# Discovery of Caledonian island-arc granodiorite-tonalite in Buqingshan, Qinghai Province*

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**Abstract** The granodiorite-tonalite rock occurred in ophiolitic melange was discovered in Buqingshan area, Qinghai Province. Its Rb-Sr isochron age is $578.15 \pm 54.4$ Ma which belongs to Early Paleozoic. The rock, belonging to calcic-alkaline series, has the features of island-arc granite, which hints that oceanic crust subduction and island-arc magmatism occurred in this area in Early Paleozoic. This discovery is of great significance to recognize the tectonic framework and evolution of this area even as far as the Central Orogenic Belt.

**Keywords:** **Buqingshan, granodiorite-tonalite, Early Paleozoic, tectonics.**

The A'nyemaqen ophiolitic belt is located on the southern margin of the east sector in the East Kunlun Mts., Qinghai Province, and it joins the Qinling-Qilian-Kunlun suture system (a system including several suture zones and medium blocks resulted from the enclosure of the Qinling-Qilian-Kunlun archipelagic ocean) on the north, and the Paleotethyan suture system[1] on the south. The age of the ophiolitic belt was regarded as Late Permian-Triassic[2—4]. No Caledonian granitoid in the belt has been reported. Recently, while studying the A'nyemaqen ophiolitic belt, the authors discovered Caledonian granodiorite-tonalite in Yikehalaer valley and Delisitan valley of Buqingshan area which is situated in the west sector of the ophiolitic belt. The rock body was once regarded as the Permian-Triassic syn-orogenic tonalite[5], but there was not any isotopic data to support it. The study reveals that the rock body was formed in Early Paleozoic and the rock has the features of the island-arc granite, which tallies with the Late Sinian-Early Paleozoic N-MORB ophiolite newly discovered in the ophiolitic belt[1)]. This discovery furnishes a new important basic data for studying the tectonic framework and evolution of this area, as well as the Central Orogenic Belt.

## 1 Geological background

The Buqingshan ophiolitic melange consists of a series of structural slices, including ophiolitic slice, chert and abyssal red clay slice, flysch slice, bioclastic limestone slice, and Triassic sandstone and slate slice etc. The north part is covered by a nappe of Late Carboniferous-Early Permian bioclas-

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1) Bian, Q. T., Luo, X. Q., Li, D. H. et al., Age of the A'nyemaqen ophiolites, Qinghai Province, China, unpublished.

tic limestone (reef limestone). Recently, the study shows that there are two periods of ophiolite of Late Sinian-Early Paleozoic and Early Carboniferous-Early Permian in the ophiolitic melange1). Granodiorite-tonalite intruded in the former ophiolite, the rock body contains the xenoliths of ultramafic rocks. There are two bodies, east and west. The west one is about 10 km long and 2.5 km wide; the east one is 5 km long and about 700 m wide (fig. 1). From the center of the body to the border area, the quartz content decreases while the dark mineral content increases. The rock has slight porphyritic texture, and had undergone intensive dynamic metamorphism, universally cataclastic and mylonitization locally. The main mineralogical composition is plagioclase (45%—60%). Most of the edges are in irregular or hacked shape, polysynthetic twin has the phenomena of slip and bend, locally minor alteration, and was metasomatised by fine-grained muscovite etc. The second mineralogical composition is quartz (20%—30%), and has universal undulatory extinction and partial subgrain structure. There is a small amount of potassium feldspar (about 10%). The dark minerals are biotite, hornblende and pyroxene (10%—15%), which had undergone partial chloritization and epidotization. Common accessory minerals are sphene, apatite and magnetite etc.

