

Permian bimodal dyke of Tarim Basin, NW China: Geochemical characteristics and tectonic implications

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Abstract

This study reports for the first time the occurrence of bimodal dyke in the Shuigongtuan area of Bachu County, Tarim Basin, NW China. Here, quartz syenite porphyry and diabase dykes occur in direct contact showing bimodal feature. The quartz syenitic porphyry is metaluminous, enriched in K_2O+Na_2O (10–11 wt.%) and total rare earth elements (REE), with low $Mg/(Mg+Fe)$ ratios, high LREE/HREE, and negative Eu anomalies. The chemical characteristics and tectonic discriminative diagrams show that the rocks have geochemical affinity with A-type granites. The diabase dyke shows 45–52 wt.% SiO_2 and $Mg/(Mg+Fe)$ ratio in the range of, with high total REE, high LREE/HREE ratios and lack of Eu anomalies, broadly corresponding to tholeiitic composition. Based on low Y/Nb (as low as 0.4, and less than 1.2), enrichment in LILE and HFSE, and uniform Nb-enrichment patterns in spider diagram for the quartz syenitic porphyry, together with the geochemical patterns of the diabases, this bimodal association is interpreted to be derived from a mantle source and formed under typical within-plate environment. The quartz syenitic porphyry and diabase have Daly gap of 46 wt.%–67 wt.% in SiO_2 , which is explained through formation under bimodal rifting. The quartz syenitic dyke probably formed during Early Permian (277 Ma) and has geochemical affinity with the Xiaohaizi syenitic body. We propose that magmas sourced from the mantle intruded into middle–upper crust and were emplaced as dykes, which indicate large-scale extension during the Permian in Tarim Basin. The bimodal dyke has genetic affinity with the huge volume of Permian basalts and igneous rocks (248–292 Ma) that occur in the Tarim Basin. The magmatism manifests the culmination of the major thermal event in the Tarim Basin.

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Keywords: Permian within-plate magmatism; Bimodal dyke; Rifting environment; Mantle source; Tarim Basin

1. Introduction

Bimodal volcanic suites form in various tectonic settings, such as intracontinental rifting (Shao et al., 2001; Li et al., 2002a; Dusel-Bacon et al., 2004; Lindline et al., 2004; Vorontsov et al., 2004; Li et al., 2005a; Shu et al., 2005), back-arc basins (Hochstaedier et al., 1990; West et al., 2004), island arc (Geist et al., 1995; Qian and Wang, 1999), active continental margins (Donnelly and Rogers, 1980), and rifting of the passive margin (Oberc-Dziedzic et al., 2005). They have also been genetically correlated with mantle plumes (Li et al., 2002a, 2003; Jordan

et al., 2004; Li et al., 2005a; Dobretsov, 2005). Therefore, the study of bimodal igneous suites and their geochemical as well as tectonic discrimination can provide important clues on the geodynamics and crust–mantle interaction.

The Tarim Basin, the largest basin in China, has not been well studied as yet in terms of its geological and tectonic evolution. The basin is surrounded by the Tianshan, Kunlun and Altun orogenic belts and is an important area for oil and natural gas exploration in China (Fig. 1). The Tarim Basin consists predominantly of Precambrian basement and Phanerozoic strata; and the Tarim plate constitutes the tectonic basement and records a long span of magmatic history during ca. 2500–260 Ma. Four major tectonothermal events can be identified in the Tarim Basin as follows: Neoproterozoic–Cambrian (774–673 Ma), Ordovician (460–484 Ma), Permian (264–282 Ma) and Cretaceous (ca. 100 Ma) (Yang et al., 1997). Among these,

