	1.11	1.11	1.00	0.67
H <sub>2</sub> O <sup>+</sup>	0.84	1.04	1.12	0.70	1.13	1.09	0.47
CO <sub>2</sub>	1.13	0.70	1.61	1.00	1.00	0.87	0.57
Regional distribution type	Si-Fe-Na	Al-Fe-Na	Al-Fe-Mg-Ca-Na	Al-Fe-Mg-Ca	Si-Fe-Mg	Si-Fe-K	Si-Al-Ca-Na

Note: 1) Tianshan–Xing’an orogenic series; 2) Sino–Korean metaplatform; 3) Kunlun–Qilian–Qinling orogenic series; 6) Yunnan–Tibet orogenic series; 7) Yangtze metaplatform; 8) South China–Youjiang orogenic belt; 9) Himalayan orogenic belt.

Yangtze metaplatform to South China–Youjiang orogenic belt (Fig. 3). They are the highest in South China–Youjiang orogenic belt and the lowest in Himalayan orogenic belt.

Contents of chalcophile elements of Cu, Zn, Se, Cd, Ag, Pb, and Bi are higher in South China–Youjiang orogenic belt, and the changing of other element contents is not clear. Most of



**Fig. 1** Element content change in alkalfeldspar granite of different geotectonic units

1) Tianshan–Xing’an orogenic series; 2) Sino–Korean metaplatfrom; 3) Kunlun–Qilian–Qinling orogenic series; 6) Yunnan–Tibet orogenic series; 7) Yangtze metaplatfrom; 8) South China–Youjiang orogenic belt. The abundance data of granitoids come from Shi et al. (2005b)

the REE in South China–Youjiang orogenic belt are higher than that in other units. Thereunto, LREE and HREE of Gd, Tb, Dy, Ho and Er are also higher in Yangtze metaplatfrom.

Overall, it is considered that element abundances in alkalfeldspar granite, syenogranite, and adamellite are evidently different among different geotectonic units. Different rock types of granitoids in different geotectonic units have different features of element abundances. It sufficiently reflects that the chemical components of regional granitoids are inhomogeneous.

### 3.2 The characters of petrochemistry and element ratios

#### 3.2.1 Characters in different geotectonic units

It can be found from Table 6 that the petrochemical parameters and element ratios of granitoids in different geotectonic units are different.

**Tianshan–Xing’an orogenic series:** the feature is that  $K'$  and  $K/Na$  are the smallest values and  $Na'$ ,  $K/Rb$  and  $Ti/V$  are the biggest values among all units.

**Sino–Korean metaplatfrom:** the feature is that  $\sigma$ ,  $Fe'$ ,  $K + Na$  and  $Nb/Ta$  are the biggest values and  $Mg^\#$  and  $Rb/Sr$  serve as the smallest values among all units.

**Kunlun–Qilian–Qinling orogenic series:**  $Fe'$  is the smallest value and  $Mg^\#$  is the biggest value among all units.

**Yunnan–Tibet orogenic series:** the feature is that  $\sigma, f$  and  $K + Na$  act as the smallest values among all units. It shows that the alkalinity is low. Differentiation coefficient (DC) is the smallest value among all units and it indicates that the differentiation degree is low.

**Yangtze metaplatfrom:** the feature is that  $Ti/V$  is the smallest value among all units.

**South China–Youjiang orogenic belt:** the feature is that  $f$ ,  $K'$ ,  $K/Na$ ,  $Rb/Sr$ , DC and  $A/CNK$  ( $A/CNK$  means  $Al_2O_3/CaO + Na_2O + K_2O$  ratio) are the biggest, but  $Na'$ ,  $C/ACF$

