GEOCHEMICAL CHARACTERISTICS OF VOLCANIC ROCKS FROM TANGBALE OPHIOLITE IN THE WESTERN JUNGGAR OF XINJIANG

Yang Ruiying (杨瑞瑛)

(Institute of High Energy Physics, Academia Sinica, Beijing 100080, China)

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ABSTRACT

An INAA technique was applied to determine simultaneously abundances of rare–earth, transitional metal, large–ion lithophile and high field strength elements in volcanic rocks from Tangbale ophiolite belt. The detailed study on trace element geochemistry shows that the volcanic rocks were erupted in the back–arc basin. The volcanic rocks of early and middle stages of the expanding period of the basin have low REE and other incompatible element contents. At early and late stages of closing period of the basin, alkalic basalts, basaltic andesites and andesites were erupted in which light REE and other incompatible elements were enriched.

Keywords: INAA Volcanic rocks Geochemical characteristics Tangbale ophiolite Basalt Andesite

1 INTRODUCTION

It has been showed that rare earth elements (REE) and high field strength elements (HFSE) are immobile in alteration and metamorphism, they play an important role in the discrimination of magmatic source, evolution and tectonic environment of volcanics. Such studies require simultaneous multi–element determination for a large number of samples. The analysis will be simple and accurate, and INAA is one of the preferred methods.

Some exposures of volcanic rocks of middle Ordovician Tangbale ophiolite are distributed in the southwestern part of Western Junggar in Xinjiang. According to petrological classification, they comprise basalts (pillow and massive lavas), basaltic andesites and andesites which are spatially close to or contact in fault with ultramafic bodies. The concentrations of several trace elements (REE, Rb, Sr, Ba, Cs, K, U, Th, Ta, Hf, Zr, Sc, Fe, Cr, Co, Zn, Sb, *etc.*) have been measured by INAA, in order to study the tectonic environment and origin of these rocks.

2 EXPERIMENTAL

2.1 Preparation of sample and standard

About 50 mg of crushed rock was weighed and wrapped in aluminium foil or filter paper. Mixed chemical standards were used. About 50 mg USGS standard rocks BCR–1 and AGV–1 were weighed respectively, they were used as a control and to check the accuracy. Then samples and standards were wrapped together in aluminium foil and put into an aluminium can.

2.2 Irradiation

Irradiation was carried out for 8 h at the thermal neutron flux of about 7×10^{13} $\mathrm{n\cdot cm^{-2}\cdot s^{-1}}$ in the reactor of China Institute of Atomic Energy. After cooling the samples were transferred to fresh polyethylene vials.

2.3 Radioactive measurement

The gamma–ray spectra of irradiated samples were measured on the 7th, 13–15th and 30th days after the irradiation respectively, depending on the nuclear properties of individual radioactive isotope. The gamma rays were detected by computer aided coaxial Ge(Li) detector system (made by Canberra). The efficient volume of the detector is 136 $\mathrm{cm^3}$. FWHM of the detector is 1.87 keV at 1332 keV gamma rays of ^{60}Co with a peak to Compton ratio 55.5:1. The data were processed by gamma spectral analysis program in the Scorpio/Spectran software package.

2.4 Results

The optimum conditions were determined to obtain interference–free photopeaks of the desired elements. The irradiation and the cooling time varied for different radioisotopes and the gamma–ray spectra for various types of rocks were studied[1,2]. Samples of the USGS BCR–1 and AGV–1 were analyzed (see Table 1), some results agree quite well with those given by Flanagan[3]. The abundances of some trace elements of volcanic rocks are shown in Table 2. The accuracy and precision of the analysis is as good as that of standard rocks.