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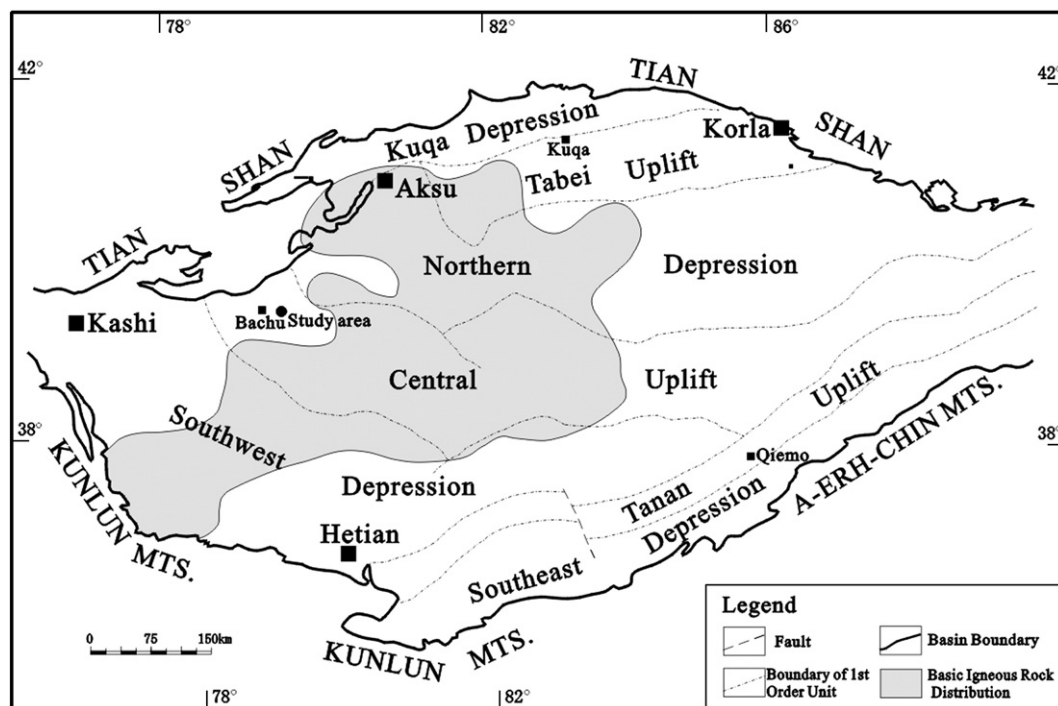


Fig. 1. Tectonic sketch map of Tarim Basin and study area.

the Permian geological event was the largest one with respect to magmatic scale and spatial distribution. The Permian rocks that outcrop in the Tarim Basin mainly consist of volcano-sedimentary sequences, limestone and basic- to intermediate-acidic volcanic rocks and related igneous rocks. Major magmatic events occurred during the Neoproterozoic and Late Paleozoic, with the latter being more intense than the former.

Studies on large scale Permian magmatism in the Tarim Basin has drawn attention for its tectonic significance since they provide important information on the source characteristics, tectonic setting, crust–mantle interaction, and controls on the three major episodes of formation of the oil and natural gas reservoir in this region (Yang et al., 1996; Chen et al., 1997; Yang et al., 1997; Jia, 1997; Jiang et al., 2004a,b,c). Recent studies have also drawn a genetic correlation for the magmatism with mantle plume activity (Jiang et al., 2004a; Yang et al., 2005a,b). This study is the first report of Permian bimodal dyke consisting of quartz syenitic porphyry and diabase from the Tarim Basin. In order to improve the understanding of the evolution history of the Permian magmatic event, a geochemical study has been carried out on Shuigongtuan bimodal dyke in Bachu area, northwestern Tarim Basin (NW China). This paper presents the results from petrological and geochemical study of the bimodal dykes, and evaluates the results in understanding the major thermal event in the Tarim Basin during the Permian.

2. Geological background and petrography

2.1. Geological background

Through systematic investigations of field geology, drill-core records, geophysical investigations and isotopic data, the

Permian magmatic has been divided into two zones, with an intermediate-acidic igneous zone in the north and a basic volcanic zone in the central-western part of the Tarim Basin (Yang et al., 1997), the latter formed earlier than the former. The intermediate-acid igneous rock zone consists of andesite, rhyolite, granodiorite, granite, granophyre and tuff, and their isotopic ages range from 288 to 246 Ma. The voluminous Permian basic volcanic zone (Yang et al., 1997) consists mainly of basaltic rocks and diabases with minor basaltic andesites and syenites, showing an age concentration around 248–292 Ma (Table 1, Yang et al., 2006b). The thickness of basalt layers range from several tens of meters to more than hundred meters, with distribution estimated to be over 250,000 km² area (Yang et al., 1997; Chen et al., 1997), and has been compared with the Emeishan large igneous province (Chung and Jahn, 1995; Xu et al., 2001). Jia et al. (1992) reported large-scale diabase dykes along NNW–SSE trend and steep dips which intruded into Silurian, Devonian, Carboniferous and Early Permian as recorded from outcrops, and into Silurian and Devonian as observed in some drill cores. These dykes yielded Sm–Nd ages of 259 ± 57 Ma (Table 1). Geochronological data for the Permian magmatic rocks are shown in Table 1. These two zones may have no genetic linkage, and are regarded as two separate suites. According to the study of Yang et al. (2005b), the sequence of formation of the magmatic rocks in the central and western part of the Tarim Basin is: Wajilitag ultrabasic and basic rocks → diabase → basalt → syenite, from older to younger.