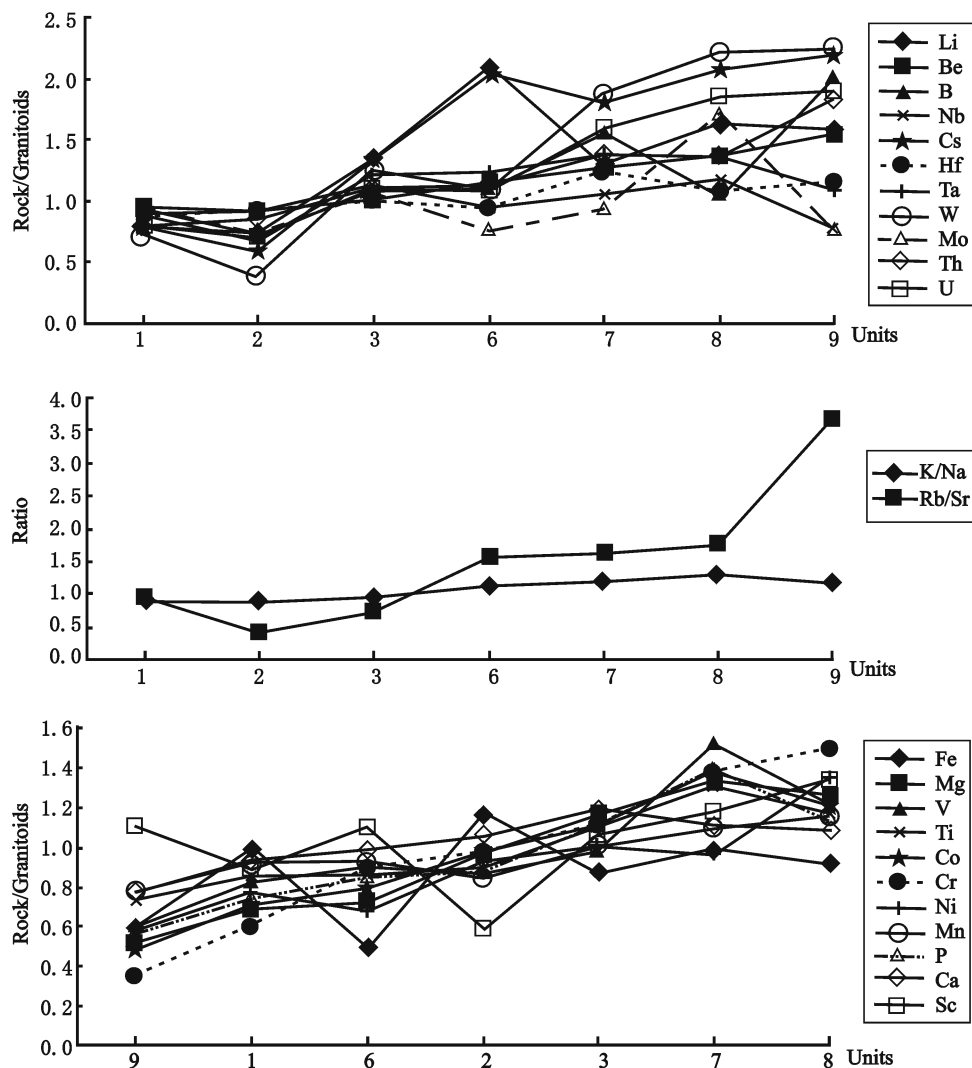


Fig. 2 Element content change in syenogranite of different geotectonic units

1) Tianshan–Xing’an orogenic series; 2) Sino–Korean metaplateau; 3) Kunlun–Qilian–Qinling orogenic series; 6) Yunnan–Tibet orogenic series; 7) Yangtze metaplateau; 8) South China–Youjiang orogenic belt; 9) Himalayan orogenic belt. The abundance data of granitoids come from Shi et al. (2005b)

( $C/ACF$  means  $CaO/(Al_2O_3 + CaO + FeO + Fe_2O_3)$  ratio),  $K/Rb$ ,  $Sr/Ba$  and  $\delta Eu$  are the smallest values among all units. It indicates that the differentiation degree is the highest.

**Himalayan orogenic belt:** the feature is that  $A/CNK$  and  $Nb/Ta$  serve as the smallest values and  $C/ACF$ ,  $Sr/Ba$  and  $\delta Eu$  act as the biggest values among all units.

