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Geochemical Characteristics and Tectonic Significance of the Acidic Volcanic Rocks from the Shetang-Boyang Area, Western Qinling Orogenic Belt, China

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Abstract

Acidic volcanic rocks of Shetang-Boyang area are located in the western Qinling orogenic belt, consist of rhyolite and granite porphyry. They are comparable in the chemical composition, enriched in Si, alkali, Al and a little bit of Mg, Ca and Ti. The contents of HFSE (Zr, Hf) and LILE (Rb, Th, U) are high, however, the content of Ba, Sr, Ti, P have obviously depleted and there are obvious negative Eu anomalies (Eu/Eu*=0.06-0.13). These geochemical characteristics are revealed that these volcanic rocks have an A_1 type affinity. Geochemical data combined with regional studies, show that these volcanic rocks were formed in a continental extension setting and the western Qinling orogenic belt in 211Ma has been in the tectonic setting of post-collisional extension.

Keywords: Volcanic rocks, Geochemistry, A_1 type granite, Post-collisional extension

1. Introduction

Shetang-Boyang area in Tianshui city is located in the convergent juncture of the North China block, Qinling orogen, and Yangtz block, and is an important region during the western Qinling orogenic belt tectonic evolution. Previous studies have shown that there are terrestrial acidic volcanic rocks developing in Shetang-Boyang area (Pei et al., 2004; Ding et al., 2005; Lai et al.,2006; Xu et al.,2007), and achieved certain results, however, the geochemistry and tectonic genesis remain controversial. Some scholars believed that the volcanic rocks belong to nonorogenic alkaline rocks, comparable to continental rift type alkaline rhyolite, were formed by partial melting of crustal rocks in continental extension setting, related to sinistral strike-slip shearing of Weihe faulted zone in Early Cenozoic (Pei et al., 2004; Ding et al., 2005.). Some workers suggested that the volcanic rocks were resulted from the Late Triassic under the tectonic setting of post-collisional of the western Qinling orogenic belt (Xu et al., 2007). Much of the debate significantly constrains on better exploring the tectonic evolution of western Qinling orogenic belt. Therefore, based on detailed field investigation, petrography and geochemistry study, this paper has done systematic research of the volcanic rocks and has finally drawn conclusions of the type of the volcanic rock, petrogenesis and tectonic significances. This provides important fundamental data for the tectonic evolution of western Qinling orogenic belt, China.

2. Geological Settings and Samples

The study area is located in the north margin of western Qinling orogenic belt, related to the mid segment of the Central orogenic belt, also is the convergent juncture of the North China block, Qinling orogen, and Yangtz block, and is an important region during the western Qinling orogenic belt tectonic evolution (Feng et al., 2003; Sun et al., 2004; Pei et al., 2007 and 2009; Liu et al., 2014; Zhang et al., 2005). Affected by the long-term activity of the Tianshui-Baoji fault, the area has multiple zones of tectonic activity. Since the Meso-Cenozoic, because of the collision between the Indian plate and the Eurasian plate, and the northeast extension of the Qinling-Tibet Plateau, the structures are strongly deformed and strike-slip has widely developed (Zhang et al.,2001; Pei et al., 2004).

The acidic volcanic rocks are composed of lava, tuff, hypabyssal granite porphyry and rhyolite, dominantly occurred at the Shetang-Boyang-Yuanlong- Putaoyuan region with the acreage of $34km^2$, extend along a north-south orientation (Fig. 1). The volcanic rocks extend southward to meet the Paleoproterozoic Qinling Group, northward to join Paleozoic Huluhe group, and fault contact with The Indo-Chinese epoch monzogranite.

The quartze sysenite-porphyry invaded into acidic volcanic rocks and Qinling group.

To ensure the accuracy of the results, four representative samples, including two rhyolites (No.TSP1 and TSP4) and two hypabyssal granite porphyry (No.TSP7 and TSP8) were chosen for studying, and excluded the contaminated samples.