In Bachu area, where the dyke association is well developed, it is seen that syenite batholith, ultramafic rocks, and quartz syenitic dyke intrude into the Silurian, Devonian, and Carboniferous–Lower Permian strata (Fig. 2). Majority of the dykes have vertical dips. Closely packed diabase dykes trending

Table 1
Geochronological data of the Permian diabase, syenite and basalt from the Tarim Basin

Sampling sections	Stratum (formation)	Lithology	Methods	Results (Ma)	References
Bachu		Diabase	Sm–Nd	259±57	Jia et al. (1992)
Bachu		Syenite	Ar–Ar	277±1.3	Yang et al. (1996)
Yigan (different layers)	Kupukuziman	Basalt	K–Ar	289.0±6.1 ^a ; 272.9±4.0 ^a ; 288.4±4.4 ^a ; 248.3±3.8 ^a ; 287.2±5.6 ^b	^a Zhang et al. (2003); ^b Yang et al. (2005a,b)
Taxinan	Qipan	Basalt	K–Ar	289.6±5.6	Yang et al. (2005a,b)
Sishichang	Kupukuziman	Basalt	K–Ar ^{c,d} , Ar–Ar ^e	292.4±0.5 ^c ; 278.5±1.4 ^d ; 278 ^e	^c Liu and Li (1991); ^d Yang et al. (1996); ^e Jia et al. (1992)
Kaipaizilaike	Kaipaizilaike	Basalt	K–Ar	259.8±0.9	Liu and Li (1991)

N 70° outcrop in the Bachu Shuigongtuan area and intrude into Devonian stratum. In one of the outcrops, purple quartz syenitic dyke with approximately 1–2 m width occurs in direct contact with dark-bluish diabase dyke in the Shuigongtuan area. Both the dykes show steep dip (78°) and trend N 55°. The dyke rocks are surrounded by the Devonian strata (Fig. 3).

2.2. Petrography

The massive quartz syenite porphyry shows mostly coarse phenocrysts of K-feldspar with minor plagioclase, together with microlites of K-feldspar (70–90%) and minor plagioclase. The groundmass K-feldspar (0.5 mm) in this rock is coarser than that in the dyke (0.25 mm) of ca. 1.5 m width, reflecting their difference in crystallization order. Some fine-grained (up to

0.25 mm) anhedral quartz (<5%) commonly occurs interstitially in microlitic K-feldspar/plagioclase. Microlitic plagioclases in some samples have locally preferred orientation and the rocks show pilotaxitic structure in ground mass. Accessory minerals are apatite, zircon, titanite and iron oxides. Diabases occur in direct contact with the quartz syenite porphyry (Fig. 3, Table 2) and consist of phenocrysts of plagioclase together with a groundmass assemblage of microlitic plagioclase, clinopyroxene and hornblende. The rock shows mineral assemblage and igneous textures compared with other diabases in the Bachu area.

3. Geochemistry

Major and trace elements were analyzed by XRF (Rigaku 3270E) and inductively coupled plasma mass spectrometer