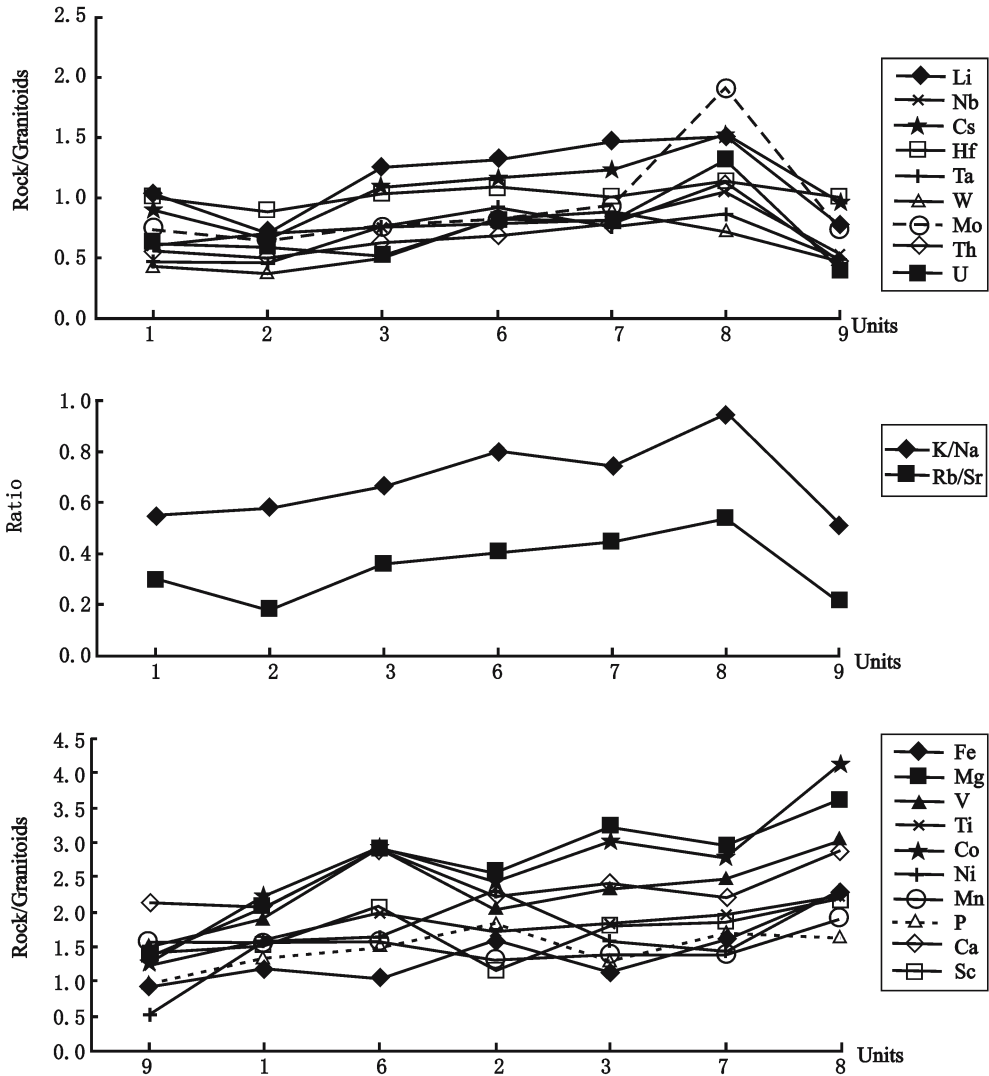
### 3.2.2 Regional distribution features

It can be also found from Table 6 that the petrochemistry and element ratios of granitoids present some regional distribution features.

The  $\sigma$  values of every geotectonic unit are smaller than 3.3, and thus they belong to calc-alkali series. However, there are still some differences among them. Using Yangtze River as a boundary, the  $\sigma$  values of Tianshan–Xing’an orogenic series, Sino–Korean metaplateau, and Kunlun–Qilian–Qinling

orogenic series in the north are bigger than 2, but the  $\sigma$  values of Yunnan–Tibet orogenic series, Yangtze metaplateau, South China–Youjiang orogenic belt, and Himalayan orogenic belt in the south are smaller than 2. Among them, the  $\sigma$  value of Sino–Korean metaplateau is the biggest, and Yunnan–Tibet orogenic series is the smallest.