Table 1

Determined values of USGS standard rocks

ppm

Element	BCR–1			AGV–1			Element	BCR–1			AGV–1		
	This work	n	Ref	This work	n	Ref		This work	n	Ref	This work	n	Ref
La	28.1±0.2	3	26.0	35.1±0.17	4	35.0	Sr	355±7	3	330	633±30	4	657
Ce	53.8±0.1	3	53.9	64.7±1.68	4	63.0	Sc	34.8±0.5	3	33.0	13.0±0.43	4	13.4
Nd	33.9±1.5	3	29.0	36.2±2.73	4	39.0	Cr	15.9±0.8	3	17.7	10.4±1.74	4	12.2
Sm	6.60±0.06	3	6.60	5.88±0.13	4	5.90	Cs	0.95±0.01	3	0.95	1.32±0.09	4	1.40
Eu	2.07±0.09	3	1.94	1.69±0.04	4	1.70	Rb	61.6±2.96	3	67.0	69.2±4.46	4	67.0
Tb	1.11±0.10	3	1.00	0.65±0.04	4	0.70	Co	38.6±0.03	3	38.0	15.8±0.54	4	14.1
Yb	3.31±0.33	3	3.66	1.66±0.07	4	1.70	Hf	5.08±0.14	3	4.70	5.40±0.05	4	5.20
Lu	0.573±0.08	3	0.55	0.29±0.02	4	0.28	U	1.77±0.11	3	1.74	1.84±0.15	4	1.88
Ba	679±24	3	675	1180±52	4	1208	Th	5.54±0.21	3	6.00	6.26±0.37	4	6.41

2.5 Trace element characteristics

On the basis of petrochemical characteristics of volcanics, more than half of the rock samples are subalkalic and the others are alkalic volcanics. The subalkalic volcanics include low-TiO_2 island-arc tholeiite and high-TiO_2 abyssal tholeiite or transitional type. Major and trace elements of rocks show multiple characters.

Table 2

Trace elements concentrations of Tangbale volcanic rocks ppm

Number	T35	T40	T14-1	T14-2	T14-3	T16	T15-1	T15-2	T37
Rock	Pillow basalt	Pillow basalt	Pillow basalt	Pillow basalt	Pillow basalt	Masive basalt	Andestite	Andestite	Andestite
Cs	1.09	1.26	0.491	0.464	0.521	0.949	1.02	1.28	1.74
Sc	29.1	25.5	46.6	48.7	46.5	9.13	13.7	15.4	45.9
* Ti	4852	4792	5890	5870	5810	14436	4792	3055	—
* V	253	187	269	228	200	377	59.2	290.7	—
Cr	21.6	26.1	84.1	18.8	71.0	16.5	25.9	22.8	—
Fe	58716	93666	72564	72812	73271	85931	59415	60813	57000
Co	29.8	35.7	51.3	52.1	50.3	4.50	7.97	7.20	28.2
Ni	137	176	143	160	43	17.3	22.3	74.8	—
Zn	123	119	77	77.7	78.7	44.5	74.8	75.6	152
Sr	270	183	141	98	101	111	243	269	—
Ba	158	161	82.2	88.4	83.2	214	535	486	185
Rb	45.1	7.71	12.1	10.1	10.7	61.7	33.4	27.1	23.1
Th	0.527	0.598	0.269	0.329	0.296	2.33	1.90	1.67	1.95
Ta	0.231	0.152	0.16	0.315	0.319	0.158	0.207	0.284	0.26
Zr	62.1	57.0	63.5	74.8	64.2	187	100	139	104
Hf	1.31	1.15	2.03	1.76	1.95	3.24	2.98	3.08	1.96
* Y	15.8	14.4	21.8	22.4	22.3	28.2	38.2	29.3	—
La	3.31	3.21	3.99	4.17	4.32	21.9	16.6	14.2	13.7
Ce	7.90	7.51	10.1	10.5	10.5	37.2	37.4	31.7	28
Nd	5.19	5.67	7.78	8.97	8.35	20.6	25.7	22.0	15.5
Sm	1.51	1.61	2.60	3.16	2.98	3.77	5.05	4.92	3.30
Eu	0.514	0.496	0.813	0.987	0.968	1.20	1.44	1.15	0.99
Tb	0.31	0.424	0.682	0.792	0.665	0.883	0.845	0.698	0.526
Yb	1.18	1.51	2.81	2.93	2.87	3.26	3.10	2.70	1.62
Lu	0.175	0.231	0.437	0.448	0.437	0.463	0.465	0.421	0.252
U	0.652	0.291	0.315	0.421	0.356	1.08	0.902	0.84	0.497
Sb	0.078	0.248	20.6	29.7	19.5	19.0	22.4	15.1	0.224
K	4565	2075	1743	913	1992	1975	1743	2075	2120

