Zircon U-Pb age and geochemistry of the late ordovician monzonitic granite in the Xiaoxilin from the lesser Khingan

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Abstract: In this paper, we present new U-Pb zircon ages and major and trace elements for the Late Ordovician monzonitic granite rocks in Xiaoxilin area in the Eastern lesser khingan of Northeast China to elucidate the westward subduction of the Oceanic plate in Late Ordovician. U-Pb zircon dating results demonstrate that the monzonitic granites formed at 451±5Ma, belonging to the Late Ordovician.These monzonitic granites are characterized have SiO_2 of 66.45%~72.93%, Na_2O of 2.41%~3.93%, K_2O of 3.09%~5.58%, CaO of 2.02%～3.76%, ALK of 6.56%～7.99% and A/CNK=0.97~1.02, belonging to the high-K calc-alkaline series. The monzonitic granites is characterized by the enrichment of LILEs (e.g., Rb and K) and incompatible elements(e.g., Th and U), and depletion of HFSEs(e.g., Nb, Ta, Sr, P and Ti), as well as very lesser Eu anomalies (Eu/Eu*=0.49~1.06). The rock falls into the zone of Pre-Plate collision with the characteristics of active continental margin before the collision. Combine the mineral assemblage and geochemical characteristics, it is believed that the monzonitic granite in Xiaoxilin area was formed in the environment of oceanic crust subduction, which indicates that there was an westward subduction oceanic plate between Jiamusi Massif and Songnen-Zhangguangcailing Massif. The melt/fluid precipitated from the subducting oceanic plate confessed the overlying mantle wedge and caused the partial melting of it, which resulted in the arc magmatism. The Jiamusi Massif and Songnen-Zhangguangcailing Massif had not yet joined in the Late Ordovician.

1 Introduction

The study of the granites in the Xiaoxilin area mostly focus on the Mesozoic granite. In this paper we present new U-Pb zircon ages, and major and trace elements for poorly studied Early Paleozoic granitic rocks in Xiaoxilin area in the Lesser Khingan of Northeast China.

2 Geological background

The Xiaoxilin area is located in 40 km southeast of Yichun City, Heilongjiang Province, the geographic coordinates range between 129°07′56″～129°11′07″E and 47°21′59″～47°26′18″N. The tectonic location belongs to the Wuxing-Guansongzhen uplift belt in the central part of the Yichun-Yanshou fold orogenic belt which lactated in the outer edge with overlapping parts of Mongolian-Okhotsk collision orogenic belt and the continental Pacific subduction zone. In the east, it's bounded the Jiamusi Massif by Jiameng-Yilan-Mudanjiang fault and connected with the Songliao Basin in the western part (Fig. 1).
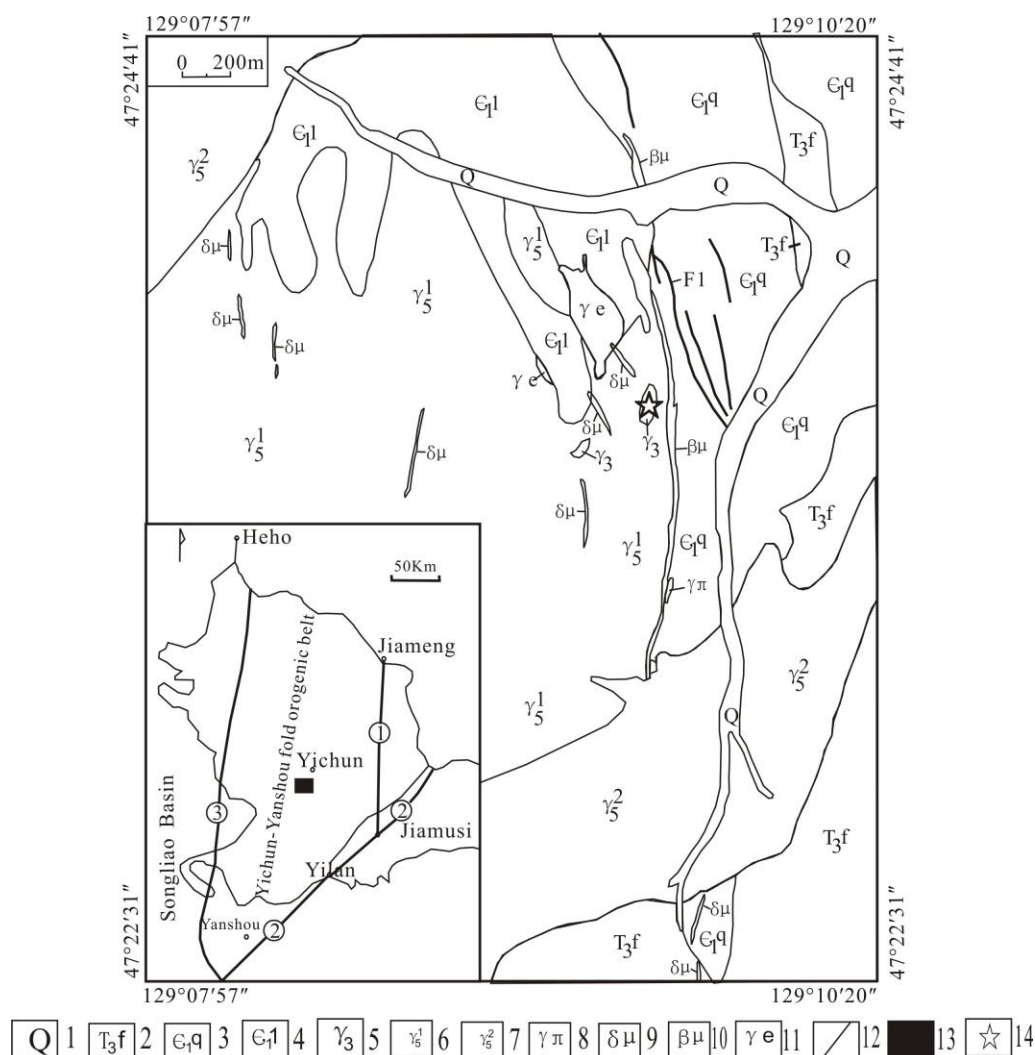
Fig.1 The geological map of the Xiaoxilin area
① Jiameng-Yilan-Mudanjiang fault; ② Jiamusi-Yisuhe Fault; ③ Xuhe-Shangzhi Fault.
1. Quaternary; 2. Fengshan Formation; 3. Qianshan Group; 4. Laodaomiaogou Formation; 5. Caledonian granite; 6. Indosinian granite; 7. Yanshanian granite 8. Granite porphyry; 9. granite diorite veins; 10. Diabase porphyry; 11. Granite fine crystal; 12. fault; 13. mine location; 14. sampling position.