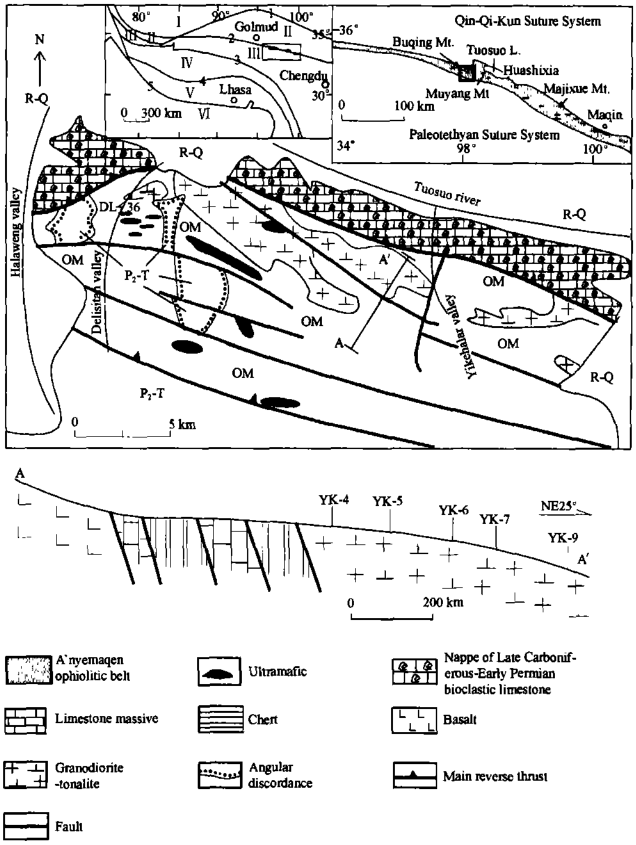


Fig. 1. Geological sketch map showing the distribution of Granodiorite-tonalite in Buqingshan area. R-Q, Tertiary-Quaternary; $P_2$-T, Late Permian-Triassic; OM, Ophiolitic melange belt. Top insertion: I, Tarim-North China block; II, Qinling-Qilian-Kunlun suture system; III, Paleotethyan suture system; IV, South Qiangtang block; V, Gangdise block; VI, Indian block; 1, West Kunlun-A'erjing-north Qilian suture zone; 2, South margin of Kunlun suture zone; 3, Hongshanhu-Shuanghu-Lancangjiang suture zone; 4, Bangonghu-Nujiang suture zone; 5, Yarlung Zangbo suture zone.

## 2 Isotopic chronology

### 2.1 Rb-Sr isochron age

Along a profile, the granodiorite-tonalite samples were systematically sampled in fixed intervals (sampling positions are drawn in fig. 1). The Isotopic Office of the Institute of Geology, Chinese Academy of Sciences was assigned to measure the Rb-Sr isotopic age. The result is listed in table 1.

1) Seee footnote 1) on pape 74.

The Rb-Sr isochron age is 578.15 ± 54.4 Ma (fig. 2), belonging to Early Paleozoic.

Table 1 Data of Rb-Sr isotope measurement for granodiorite-tonalite in Buqingshan area

| Sample | Rb/$\mu g \cdot g^{-1}$ | Sr/$\mu g \cdot g^{-1}$ | $^{87}Rb/^{86}Sr$ | $^{87}Sr/^{86}Sr \pm (2\sigma)$ |
|---|---|---|---|---|
| YK-4 | 53.37 | 513.1 | 0.317 2 | 0.708 227 ± 11 |
| YK-5 | 48.15 | 405.7 | 0.342 7 | 0.708 359 ± 16 |
| YK-6 | 43.38 | 542.4 | 0.230 9 | 0.707 491 ± 16 |
| YK-7 | 45.46 | 527.2 | 0.247 0 | 0.707 616 ± 10 |
| YK-9 | 27.93 | 516.4 | 0.156 2 | 0.706 869 ± 12 |

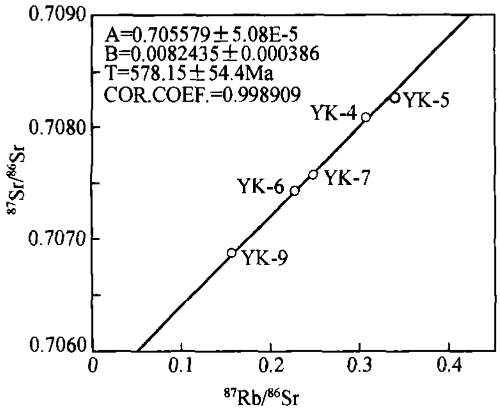


Fig. 2 Rb-Sr isochron diagram of the granodiorite-tonalite in the Buqingshan area of the A'nyemaqen ophiolitic belt. A, Sr isotopic initial ratio; B, slope; T, age; COR. COEF., correlation coefficient.