* Determined by ICP

2.6 REE

According to the REE geochemical behaviors, the basaltic rocks of Tangbale ophiolite can be divided into three groups. The total REE of the 1st group is about 18.6— 20.2 ppm, which are lower than those in typical mid-ocean ridge basalts. Chondrite-normalized REE patterns exhibit flat or slight enrichment of light REE (LREE) and a $(La/Yb)_{cn}$ ratios ranging from 1.3 to 1.8 without Eu anomaly. The total REE of the 2nd group is about 29.3— 32 ppm, and shows a slight depletion of LREE which $(La/Yb)_{cn}$ ratios 0.9—0.98 are similar to that found in N-type mid-ocean ridge basalts (N MORB), but LREE fractionated $[(La/Sm)_{cn} = 0.8— 0.93]$ are less than N-MORB $[(La/Sm)_{cn} = 0.4— 0.7]$. The 3rd group has 89.3 ppm of the highest REE and the largest $(La/Yb)_{cn}$ ratio (4.42) which are similar to the alkalic basalts.

Three andesite samples (T15-1, T15-2 and T37) have strongly fractionated REE patterns with $(La/Yb)_{cn}$ ratios of 3.49— 5.58, and LREE abundances 43.5— 52.7× chondrite and heavy REE (HREE) contents 8—14.3× chondrite with a small negative Eu anomaly (Eu/Eu* =0.8—0.9). Their REE distribution patterns are more similar to those of andesites in the north part of Chile[4].

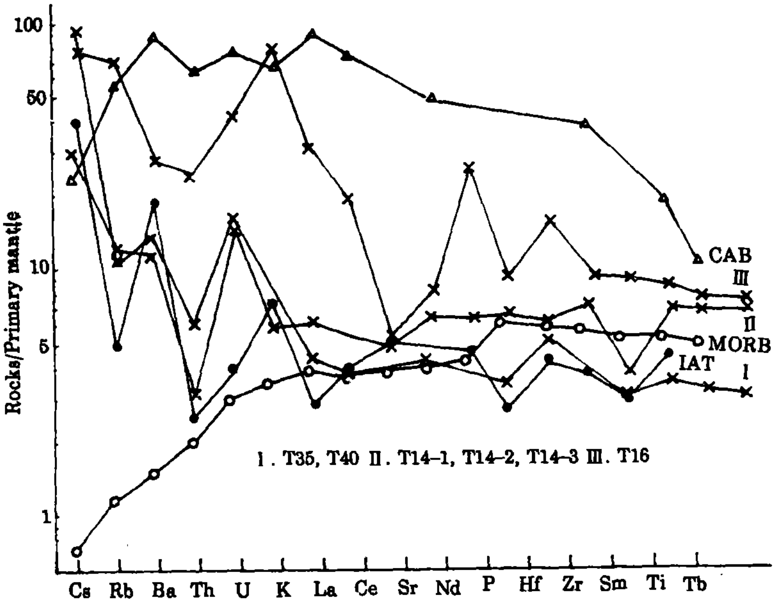

Fig.1 Primordial mantle —normalized incompatible element patterns of Tangbale basalts

2.7 Transition metal elements (TME)

In these rocks, the average chondrite normalized abundances of TME show strong depletion of Cr and Ni, suggesting that the rocks were affected by fractional crystallization of olivine, spinel and/or clinopyroxene. In fact, considering the partition coefficients of TME and major elements. It has been indicated that olivine and in some extent clinopyroxene was the predominant fractionating phase. There is obvious difference in TME contents between the first and second group basalts, it is suggested that these two group basalts have a similar mantle source and similar primitive oceanfloor basalts. The Ti/V ratios remain constant with values (24—29.1) which are close to, but slightly lower than average values of N-MORB (36).