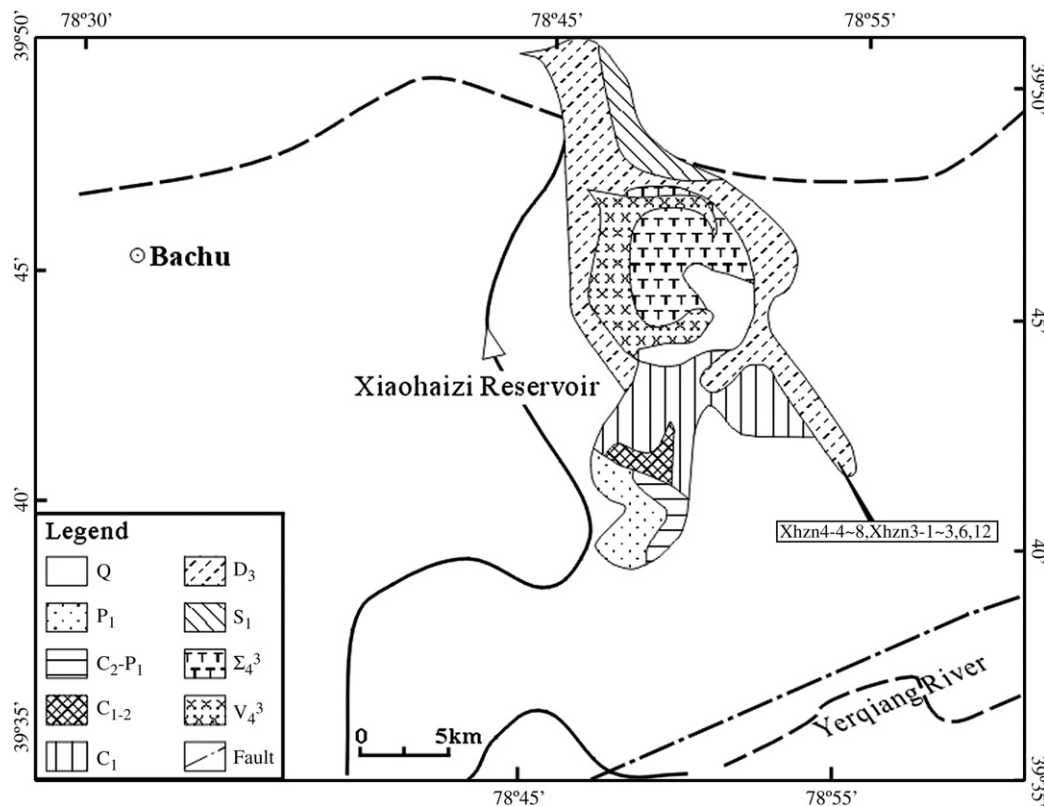


Fig. 2. Simplified geological map of the Xiaohaizi area, Bachu, Tarim Basin and sample location. Note: P₁: Early Permian Nanza Formation limestone interlayered calcic siltstone, marl and mudstone; S₁: Early Silurian Keziertage Formation siltstone and silty mudstone; D₃: Late Devonian Donghetang Formation quartz sandstone; C₁₋₂: Early–middle Carboniferous Kalasayi Formation limestone, marl and mudstone; C₁: Early Carboniferous Bachu Formation pelitic and calcic siltstone, and limestone; C₂–P₁: Middle Carboniferous to Early Permian Xiaohaizi Formation limestone intercalated with fine sandstone and salty mudstone; Σ₄³: Late Hercynian syenite; and V₄³: Late Hercynian gabbro.

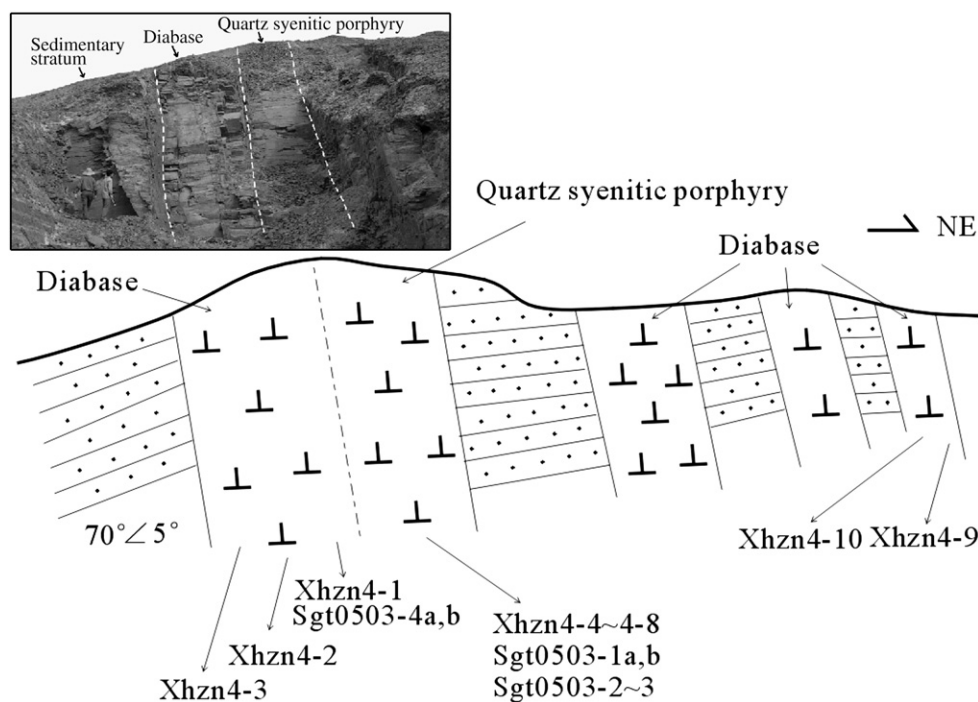


Fig. 3. Field contact relationship between diabase and syenitic dykes.

(ICP-MS) respectively at the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, using the analytical methods described in Li (1997). The trace and rare earth elemental analyses were performed in a PE Elan 6000 ICP-MS, standardised with only 5–10% variation of mass response during the measurement. BCR-1 standard was chosen as calibration standard for calculation of element concentrations of the measured samples. Representative major, trace and rare earth element data from samples of the diabase and quartz syenite porphyry are listed in Table 2.