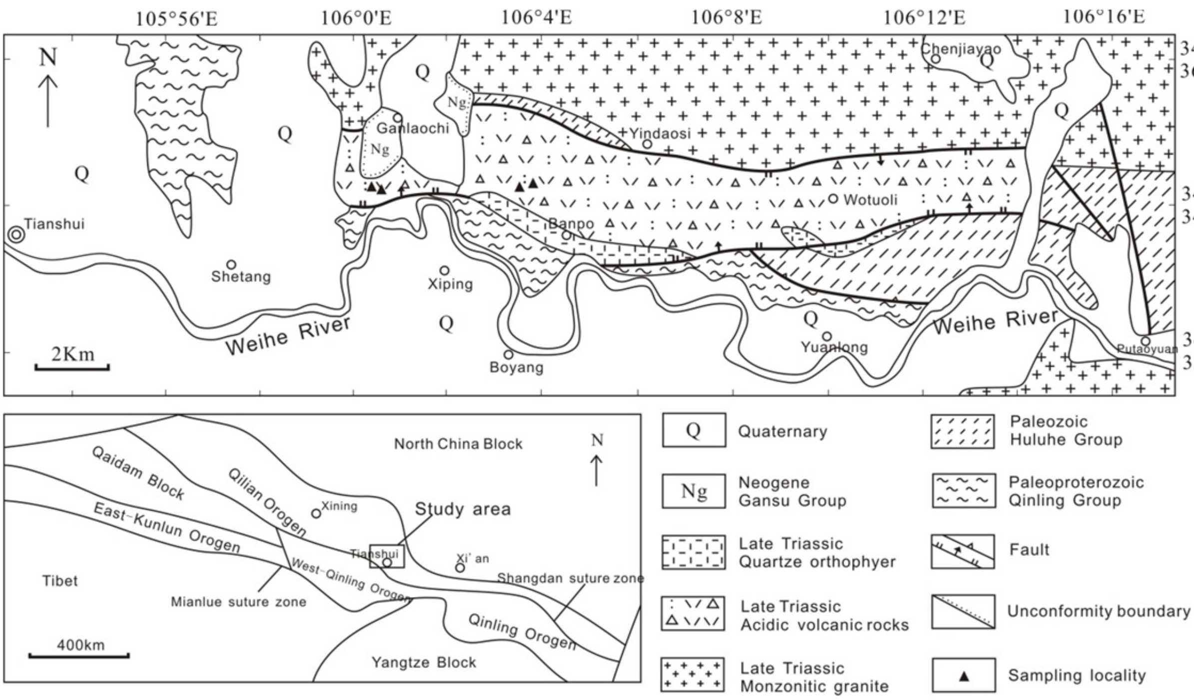

Figure 1. Geological and location maps of the study area (after Pei et al., 2004)

3. Analytical Methods

Rocks were grinded into thin sections, and study under the Polarizing microscope, research there optical properties, structure, and ensure the features, genesis of rocks.

Geochemical analyses were undertaken at the Laboratory of Mineralization and Dynamics, Chang'an University (Xi'an, China). The major element compositions were analyzed by X-ray fluorescence spectroscopy (XRF-1500). Trace elements and rare earth elements (REE) were measured by ICP-MS.

4. Results

4.1 Petrography

Microscopic thin section analysis indicates that the phenocrysts mainly consist of plagioclase, orthoclase and quartz, and the content proportion of the three is nearly the same. The matrixes are quartz-feldspathic, with rhyolitic structure and felsitic texture, and the accessory mineral is corundum.

4.2 Geochemical Analyses

Major and trace element compositions of the analyzed samples are listed in Table 1.

4.2.1 Major Elements

According to the observation under the microscope and geochemical characteristics, the samples can be divided into two types of granite: rhyolite and granite porphyry.

(1) Rhyolite

The rhyolite samples are enriched in silica (SiO_2 ranges from 75.11% to 75.25%), alkalis (Na_2O+K_2O=8.38%-8.53% and K_2O>Na_2O) and Al_2O_3 (12.93%- 12.94%), all samples display low CaO (0.67%-0.76%), MgO (0.34%-0.36%) and TiO_2 (0.17%- 0.18%), but high FeO^{tot}/MgO (5.75-5.95). In the TAS diagram (Le Maritre RWA， 1989), all samples plot within the rhyolite field. The AR (alkalinity ratio) ranging from 3.09 to 3.29, SiO_2-AR diagram (Wright J B, 1969), all the rhyolite samples plot within the alkaline field (Fig. 2a). The low ANCK [molar Al_2O_3/ ($CaO+Na_2O+K_2O$)] values (0.99-1.08) suggest that weakly peraluminous characteristics. All samples are plotted within the weakly peraluminous field in the ANK-ANCK diagram (Fig. 2b). In addition, corundum data in CIPW (Tab. 2) revealed that the rhyolite belongs to aluminous granite rock.