2.8 Incompatible elements

Geochemical patterns of the primordial mantle-normalized incompatible elements for the 1st and 2nd groups basalts (see Fig.1) reveal that they are quite similar to the island arc tholeiites and obviously different from the N-MORB, since basalts from Tangbale have higher contents of incompatible elements (such as Cs, Rb, Ba and U).

3 DISCUSSION ON PETROGENESIS

3.1 Geochemical character of mantle source

In Table 3, comparison of some large ion lithophile elements (LILE) was made among various basaltic rocks including N-MORB, island arc tholeiites (IAT), the 1st and 2nd group basalts from Tangbale. The 1st and 2nd group basalts show LILE enrichment such as high Cs, Rb, Ba, Ba/Ce, Ba/Zr and Ba/Th and low Ti content and K/Ba, K/Rb, Sr/Rb ratios and as well as Th, Ta, Sr contents and Th/Ta ratio relative to N-MORB. Therefore these geochemical features are similar to the typical IAT. However, their abundances of HREE and Ti/V, La/Ta ratios are comparable with those of N-MORB on an equivalent degree of differentiation. It is possible that the rocks were generated by partial melting of LILE enriched upper mantle wedge overlying the subduction zone.

Table 3

Some LILE abundances and ratios

	First group	Second group	N type MORB	IAT	CAT
Cs	1.18	0.735	0.013	0.22	0.72
Rb	9.10	10.97	1.00	4.60	14.0
Ba	160	84.6	12.0	110	300
Th	0.563	0.298	0.20	0.25	1.10
Ta	0.192	0.265	0.16	—	—
La	3.26	4.16	3.00	1.30	10.0
Sr	227	113	124	200	550
Zr	60.3	67.5	85.0	22.0	44.0
Ti	5810	4822	9300	3000	4650
K	3320	1549	1060	3240	3640
$(La/Ce)_N$	1.09	1.03	0.86	0.89	1.12
Ba/Ce	20.8	8.23	1.30	29.4	13.0
Ba/Zr	9.32	1.25	0.14	5.00	7.50
Ba/Th	284	284	60.0	440	2.73
Th/Ta	2.93	1.12	1.25	—	—
La/Ta	17.0	15.7	19.0	—	—
K/Ba	20.8	18.3	88.0	29.5	28.8
K/Rb	365	141	1060	704	617
Sr/Rb	24.9	10.3	125	43.5	39.3

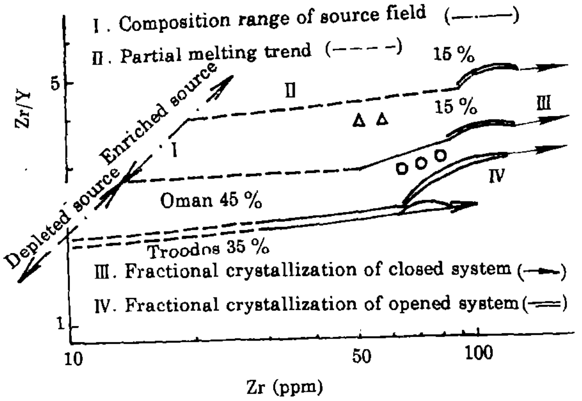

Fig.2 Original paths of the lavas in typical ophiolite (after Pearce, 1980)

Plot of Zr/Y against Zr for the basalts (see Fig.2) shows that they distribute along partial melting curve. It implies that the basalt magma can be formed by about 15% partial melting of enriched mantle source, and obviously different from the Troodos and Oman basalts.