According to the  $f$  values, they can be divided into two groups: the first group includes Yunnan–Tibet orogenic series and Himalayan orogenic belt, whose  $f$  values are smaller than 80; the second group includes Tianshan–Xing’an orogenic series, Sino–Korean metaplateau, Kunlun–Qilian–Qinling orogenic series, Yangtze metaplateau, and South China–Youjiang orogenic belt, whose  $f$  values are bigger than 80. Among them, the  $f$  value of South China–Youjiang orogenic belt is the biggest, but the  $f$  value of Yunnan–Tibet orogenic series is the smallest.



**Fig. 3** Element content change in adamellite of different geotectonic units  
 1) Tianshan–Xing’an orogenic series; 2) Sino–Korean metaplatteform; 3) Kunlun–Qilian–Qinling orogenic series; 6) Yunnan–Tibet orogenic series; 7) Yangtze metaplatteform; 8) South China–Youjiang orogenic belt; 9) Himalayan orogenic belt. The abundance data of granitoids come from Shi et al. (2005b)

The values of K/Na gradually increase by degree in sequence of Tianshan–Xing’an orogenic series, Kunlun–Qilian–Qinling orogenic series, Sino–Korean metaplatteform, Himalayan orogenic belt, Yunnan–Tibet orogenic series, Yangtze metaplatteform, and South China–Youjiang orogenic belt. In opposition to the distribution tendency of  $\sigma$ , the K/Na values of Tianshan–Xing’an orogenic series, Sino–Korean metaplatteform and Kunlun–Qilian–Qinling orogenic series in the north are smaller than 1.1; but the K/Na values of Yunnan–Tibet orogenic series, Yangtze metaplatteform, South China–Youjiang orogenic belt, and Himalayan orogenic belt in the south are bigger than 1.1. Among them, the K/Na value of South China–Youjiang orogenic belt is the biggest, and that of Tianshan–Xing’an orogenic series is the smallest.

For Sino–Korean metaplatteform, South China–Youjiang orogenic belt and Himalayan orogenic belt, the  $Fe'$  values are relatively big, bigger than 80; but the  $Mg^{\#}$  values are

relatively small, smaller than 20. For Kunlun–Qilian–Qinling orogenic series and Yunnan–Tibet orogenic series, the  $Fe'$  values are smaller than 75, which are the smallest; but the  $Mg^{\#}$  values are bigger than 25, which are the biggest. For Tianshan–Xing’an orogenic series and Yangtze metaplatteform, their  $Fe'$  and  $Mg^{\#}$  values are in the middle.

The A/CNK values of Yangtze metaplatteform and South China–Youjiang orogenic belt are bigger than 1.1; others are close to or smaller than 1.1. Obviously, it shows that the aluminium of the granitoids in Yangtze metaplatteform and South China–Youjiang orogenic belt is more abundant than that in other units. However, the aluminium in Himalayan orogenic belt is poor.

For the C/ACF values, they are bigger than 0.18 in Yunnan–Tibet orogenic series and Himalayan orogenic belt and are the biggest. They are comparatively smaller in Yangtze metaplatteform, South China–Youjiang orogenic belt and

**Table 6** Petrochemical parameters and some element ratios for granitoids of different geotectonic units in China

Geotectonic Units	1	2	3	6	7	8	9
Rittmann index ( $\sigma$ )	2.13	<b>2.29</b>	2.10	<b>1.88</b>	1.89	1.96	1.94
Felsic index ( $f$ )	85.73	86.17	80.22	<b>77.70</b>	84.74	<b>88.75</b>	79.24
Kali index ( $K'$ )	<b>51.45</b>	52.24	51.93	56.01	57.69	<b>61.08</b>	53.97
Agpaitic index ( $Na'$ )	<b>48.55</b>	47.77	48.07	43.99	42.32	<b>38.92</b>	46.03
Ferruginous index ( $Fe'$ )	79.58	<b>80.70</b>	<b>74.71</b>	74.83	78.48	80.70	80.52
Magnesian index ( $Mg^{\#}$ )	20.42	<b>19.30</b>	<b>25.29</b>	25.17	21.52	19.30	19.48
K/Na	<b>1.06</b>	1.09	1.08	1.27	1.36	<b>1.57</b>	1.17
K + Na	7.95	<b>8.17</b>	7.58	<b>7.24</b>	7.46	7.70	7.70
A/CNK	1.1	1.1	1.1	1.1	1.2	<b>1.2</b>	<b>1.0</b>
C/ACF	0.13	0.13	0.16	0.18	0.13	<b>0.10</b>	<b>0.19</b>
Rb/Sr	0.108	<b>0.074</b>	0.108	0.105	0.230	<b>0.330</b>	0.084
K/Rb	<b>135.8</b>	135.7	111.6	107.0	90.7	<b>82.3</b>	98.9
Sr/Ba	0.389	0.340	0.362	0.432	0.308	<b>0.230</b>	<b>0.461</b>
Nb/Ta	12.01	<b>14.44</b>	11.20	8.91	8.88	9.24	<b>7.83</b>
Ti/V	<b>69.45</b>	68.42	62.27	61.44	<b>58.81</b>	68.05	64.77
DC	1 345	1 202	1 192	<b>1 099</b>	9 307	<b>35 935</b>	1 391
$\delta Eu$	0.583	0.687	0.664	0.69	0.564	<b>0.436</b>	<b>0.746</b>