## 2.2 Reliability analysis of the isochron age

The granodiorite-tonalite was only slightly altered, and the five isochron samples show good linear correlation, so the isochron age data should be reliable. Recently, the authors obtained two isochrons of the gabbro-diabase, which are 517.89 ± 101.6 Ma and 495.32 ± 80.6 Ma respectively, and a doubtful Early Paleozoic radiolarian in the ophiolitic melange[1)]. These age data and information agree roughly with the Rb-Sr isochron for the granodiorite-tonalite, and they support each other.

# 3 Tectonic setting and geotectonic significance

## 3.1 Tectonic setting

The petrochemical analyses for this granodiorite-tonalite are listed in table 2. Using the CIPW (Cross, Iddings, Pirsson, Washington System of Rock Classification) method, the normative mineral contents are as follows: quartz 15.51%—26.97%, anorthite 7.38%—16.98%, albite 40.52%—45.94%, orthoclase 9.21%—19.76%, hypersthene 2.04%—9.65%, corundum 0.13%—1.61%, magnetite 0.63%—1.86%, ilmenite 0.56%—1.26%, apatite 0.27%—0.55%, zircon 0.03%, and chromite 0.03%—0.04%. On the Q-A-P diagram, two samples are projcted within the field of granodiorite and other two samples are within the field of tonalite. The rock belongs to sub-alkali and calcic-alkaline series (fig. 3(a)), and can be compared with the island-arc calcic-alkaline volcanic suite. $\sum$REE = 140.3—143.8 $\mu g/g$, LREE/HREE = 16.47—29.65, $(La/Yb)_N$ = 26.71—54.02, and $\delta Eu$ = 0.81—0.98 shows slight negative Eu abnormality (REE: rare earth elements; LREE: light rare earth elements; HREE: heavy rare earth elements). The curve of the chondrite-normalized REE pattern shows that the LREE is of the enriched model (fig. 3(b)), which accords with the island-arc calcic-alkaline series; Eu has slight abnormality, and the curve is flat from Dy to Lu. On the spider diagram of the Ocean Ridge Granites-normalized trace element (fig. 3(c)), the rock sample curves show that the large ion lithophiles K, Rb, Ba, Th enriched evidently, and

1) Bian, Q. T., Luo, X. Q., Li, J. H. et al., Discovery of two periods of ophiolites in the Buqingshan-Muyangshan, Qinghai Province and its geo-tectonic significance, in press.

Table 2 Data of chemical analysis for granodiorite-tonalite in Buqingshan area (wt%)[a)]

| Sample | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | FeO | $Fe_2O_3$ | MnO | CaO | MgO | $K_2O$ | $Na_2O$ | $P_2O_5$ | LOI | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dl-36 | 71.59 | 0.29 | 14.81 | 0.84 | 0.43 | 0.01 | 1.51 | 0.52 | 3.28 | 4.87 | 0.11 | 1.24 | 99.50 |
| Yk-5 | 68.77 | 0.47 | 14.97 | 1.43 | 0.90 | 0.05 | 2.46 | 1.22 | 2.39 | 4.74 | 0.15 | 1.91 | 99.46 |
| Yk-9 | 67.28 | 0.46 | 16.11 | 1.81 | 0.77 | 0.04 | 3.50 | 1.37 | 1.52 | 4.68 | 0.18 | 1.58 | 99.30 |
| Yk-72 | 63.65 | 0.65 | 16.92 | 3.12 | 1.26 | 0.07 | 2.86 | 2.30 | 1.78 | 5.33 | 0.23 | 2.08 | 100.25 |