3.1. Quartz syenitic porphyry

The quartz syenitic porphyries from the Shuigongtuan have SiO_2 of 66.52–67.67 wt.%, TiO_2 of 0.30–0.31 wt.%, Al_2O_3 of 14.77–15.00 wt.%, MgO of 0.32–0.46 wt.%, and are characterized by alkali content ($\text{K}_2\text{O} + \text{Na}_2\text{O}$ of 10.1–10.6 wt. %), $\text{K}_2\text{O}/\text{Na}_2\text{O}$ (0.8–0.9) and low $\text{Mg}/(\text{Mg} + \text{Fe})$ ratios (0.11–0.18). They have $\text{A}/\text{CNK} < 1$ and $\text{A}/\text{NK} > 1$ being metaluminous; and have geochemical affinity with A-type granites. The CIPW mineral calculation shows quartz, K-feldspar, albite and anorthite components of 10–13, 27–29, 48–50 and 1–2 respectively. The rocks fall in the field of rhyodacite–dacite in the Nb/Y – Zr/TiO_2 classification diagram (Fig. 4).

The quartz syenitic porphyry shows very high $\sum\text{REE}$ amounts of 631.1–733.8 ppm with moderate negative Eu anomalies of 0.5, reflecting magmatic differentiation. The high $(\text{La}/\text{Lu})_{\text{N}}$ ratios of 15.8–16.9 and $(\text{La}/\text{Sm})_{\text{N}}$ of 2.5–3.1 indicate LREE fractionation (Fig. 5). The REE patterns of the quartz syenitic porphyry are comparable to those of the Fujian A-type quartz syenitic porphyry, China and Mefjell syenites in the Sor Rondane Mountains from Antarctica (Li et al., 2005b).

3.2. Diabase

The diabase dykes in the Bachu area have SiO_2 of 44.39–51.98 wt.%, TiO_2 of 2.66–3.89 wt.%, Al_2O_3 of 11.64–15.90 wt.%, MgO of 3.47–7.97 wt.%, $\text{K}_2\text{O} + \text{Na}_2\text{O}$ of 2.8–5.9 wt.%, P_2O_5 of 0.32–0.88 wt.%, and $\text{Mg}/(\text{Mg} + \text{Fe})$ ratios of 0.36–0.47. K_2O contents are lower than those of Na_2O and show a wide range. The diabases show alkaline to subalkaline in nature within SiO_2 vs. $(\text{Na}_2\text{O} + \text{K}_2\text{O})$ diagram, and are broadly tholeiitic in composition with minor alkali basalt and andesite basalt nature as indicated in Zr/TiO_2 – Nb/Yb diagrams (Fig. 4). Their total rare earth element contents are in the range of 179.6–390.8 ppm, with high LREE/HREE ratios [$(\text{La}/\text{Yb})_{\text{N}}$ of 10.4–14.2] and lack of Eu anomalies (Fig. 5).

4. Discussion

4.1. Geochemical implications for the quartz syenitic porphyry and diabase in Shuigongtuan

The quartz syenite porphyry reported in this study has high Zr (920–1060 ppm), Hf (21–25 ppm), Ba (446–511 ppm), Sr, Rb, Nb (148–162 ppm), Y (54–65 ppm), LREE and Ga/Al ratios (3.9–4.2), with low P and Ti contents, and negative Eu anomaly, being comparable with A-type granites (Whalen et al., 1987). In the FeO/MgO vs. $(\text{Zr} + \text{Nb} + \text{Ce} + \text{Y})$ diagram (Fig. 6), they are indicated to be the products of anorogenic magmatism in within-plate environment, and this was clarified also by that from MORB normalized trace element spider diagram (Yang et al., 2006a).

In MgO – Al_2O_3 – FeO^* tectonic discriminative diagram, most of the diabase samples fall in the within-plate environment (Pearce et al., 1977) with minor component in the field of

Table 2
Representative major and trace elemental data of the Shuigongtuan Permian quartz syenitic porphyry and diabase