Note:  $\sigma = (K_2O + Na_2O)/(SiO_2 - 43)$ ;  $f = 100 * (Na_2O + K_2O)/(Na_2O + K_2O + CaO)$ ;  $K' = 100 * K_2O/(Na_2O + K_2O)$ ;  $Na' = 100 * Na_2O/(Na_2O + K_2O)$ ;  $Fe' = 100 * (FeO + Fe_2O_3)/(MgO + FeO + Fe_2O_3)$ ;  $Mg^{\#} = 100 * MgO/(MgO + FeO + Fe_2O_3)$ ;  $\delta Eu = 2Eu_N/(Sm_N + Gd_N)$ ;  $A/CNK = Al_2O_3/(CaO + Na_2O + K_2O)$ ;  $C/ACF = CaO/(Al_2O_3 + CaO + FeO + Fe_2O_3)$ ;  $DC = (Be \times W \times Rb \times Nb \times La \times Th)/(Cr \times V \times Cu)$ . A/CNK and C/ACF are calculated by molecule percentage, others by percentage. Chondrite data of Herrman (1970) are cited from reference Zhao and Zhang (1987). 1) Tianshan–Xing'an orogenic series; 2) Sino–Korean metaplatteform; 3) Kunlun–Qilian–Qinling orogenic series; 6) Yunnan–Tibet orogenic series; 7) Yangtze metaplatteform; 8) South China–Youjiang orogenic belt; 9) Himalayan orogenic belt.

Sino–Korean metaplatteform; it is the smallest in South China–Youjiang orogenic belt.

The ratio values of Rb/Sr of Yangtze metaplatteform and South China–Youjiang orogenic belt are clearly bigger than that of other units, and they are the smallest in Sino–Korean metaplatteform. K/Rb values are evidently bigger in Tianshan–Xing'an orogenic series and Sino–Korean metaplatteform, and are obviously on the low side in Yangtze metaplatteform and South China–Youjiang orogenic belt. Sr/Ba values are on the high side in Yunnan–Tibet orogenic series and Himalayan orogenic belt, but are evidently smaller in Yangtze metaplatteform and South China–Youjiang orogenic belt.

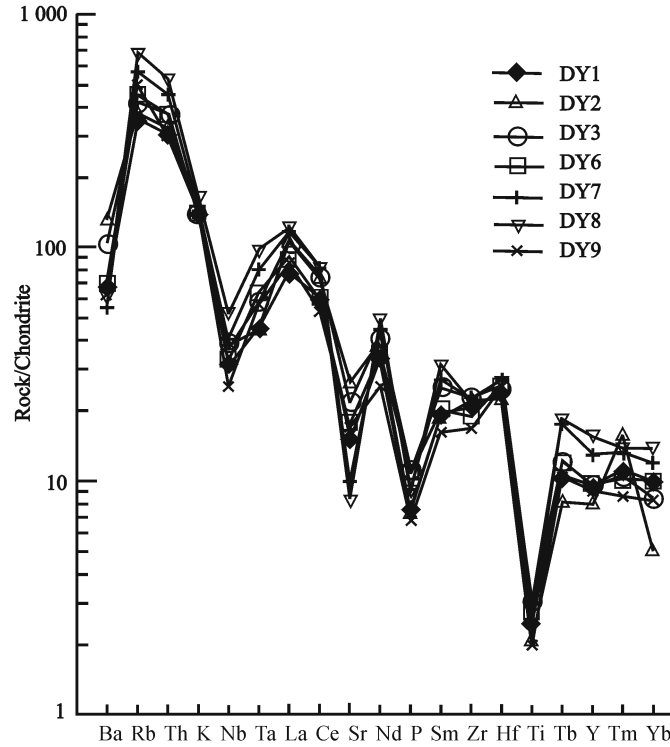
The DC values of differentiation coefficient in Yangtze metaplatteform and South China–Youjiang orogenic belt are outstandingly bigger than that in others and are the smallest in Yunnan–Tibet orogenic series. However, the  $\delta Eu$  values present opposite features. They are on the low side in Yangtze metaplatteform and South China–Youjiang orogenic belt, but are obviously bigger in Yunnan–Tibet orogenic series and Himalayan orogenic belt. That means they are the smallest in South China–Youjiang orogenic belt and the biggest in Himalayan orogenic belt.