| Sample | Ti | Cr | Co | Ni | Rb | Sr | Y | Zr | Nb | Hf | Ta | Ba | Th | U | La | Ce |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dl-36 | 1696.3 | 172.8 | 5.1 | 32.3 | 65.4 | 519.2 | 4.9 | 143.0 | 8.7 | 5.6 | 1.2 | 1081.9 | 12.7 | 0.9 | 34.6 | 71.9 |
| Yk-5 | 2840.5 | 137.9 | 9.6 | 88.5 | 54.9 | 444.1 | 6.9 | 158.3 | 9.0 | 6.6 | 2.1 | 1497.8 | 8.2 | 1.7 | 35.7 | 66.9 |
| Yk-9 | 3075.0 | 143.0 | 9.8 | 78.0 | 33.5 | 560.4 | 11.0 | 160.3 | 18.1 | 6.6 | 1.07 | 734.7 | 9.5 | 1.2 | 33.3 | 66.7 |

| Sample | Pr | Nd | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu | δEu | ΣREE | $(La/Yb)_N$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dl-36 | 6.8 | 21.95 | 3.09 | 0.81 | 2.22 | 0.27 | 0.93 | 0.19 | 0.57 | 0.05 | 0.38 | 0.08 | 0.98 | 143.8 | 54.02 |
| Yk-5 | 6.5 | 20.96 | 3.03 | 0.85 | 3.03 | 0.28 | 1.31 | 0.26 | 0.60 | 0.09 | 0.62 | 0.08 | 0.93 | 140.3 | 34.25 |
| Yk-9 | 6.5 | 22.01 | 4.46 | 0.97 | 3.30 | 0.47 | 1.99 | 0.37 | 1.01 | 0.14 | 0.74 | 0.11 | 0.81 | 142 | 26.71 |

a) The major elements were analyzed by X-ray fluorescence analysis, the REE and trace elements were by ICP-MS.

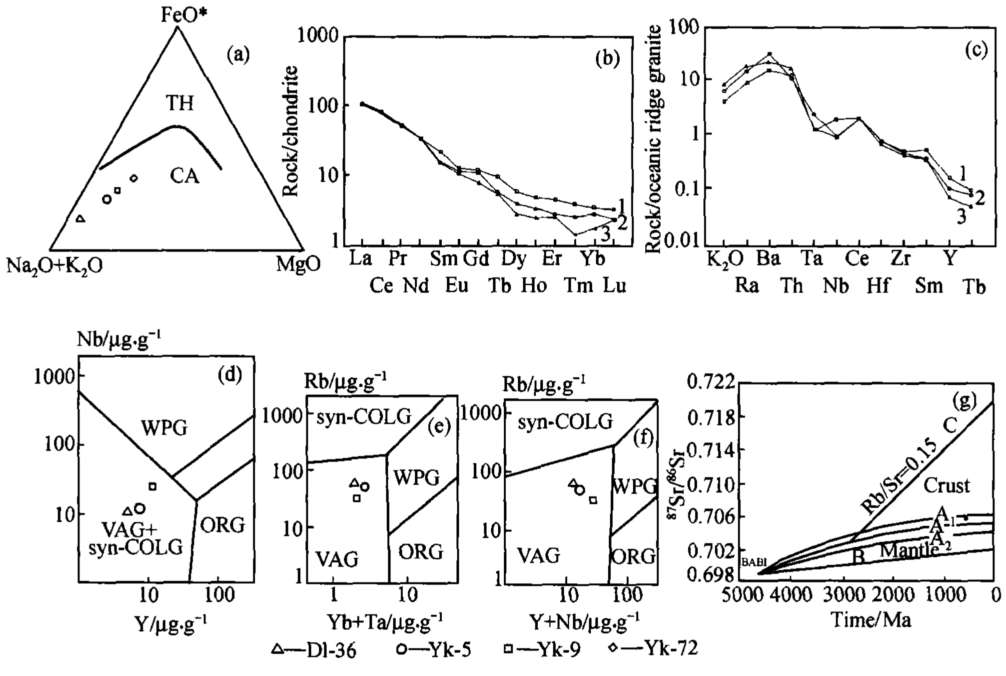


Fig. 3. Geochemical diagrams of the granodiorite-tonalite in Buqingshan area. (a) Map of ALK-FeO*-MgO[6]; TH, tholeiitic series; CA, calcic-alkaline series; (b) chondrite-normalized REE distribution patterns; (c) spider diagram of ocean ridge granite-normalized trace element; (d) map of Nb-Y[7]; (e) map of Rb-(Y + Nb)[7]; (f) map of Rb-(Yb + Ta)[7]; (g) evolution diagram of the earth Sr isotope[8]: $^{87}Sr/^{86}Sr$, Initial Sr isotopic ratio; BABI, Basaltic achondrite best initial (0.698 97 ± 0.000 03); curve A, Mantle's Sr isotope average evolution; curve $A_1$-$A_2$, fluctuated range of Sr isotope evolution; straight line B, Sr isotope evolution line of mantle depleted Rb; straight line C, continental crust Sr isotope ratio.