Rock name	Quartz syenitic porphyry					Diabase				
Samples	Xhzn4-4	Xhzn4-5	Xhzn4-6	Xhzn4-7	Xhzn4-8	Xhzn3-1	Xhzn3-2	Xhzn3-3	Xhzn3-6	Xhzn4-12
SiO ₂	67.08	67.49	67.71	66.52	67.54	51.98	51.31	50.70	46.97	46.10
TiO ₂	0.30	0.31	0.30	0.30	0.30	3.00	2.66	2.69	2.81	3.75
Al ₂ O ₃	14.77	14.83	14.93	14.92	15.00	14.61	15.90	15.78	14.22	13.13
FeO	3.56	3.77	3.76	4.66	3.84	11.31	10.48	10.56	12.89	13.90
MnO	0.12	0.13	0.16	0.14	0.15	0.19	0.16	0.17	0.17	0.17
MgO	0.38	0.44	0.40	0.32	0.46	3.71	3.35	3.46	6.39	4.93
CaO	1.13	1.11	1.13	0.72	0.56	7.02	7.41	6.88	9.11	9.97
Na ₂ O	5.79	5.92	5.58	5.63	5.77	4.01	4.12	5.23	2.46	2.64
K ₂ O	4.40	4.69	4.50	4.79	4.63	0.26	1.82	0.26	0.30	0.96
P ₂ O ₅	0.01	0.01	—	0.01	—	0.49	0.48	0.49	0.42	0.42
LOI	1.26	1.16	1.15	0.85	1.00	1.84	1.51	2.51	2.49	2.09
Total (wt.%)	99.19	100.27	100.04	99.37	99.69	99.69	100.40	99.93	99.69	99.60
Ba (ppm)	445.9	511.6	455.7	505.2	461.2	189.2	825.8	311.8	457.0	318.0
Rb	109.3	107.6	107.2	108.3	94.9	6.6	33.2	7.0	5.7	31.5
Sr	283.3	56.9	53.1	40.0	38.6	714.1	585.9	596.8	689.5	658.7
Zr	1006.5	1000.7	987.4	999.6	920.2	324.8	299.9	309.1	238.4	275.8
Nb	162.9	157.9	161.1	154.9	148.2	39.2	40.0	41.5	33.6	37.6
Y	65.4	65.4	65.1	59.7	54.4	33.1	28.5	31.8	25.3	29.0
Ga	31.9	32.1	32.4	33.4	30.8	22.3	22.8	24.1	21.2	22.8
Th	27.9	26.8	26.4	24.0	24.5	8.5	5.8	6.5	5.2	5.2
Ta	10.4	9.9	10.4	8.9	8.8	2.7	2.9	2.8	2.3	2.3
Hf	24.8	24.1	23.7	22.3	21.3	8.1	7.5	7.8	6.1	6.5
Sc	3.7	3.5	3.6	3.5	3.2	18.6	14.9	19.7	19.9	22.4
Cr	0.3	0.8	0.6	0.0	0.5	0.0	0.7	0.4	155.0	51.0
La	146.9	143.7	131.1	132.6	123.6	54.2	45.9	51.0	39.7	37.5
Ce	298.3	299.8	271.6	277.1	259.7	111.8	95.2	103.2	81.7	79.6
Pr	33.0	32.6	30.5	30.8	29.2	13.9	11.8	12.9	10.3	10.1
Nd	117.6	112.6	110.1	105.6	102.4	53.7	45.9	51.1	41.8	42.9
Sm	21.2	20.8	20.4	19.0	17.7	10.6	9.3	10.4	8.3	9.2
Eu	2.8	2.8	2.9	2.7	2.6	3.1	3.1	3.3	2.6	3.1
Gd	14.2	15.4	14.8	12.9	12.7	8.9	8.1	8.9	7.2	8.0
Tb	2.6	2.7	2.7	2.4	2.3	1.4	1.3	1.4	1.1	1.2
Dy	14.8	14.7	14.5	12.8	12.4	7.3	6.9	7.2	5.9	6.4
Ho	2.6	2.5	2.5	2.2	2.2	1.3	1.2	1.3	1.0	1.1
Er	6.7	6.5	6.7	5.7	5.6	3.5	3.0	3.2	2.6	2.7
Tm	0.9	0.9	0.9	0.8	0.8	0.5	0.4	0.5	0.4	0.4
Yb	5.9	5.8	5.6	5.1	5.0	2.9	2.5	2.9	2.3	2.2
Lu	0.8	0.8	0.8	0.7	0.7	0.4	0.4	0.4	0.3	0.3
Mg#	16.0	17.2	15.9	10.9	17.6	36.9	36.3	36.9	46.9	38.7
K ₂ O/Na ₂ O	0.8	0.8	0.8	0.9	0.8	0.1	0.4	0.1	0.10	0.4
Zr/TiO ₂	0.3	0.3	0.3	0.3	0.3	108.3	112.7	114.9	84.8	73.6
Y/Nb	0.4	0.4	0.4	0.4	0.4	0.8	0.7	0.8	0.8	0.8
ΣREE (ppm)	733.8	726.9	680.0	670.2	631.1	306.7	263.5	289.5	230.6	233.7
(La/Lu)N	18.2	18.3	17.1	19.0	17.7	13.1	13.2	13.0	12.3	12.1

ocean–island basalt (Fig. 7). The geochemical characteristics including Y/Nb of 0.4, enrichment in LILE and HFSE, and near-even enrichment of Nb (Fig. 8), together with the above features, indicate that the diabases were derived from a mantle source under within-plate environment.

4.2. Preliminary genetic model for bimodal dyke in Bachu Shuigongtuan

In the Tarim Basin, although Permian diabase dykes are well developed in the Bachu area, the occurrence of quartz syenite porphyry was reported recently (Yang et al., 2006a). Our discovery of the bimodal dyke in this study has important

implications for the tectonic setting of the voluminous Permian volcanic rocks occurring in the Tarim Basin.