In a word, among all the units, the granitoid in Yunnan–Tibet orogenic series is poor in alkali and rich in calcium; the granitoids in Himalayan orogenic belt is poor in aluminium and rich in calcium. The differentiation degree of the magma in these two units is lower. On the other hand, the granitoid in Yangtze metaplatteform and South China–Youjiang orogenic belt is rich in aluminium and poor in calcium, and the differentiation degree of the magma in these two units is higher.

### 3.3 The characteristics of trace elements

In China's granitoids, the strong incompatibility elements are greatly concentrated and the content level of compatibility elements is lower. The character of the spider diagram of trace elements is that it possesses the clear positive anomalies of Rb and Th and the negative anomalies of Nb, Sr, P, and Ti (Shi et al., 2005b).

The spider diagram of trace elements normalized by chondrite in granitoids of different geotectonic units (Fig. 4) shows a similar distribution pattern to the spider diagram of China's granitoids (Shi et al., 2005b). It reveals that the content level of trace elements in different units is different. The most distinct feature is that, except for Ba, Sr, P, and Ti, the contents of other elements are evidently on the high side in Yangtze metaplatteform and South China–Youjiang orogenic belt. They have very strong positive anomalies of Rb and Th and negative anomalies of Sr, P, and Ti. It shows obvious difference from other units. For Tianshan–Xing'an orogenic series, there are positive anomalies of Rb and Th and the lower negative anomalies of Nb, Sr, P, and Ti. Compared with other units, the positive anomalies of Rb and Th are the lowest. Positive anomalies of Rb and Th, negative anomaly of Nb and lower negative anomalies of P and Ti appear in Sino–Korean metaplatteform. Contents of most elements are on the lower side, and positive anomalies of Rb and Th are slightly higher than that of Tianshan–Xing'an orogenic series. Positive anomalies of Rb and Th and negative anomalies of Nb, P, and Ti appear in Kunlun–Qilian–Qinling orogenic series, and positive anomalies of Rb and Th are slightly higher than that of Sino–Korean metaplatteform. Positive anomalies of Rb



**Fig. 4** Chondrite-normalized spider diagram of trace elements for granitoids of different geotectonic units in China (chondrite data of Herrman (1970) are cited from reference Zhao and Zhang (1987))

DY1: Tianshan–Xing’an orogenic series; DY2: Sino–Korean metaplatform; DY3: Kunlun–Qilian–Qinling orogenic series; DY6: Yunnan–Tibet orogenic series; DY7: Yangtze metaplatform; DY8: South China–Youjiang orogenic belt; DY9: Himalayan orogenic belt.

and Th and negative anomalies of Nb, Sr, P, and Ti appear in Yunnan–Tibet orogenic series, and positive anomalies of Rb and Th are slightly higher than that of Kunlun–Qilian–Qinling orogenic series. For Himalayan orogenic belt, there are positive anomalies of Rb and Th and negative anomalies of Nb, Sr, P, and Ti. The negative anomalies of Nb, P, and Ti are the lowest and the positive anomalies of Rb and Th are slightly higher than that of Yunnan–Tibet orogenic series. For Yunnan–Tibet orogenic series and Himalayan orogenic belt, except for Rb and Th, the contents of other elements are on the lower side.