Table 1. Major (%) and trace element (ppm) of the studied volcanic samples

	Rhyolite		Granite porphyry	
Sample	TSP1	TSP4	TSP7	TSP8
SiO_2	74.40	73.63	69.09	71.96
TiO_2	0.17	0.18	0.32	0.25
Al_2O_3	12.78	12.68	12.40	13.46
Fe_2O_3	1.74	1.75	1.87	1.81
FeO	0.28	0.26	4.34	0.87
MnO	0.09	0.09	0.13	0.17
MgO	0.34	0.35	1.25	0.60
CaO	0.75	0.68	0.87	1.10
Na_2O	3.61	3.41	2.87	3.07
K_2O	4.68	4.95	3.31	4.88
P_2O_5	0.03	0.04	0.07	0.07
LOI	0.74	0.67	1.91	1.77
Total	98.87	98.02	96.51	98.23
La	22.51	39.36	31.78	32.81
Ce	38.30	71.65	48.39	59.82
Pr	4.43	7.73	6.53	6.50
Nd	15.61	26.78	23.27	22.68
Sm	3.13	5.08	4.56	4.48
Eu	0.11	0.21	0.37	0.18
Gd	2.52	3.86	3.64	3.54
Tb	0.37	0.54	0.54	0.50
Dy	2.13	3.02	3.09	2.79
Ho	0.42	0.58	0.61	0.55
Er	1.20	1.63	1.74	1.61
Tm	0.17	0.24	0.27	0.25
Yb	1.01	1.42	1.59	1.48
Lu	0.17	0.23	0.26	0.24
Rb	133.38	233.52	91.27	196.49
Sr	34.89	46.31	71.91	41.73
Y	10.88	14.02	14.90	14.50
Zr	134.95	186.90	181.42	194.74
Nb	20.57	29.25	20.26	29.32
Cs	7.08	8.78	3.75	5.93
Ba	64.17	138.81	339.03	140.72
Hf	3.87	5.52	4.91	5.59
Ta	1.25	1.81	1.28	1.80
Th	15.04	22.19	14.25	17.17
U	3.17	4.54	4.00	5.50
$\sum$REE	92.08	162.33	126.64	137.43
$\omega_{LREE}/\omega_{HREE}$	10.53	13.09	9.79	11.54
$\omega(La)_N/\omega(Yb)_N$	15.02	18.69	13.47	14.94
Eu/Eu*	0.06	0.07	0.13	0.07

Table 2. The CIPW of volcanic rocks

Sample	Q	or	ab	an	C	Hy en	Hyfs	mt	he	il	ap
TSP1	33.88	27.98	30.85	3.6	0.47	0.85	0	0.7	1.28	0.32	0.07
TSP4	33.65	29.87	29.41	3.19	0.56	0.9	0	0.64	1.34	0.34	0.09
TSP7	34.63	20.29	25.1	4.06	2.75	3.25	6.34	2.8	0	0.63	0.15
TSP8	32.91	29.4	26.46	5.15	1.27	1.53	0	2.67	0	0.48	0.15

(2) Granite porphyry

SiO_2 contents for granite porphyry samples range from 71.59% to 73.25%, the total alkali content (Na_2O+K_2O) varies from 6.40% to 8.09%, and $K_2O>Na_2O$, the Al_2O_3 ranges from 12.93% to 12.94%. The granite porphyry also displays low CaO (0.90%-1.12%), MgO (0.61%-1.30%) and TiO_2 (0.25%- 0.33%), but high FeO^{tot}/MgO (4.46-4.96). All the granite porphyry samples also plot within the alkaline field in the SiO_2-AR diagram (Fig.2a), and within the weakly peraluminous field in the ANK-ANCK diagram (Fig.2b). Consequently, rhyolite and the granite porphyry have the same characteristics, and may be originate from single magma. According to the geochemical classification scheme for granitoids, the volcanic rocks belong to A-type granites (Fig. 3). Overall, the major element compositions of the volcanic rocks of Shetang-Boyang are comparable to those of A-type granite, as defined by Whalen et al., (1987) and Collins et al., (1982).

4.2.2 Trace elements

Rhyolite and granite porphyry originate from single magma, and they have similar characteristics of trace elements, so we analyze them together.