Our field data shows that the quartz syenitic porphyry dyke occurs in direct contact with the diabase dyke (Fig. 3). Combined with geochemical characteristics of the two types of dykes, we suggest that the quartz syenite porphyry and diabase may have distinct magma characteristics and different source regions.

The diabase and quartz syenite porphyry show the Daly gap of 46%–67% in SiO₂, explained through formation under a bimodal rift setting. Based on their geochemical characters, they are probably derived from mantle source, plausibly enriched mantle. Intrusion of mantle sourced magmas into middle–upper

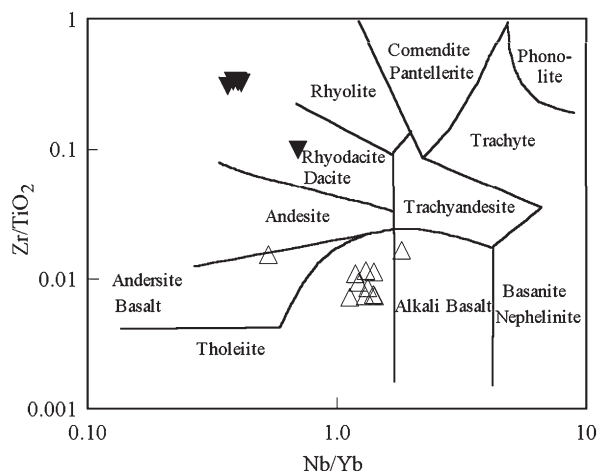


Fig. 4. Nb/Y–Zr/TiO₂ classification diagram of Permian quartz syenitic porphyry and diabase from Tarim Basin. The symbols are the same as in Fig. 3.

crust, as dykes would indicate large-scale crustal extension in the Tarim Basin during the Permian.

4.3. Tectonic evolution deduced from bimodal dykes and adjacent Permian igneous rocks

The syenite from the Xiaohaizi syenitic body has a typical A-type affinity, and represents formation in within-plate tectonic environment (Yang et al., 1996). This would indicate the major tectonothermal event in the Tarim Basin. Their geochemical characteristics (metaluminous nature, SiO₂ contents of 60.32–63.86%, high (Na₂O+K₂O) of 9.95–11.79% with Na₂O>K₂O, total REE amounts of 301.5–309.3 ppm, enrichment in LILE, HFSE, Ga/Al ratios and even pattern of Nb in the spider diagram etc.) are comparable with the Shuigongtuan quartz syenitic porphyry with A-type affinity, and they can be regarded as products under rifting setting, and derived from enriched mantle source by crystallization differentiation. They represent

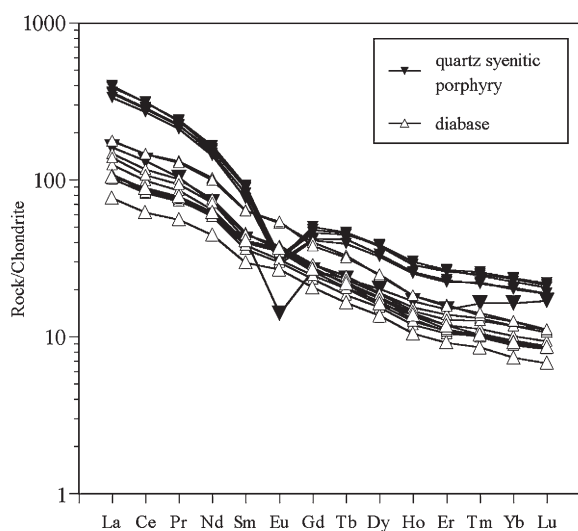


Fig. 5. Chondrite normalized rare earth elemental diagram of Permian quartz syenitic porphyry and diabase from Tarim Basin (Taylor and McLennan, 1985).

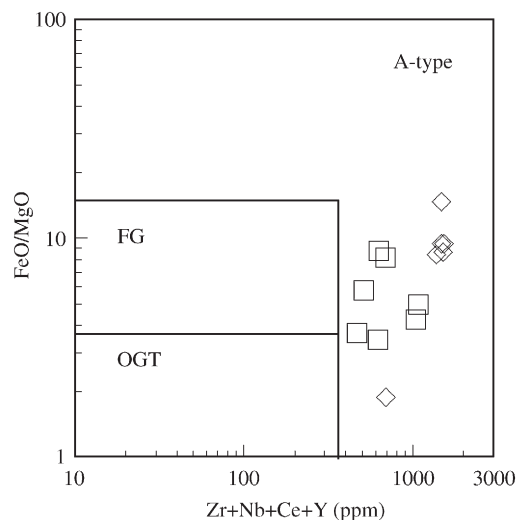


Fig. 6. FeO/MgO vs. Zr+Nb+Ce+Y diagram of the Shuigongtuan Permian quartz syenitic porphyry from Tarim Basin. Note: FG: fractionated felsic granitic rocks; OGT: unfractionated M-, I-, S-type granitic rocks; $\blacklozenge$: Shuigongtuan Porphyric samples; $\square$: Xiaohaizi syenite.

different magmatically evolved stages, albeit under the same tectonic setting of rifting.