### 3.4 The distribution characters of REE in different granitoid rocks

Chondrite-normalized REE distribution patterns for the granitoids of alkali-feldspar granite, syenogranite and adamellite in seven different geotectonic units are shown in Fig. 5. It is obvious that the same type of rock in different geotectonic units possesses a similar distribution pattern and different rocks of granitoids have different distribution patterns. From alkali-feldspar granite→syenogranite→adamellite, negative Eu anomaly intensity gradually falls. Negative Eu anomaly of alkali-feldspar granite is the most distinct and their partitioning curves assume a “V” model. However, negative Eu anomaly of adamellite is not distinct and their partitioning curves basically assume a “∩” model.

For alkali-feldspar granite, the REE partitioning curve of Yangtze metaplatform is basically at the top position in Fig. 5 and negative Eu anomaly is the strongest. Moreover, the REE partitioning curve of Yunnan–Tibet orogenic series is basically at the bottom position and negative Eu anomaly is the weakest. For syenogranite, the REE partitioning curve of South China–Youjiang orogenic belt is at the top position. The LREE partitioning curve of Tianshan–Xing’an orogenic series is generally at the bottom position and negative Eu anomaly is the strongest. The HREE partitioning curve of Sino–Korean metaplatform is basically at the bottom position. For adamellite, the REE partitioning curves of Yangtze metaplatform and South China–Youjiang orogenic belt are at the upper position and thus the latter has negative Eu anomaly. The REE partitioning curves of Tianshan–Xing’an orogenic series and Himalayan orogenic belt are at the lower position.

## 4 Conclusions

(1) On the basis of actual analytical data of 767 composited samples collected mainly from about 750 large to middle representative granitoid bodies all over China, the average chemical compositions and element abundances of about 70 chemical elements of granitoids, alkali-feldspar granite, syenogranite and adamellite in seven geotectonic units of China such as Tianshan–Xing’an orogenic series, Sino–Korean