The volcanic rocks are enriched in Rb (91.27-233.5 ppm), U (3.17-5.50 ppm), Th (14.25-22.19 ppm), and high field strength elements (HFSE) (Zr: 134.95-194.74 ppm; Hf: 3.87-5.59 ppm) and are depleted in Ba (64.17-339.03 ppm) and Sr (34.89-71.91 ppm), which are similar to A-type granite (Collins et al.,1982; Whalen et al., 1987). In A-type granite discrimination diagrams (Fig. 3), all samples of the volcanic rocks fall in the field of A-type granite. One sample only of rhyolite sample plot in I,S,M, type granite field in the relationship between 1000Ga/La with Zr (ppm), which resulting of low relatively content of Zr (about 135 ppm). The volcanic rocks are also enriched in Rare Earth Elements (REE) with total REE concentration of 92.08-162.33 ppm. Chondrite-normalized REE patterns show slight enrichment of Light Rare Earth Elements (LREE) relative to Heavy Rare Earth Element (HREE) with $(La/Yb)_N$ ratios of 13.58-18.83 and strongly negative Eu anomalies (Eu/Eu*=0.06-0.13) (Fig. 4a). In the element spider diagram (Fig. 4b), the volcanic rocks show negative anomalies of Ba, Sr, P, Ti and Eu, which agrees with element compositional patterns of A-type granites (Wu et al., 2002). The above geochemical characteristic, show clearly that the volcanic rocks are A-type granite.

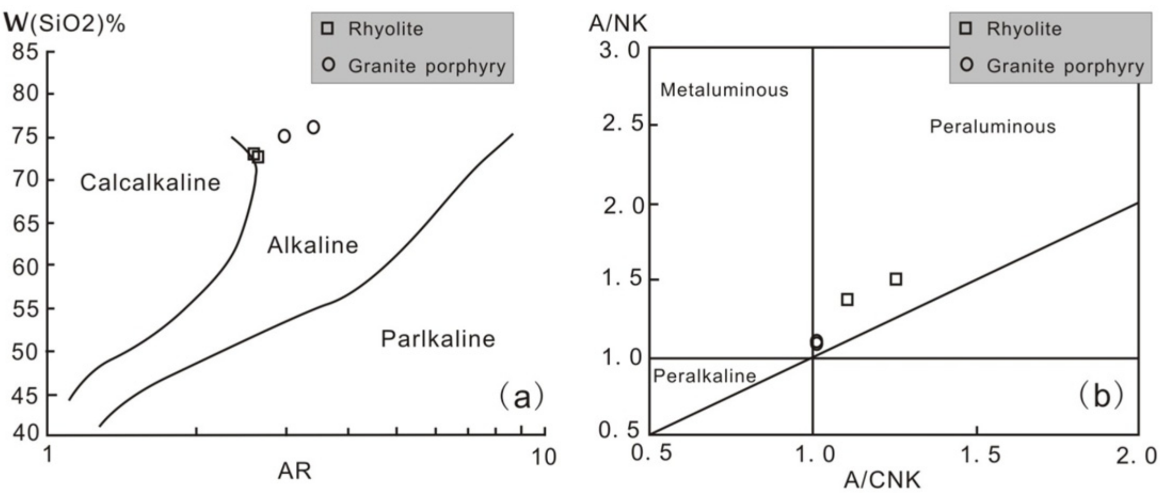

Figure 2. (a) Plots of SiO_2 versus AR of the studied samples(after Wright J. B., 1969); (b) A/NK versus A/CNK diagram (after Maniar P D et al., 1989) (The following symbols are the same)