3.2 Geotectonic setting

It can be seen from Fig.3a that the dates of basalts fall in the field of IAT and those of andesites fall in the field of calc-alkaline basalts (CAB), Plot of Ti(ppm) vs Cr (ppm) for the basalts (Fig.3b) shows that they fall in the field of IAT. The Ta-Th-Hf/3 diagram of the basalts from Tangbale ophiolite (Fig.3c) shows that most of basalts fall in field of IAT and a few samples fall in the field of mid ocean ridge basalts. It is suggested that basalts from Tangbale show transitive characteristics between mid–ocean ridge basalts and IAT.

N–MORB normalized multi–element plots (Fig.4) show the geochemical behavior of volcanic rocks. All basalts of Tangbale ophiolite have positive Sr, K, Rb, Ba, U, Th anomaly and negative Ti, Zr, Hf, Ta, Cr anomaly relative to N–MORB, which patterns fall are similar to those of back–arc basin basalts (after Pearce 1981). So they were erupted in the back–arc basin.

On the basis of the geochemical characteristics of volcanics and geological and petrological evidences, the evolution process of Tangbale Back–Arc Basin may be summarized as three continual periods as following: The first group basalts are products of the early stage volcanic of the expanding period which have low REE and other incompatible element contents, their REE patterns are flat or LREE slightly enriched. In middle and late stages of the expanding period, the continental crust was thinned gradually by tension of S–N direction, volcanic activity formed. The second group basalts of which REE patterns show clear LREE depletion, and trace element character similar to N–MORB.