Bimodal dykes may provide the key to understanding the rifting environment of the Tarim Block. Petrological and geochemical studies of diabases demonstrate features typical of within-plate tectonic setting, and have the same characteristics with the basalts from Keping–Bachu areas in Tarim Basin (Chen et al., 1997). The occurrence of a large number of diabase and basalts, combined with the host Late Paleozoic sedimentary sequences in the Tarim Basin, are indicative of widespread tectono-thermal event associated with crustal extension during early to middle Permian (260–292 Ma).

The timing of intrusion of the dykes is an important aspect to be resolved. We propose that the quartz syenite porphyry in the bimodal dyke may have an intrusion age of ca. 277 Ma similar to that of the surrounding syenite body (Ar–Ar age of 277.7 ± 1.3 Ma quoted from Yang et al., 1996) and diabase dykes. Therefore, the quartz syenite porphyry dyke in the bimodal suite

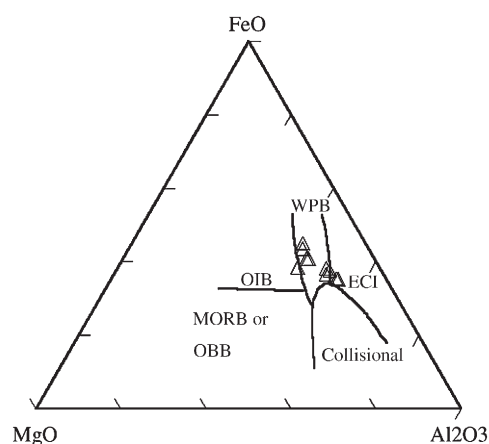


Fig. 7. FeO–MgO–Al₂O₃ diagrams of Permian diabases from Tarim Basin (Pearce et al., 1977). Note: OIB: ocean island basalt; ECI: extensional central island; OBB: ocean bottom basalt; MORB: mid-ocean-ridge basalt; WPB: within-plate basalt.

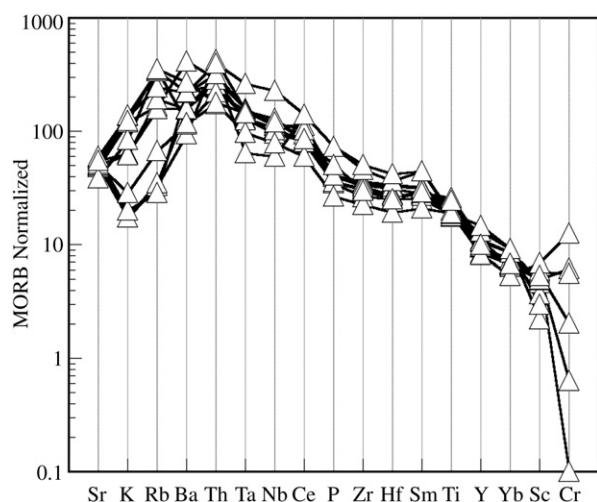


Fig. 8. MORB normalized trace spider diagram of the Shuigongtuan Permian diabases from Tarim Basin.

of our study is inferred to have formed in the same age of the diabase dyke.

A combination of data from the present study together with those of Yang et al. (1997) and Chen et al. (1997), suggests Tarim Basin evidenced a major tectonothermal event in the Permian, with strong imprints in the central and western parts of the basin. The bimodal dyke, Xiaohaizi syenite, basalt, diabase and syenite constitute a suite of magmatic rocks that formed in a rifting environment implying further that a large continental rifting setting developed in the interior of the Tarim Basin during the Permian.

5. Summary

- Geochemical characteristics of the quartz syenite porphyry within the bimodal dyke in Bachu Shuigongtuan indicate A-type affinity, formed under within-plate rifting environment and derived from mantle sources.
- The chemical characteristics of the diabase from the bimodal dyke also indicate derivation from mantle source and formation under within-plate environment.
- The quartz syenite porphyry and diabase dykes constitute the bimodal dyke in Bachu Shuigongtuan, with sharp direct contact and bimodal association. The dykes are inferred to have formed under a rift environment at ca. 277 Ma or slightly late, and probably represent the major magmatic event in the Tarim Basin.
- The quartz syenite porphyry has almost the same geochemical features with the Xiaohaizi syenite, and both show similar source characteristics and tectonic setting. The bimodal dyke suite has genetic affinity with the voluminous Permian (248–292 Ma) basalts and related magmatic rocks that occur in the Tarim Basin.

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