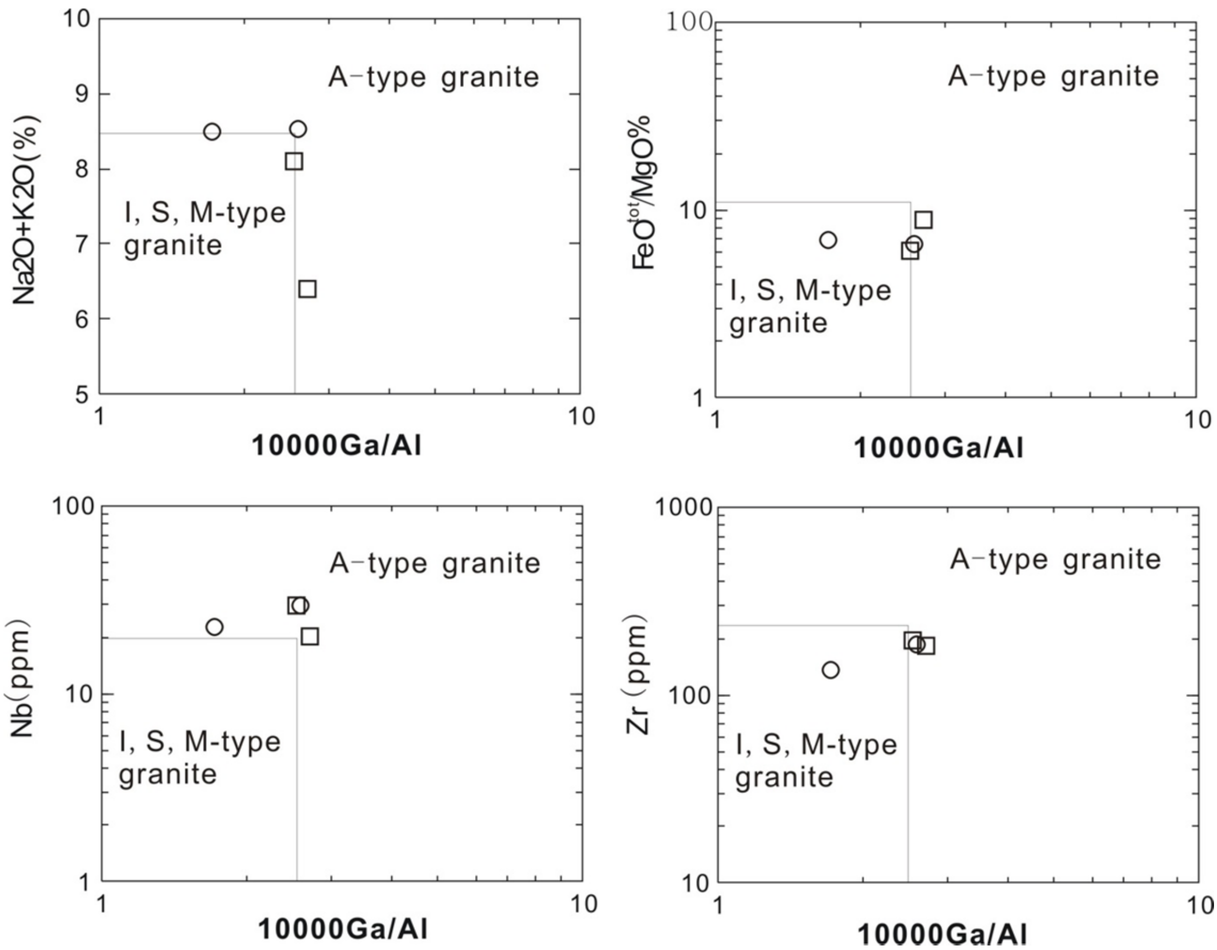

Figure 3. A-type granite discrimination diagram (after Whalen et al., 1987)

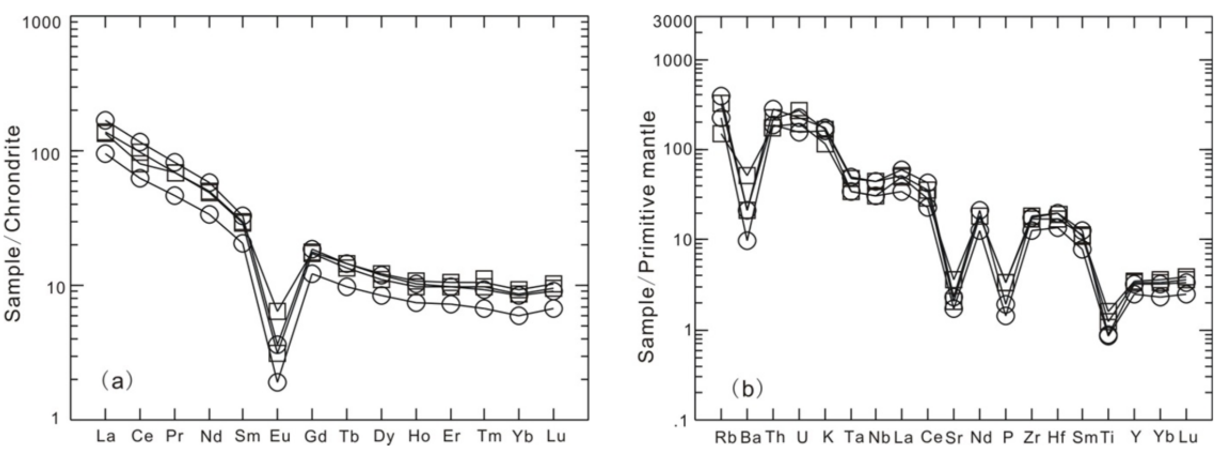

Figure 4. (a) Chondrite-normalized REE patterns; (b) primitive mantle-normalized element spider diagram of volcanic rocks