Ce, Sm is positively abnormal. The content of Y, Yb is low, which is the typical character of the island-arc granite. On the Nb-Y diagram (fig. 3(d)), all the samples are projected within the field of the volcanic island-arc granite and syn-collision granite. On the Rb-(Y + Nb) diagram (fig. 3(e)) and the Rb-(Yb + Ta) diagram (fig. 3(f)), all the samples are within the field of the volcanic arc granite. The Sr isotopic evolution diagram (fig.3(g)) shows that its initial ratio falls above the mantle Sr isotopic average evolution curve (A) and within the overlapping area between the mantle Sr isotopic fluctuating range and the crustal Sr isotopic evolution range, which suggests that the material source probably came from the partial melting matter of the subduction zone, which was mainly from the mantle and undergone crust contamination.

### 3.2 Geotectonic significance

It is the first time to discover the Early Paleozoic granodiorite-tonalite with island-arc tectonic property in the A'nyemaqen ophiolitic belt. Reasearch with isotope chronology and magmatic lithology proves that the oceanic basin subduction and island-arc magmatism in this area occurred in Early Paleozoic. The analysis on the relationship between the granodiorite-tonalite and the ophiolitic melange indicates that the granodiorite-tonalite is likely the product formed in the Early Paleozoic by subduction of the oceanic basin which is represented by the Early Paleozoic ophiolite occurred in the ophiolitic melange belt. Furthermore, it should be the product formed while the subduction zone was moving backward and the island-arc moving toward ocean, so that the island-arc magmatic rock was superimposed upon the subduction complex. The oceanic basin is probably a part of the Qinling-Qilian-Kunlun Ocean, which means that there had been also the Qinling-Qilian-Kunlun Oceanic basin in the East Kunlun, just like the West Kunlun, Qinling and North Qilian. It is of great significance to reconstruct the tectonic framework and evolution of this area, even the Central Orogenic Belt.

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## References

1 Bian, Q. T., Zheng, X. S., On the tectonic characteristics and evolution of the Hoh Xil region, Qinghai province, in *Collection of Structure of Continental Lithosphere and Mineral Resources* (in Chinese), Beijing: Ocean Press, 1992, 19.

2 Jiang, C. F., Yang, J. S., Fen, B. G. et al., *Opening-Closing Tectonic of Kunlun Mountains* (in Chinese), Beijing: Geological Publishing House, 1992.

3 Xu, Z. Q., Yang, J. S., Cheng, F. Y., Suture zone and geodynamics of "subduction-collision" in the A'nyemaqen, in *Collection of Study on Ophiolites and Geodynamics* (in Chinese), Beijing : Geological Publishing House, 1996, 185—189.

4 Yin, H. F., Zhang, K. X., Characteristics of the eastern Kunlun orogenic belt, *Earth Science* (in Chinese), 1997, 22(4): 339.

5 Wang, G. C., Zhang, B., Zhang, T. P., et al., Tectonic reposition of non-Smith strata in orogenic belt, *Regional Geology of China* (in Chinese), 1998, (supplement): 25.

6 Irvine, T. N. Barager, W. R. A., A guide to the chemical classification of the common volcanic rocks, *Canadian Journal of Earth Sciences*, 1971, 8: 523.

7 Pearce, J. A., Harris, N. B.W., Tindle, A. G., Trace element discrimination diagrams for the tectonic interpretation of granitic rocks, *Journal of Petrology*, 1984, 25: 956.

8 Fuer, G., *Principle of Isotopic Geology* (in Chinese), Beijing: Science Press, 1983, 89—91.