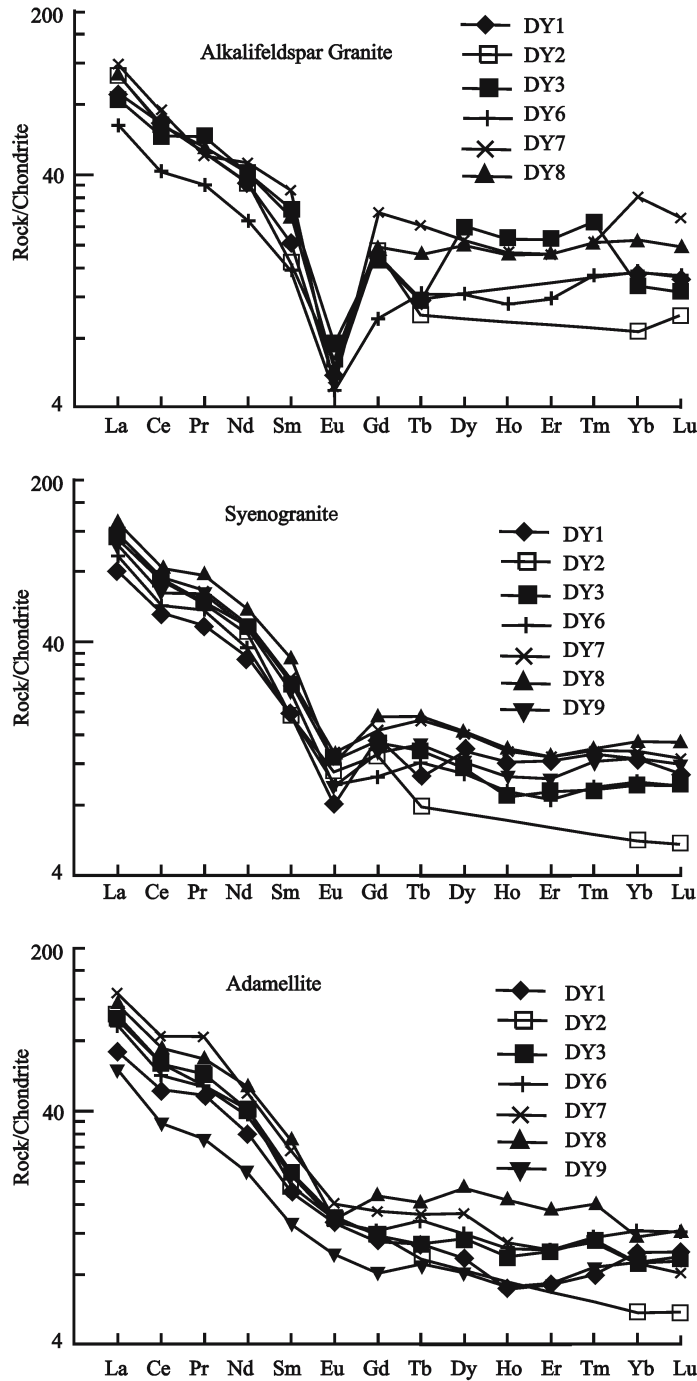


Fig. 5 Chondrite-normalized REE distribution patterns for the granitoids of different rock types in China's geotectonic units (chondrite data of Herrman (1970) are cited from reference Zhao and Zhang (1987))

DY1: Tianshan-Xing'an orogenic series; DY2: Sino-Korean metaplatfrom; DY3: Kunlun-Qilian-Qinling orogenic series; DY6: Yunnan-Tibet orogenic series; DY7: Yangtze metaplatfrom; DY8: South China-Youjiang orogenic belt; DY9: Himalayan orogenic belt

metaplatfrom, Kunlun-Qilian-Qinling orogenic series, Yunnan-Tibet orogenic series, Yangtze metaplatfrom, South China-Youjiang orogenic belt, and Himalayan orogenic belt, are calculated and presented.

(2) Regional petrochemical characters of granitoids in different regions are varied. The granitoid in Tianshan-Xing'an orogenic series is an enrichment type of Si-Fe-Na. The granitoid in Sino-Korean metaplatfrom is an enrichment

type of Al-Fe-Na. In Kunlun-Qilian-Qinling orogenic series, the granitoid is an enrichment type of Al-Fe-Mg-Ca-Na. In Yunnan-Tibet orogenic series, the granitoid is an enrichment type of Al-Fe-Mg-Ca. The granitoid in Yangtze metaplatfrom is an enrichment type of Si-Fe-Mg. The granitoid in South China-Youjiang orogenic belt is an enrichment type of Si-Fe-K. In Himalayan orogenic belt, the granitoid is an enrichment type of Si-Al-Ca-Na.

(3) The granitoids in different geotectonic units have different features of element abundances. Element abundances in alkali feldspar granite, syenogranite and adamellite in different geotectonic units have evident differences. Different rock types of granitoids in different geotectonic units have different features of element abundances. It sufficiently reflects that the chemical components of regional granitoids are inhomogeneous.

(4) The petrochemical parameters of granitoids in different geotectonic units are different. Among all the units, the granitoid in Yunnan–Tibet orogenic series is poor in alkali and rich in calcium; the granitoid in Himalayan orogenic belt is poor in aluminium and rich in calcium. The differentiation degree of the magma in these two units is lower. On the other hand, the granitoids in Yangtze metaplatform and South China–Youjiang orogenic belt are rich in aluminium and poor in calcium, and the differentiation degree of the magma in these two units is higher.

(5) The granitoids in different geotectonic units have different features of trace elements and the content level of trace elements in different units is different. It shows that the spider diagram of trace elements normalized by chondrite in granitoids of different geotectonic units presents a similar distribution pattern to the spider diagram of China's granitoids.

(6) Chondrite-normalized REE distribution patterns for alkali feldspar granite, syenogranite, and adamellite in seven different geotectonic units present that the same type of rock in different units possesses a similar distribution pattern, and different rocks of granitoids have different distribution patterns. From alkali feldspar granite→syenogranite→adamellite, negative Eu anomaly intensity gradually falls.

**Acknowledgements** This study was sponsored by the Project of the Special Society Commonweal Research Funds from the Ministry of Science and Technology, PR China (No. 2001DIB10076). Special thanks should go to Mr. Hu Shuqi, Liu Chongmin, Gu Tiexin, Bu Wei and Yan Weidong who also took part in this study. We also feel indebted to all the other people who offered us selfless help and consistent support.

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