Note. The normalizing values from Sun & McDougall (1989)

5. Discussion

5.1 Tectonic Setting

Eby (1992) subdivided A-type granites into A_1 and A_2 subgroup. These two types have different sources and tectonic setting. The A_1 group occurs in an orogenic setting such as continental rifts or intraplate environments, and their magmas are derived from sources like those of oceanic-island basalts. The A_2 group forms in a broader range of environments, and those emplaced at the end of a long period of apparently high heat flow and granitic magamatism. The A_2 group magmas were derived from continental crust or underplated crust that has experienced a cycle of continent-continent collision or island-arc magmatism (Zhang et al., 2007). The A_1 and A_2 groups can be discriminated using the Y-Nb-Ce andY-Nb-3*Ga diagrams (Fig. 5(a)). As shown in Figure 5(a), all samples fall into the A_1 group, suggesting a continental rifts or intraplate environments.

5.2 Geodynamic Implications

In this paper, the rhyolite and granite porphyry have a similar chemical composition (see above) and formed in a continental rifts or intraplate environments. In the Rb vs Yb+Ta tectonic discrimination diagram of Pearce et al. (1984) volcanic rocks fall into the field of "within plate granite" (Fig. 5(b)), indicate that the rocks were formed in a continental extension setting.

Combined with previous studies, the Qinling orogenic belt, being part of the central orogenic belt in China, was sutured to the Yangtz block during the middle to late Triassic (Li et al., 2009 and 2010), and the end period of Indo-China Movement in Qinling is characterized by changing from continental crust thickened to lithosphere mantle adjusting or crust thining (Zhang et al., 2001; Zhang et al., 1995; Zhang et al., 1996, 1997), Gong et al. (2009) proposed that the tectonic event of transition from lithospheric extrusion to extension in Qinling orogenic belt, may generated in range of 224-210Ma. Moreover, Xu et al. (2007) zircon U-Pb dating yields ages of 211Ma for magma crystallization, corresponding to the end period of Indo-China Movement, Pb isotopic data suggest an impossible source of the North Qinling basement rocks for rhyolites. Therefore, the western Qinling orogenic belt in 211Ma has been in the tectonic setting of post-collisional extension.

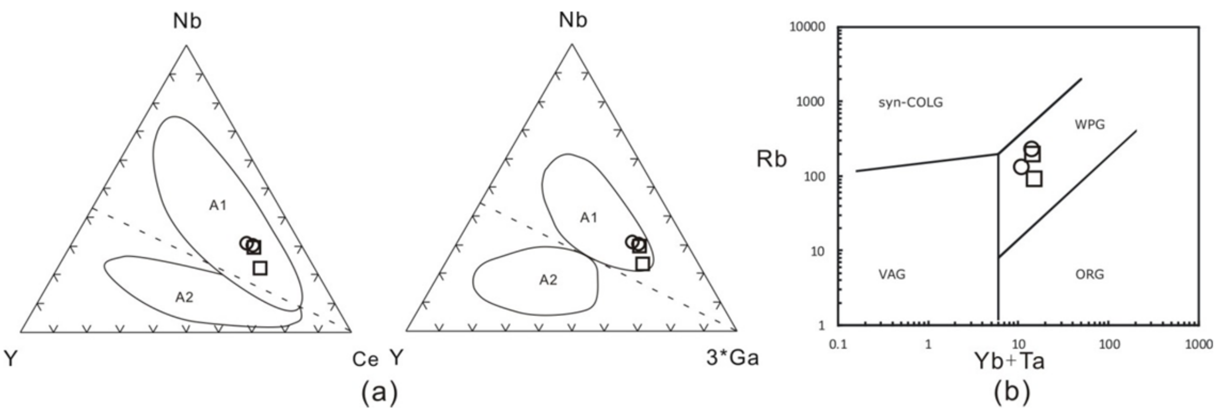

Figure 5. (a) A_1 and A_2 subgroup discrimination of A-type granite (after Eby, 1992); (b) Rb-Y+Nb and Nb-Y diagram of volcanic-subvolcanic rocks (after Pearce et al., 1984)

Note. Syn-COLG-syn-collision granite; VAG-volcanic arc granite; WPG-within plate granite; ORG-ocean ridge granite.

6. Conclusions

The rocks are A_1-type granite, including one rhyolite and three granite porphyry, and formed in a continental extension setting, combined with previous studies, we consider that the western Qinling orogenic belt in 211Ma has been in the tectonic setting of post-collisional extension.

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