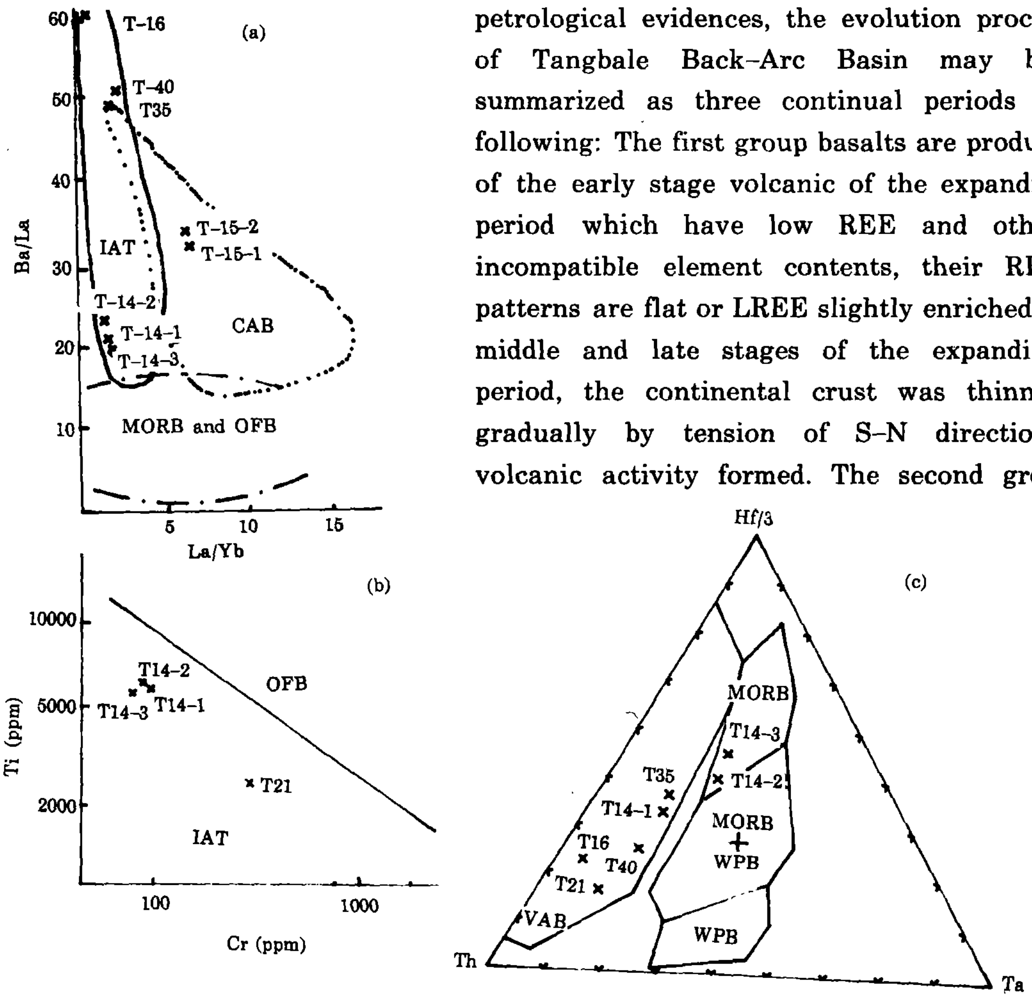

Fig.3 Geotectonic setting of basalts from Tangbale

(a) Ba/La vs La/Yb diagram (b) Ti vs Cr diagram (c) Ta–Th–Hf/3 diagram

OFB—Ocean floor field WPB—Within plate basalt field

At early stage of closing period of the basin, alkalic basalts were erupted in a small amount, but in late stage andesite or basaltic andesite were erupted in many place. Their chondrite–normalized REE patterns are LREE strongly enriched types. REE and other incompatible elements are strongly enriched. These calc–alkalic volcanics are the products of mixing magma which were formed by contamination of the basaltic melt with crystal material.

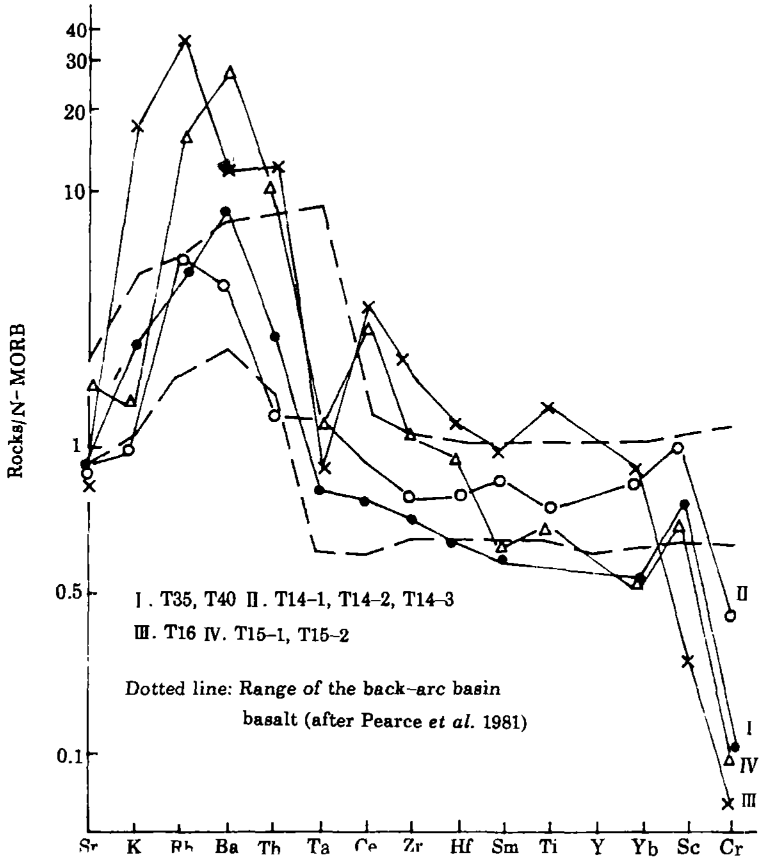

Fig.4 N—MORB normalized multi—element plots of volcanic rock from Tangbaie

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