The main strata in the area are the Laodaomiaogou Formation, the Qianshan Formation, the Fengshantun Formation of the Upper Triassic, and the quaternary system. The Laodaomiaogou Formation is mainly composed of metamorphic sandstone, siltstone, and gravel sandstone locally, the Qianshan Formation consists of dolomite, dolomitic marble folder carbonaceous slate. Fengshantun Formation mainly composed of acid volcanic rocks and their clastic rocks, local alteration and Pb - Zn mineralization. Separation fracture develops in the area, which is mainly in the longitudinal (near north-south) and the direction roughly coincides with the direction of strata or slightly oblique. F1 fracture is the largest vertical fracture in the area, exposed to the transition zone from Xilin syncline to Qianshan anticline, with the direction of strike near SN, trend E. The magmatism in the area is strong, mainly in the three periods of the Caledonian, the Indosinian and the Yanshan, on lithology it has adamellite, granite porphyry, granodiorite, granite aplite and allgovite and so on.

3 Petrography and sample descriptions
The samples of the monzonitic granite used during this study were collected from 47°23′57″N,

129°09′35″E. The sample contain Alkali feldspar(~40%), quartz (~30%), plagioclase (~20%), Sericite (~5%) and Opaque mineral(~5%)(Fig.2)..
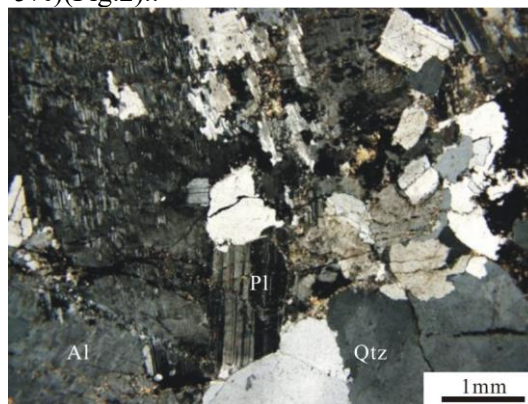

Fig. 2 Microscopic photograph of the monzonitic granite (plane polars)
Qtz: quartz; Pl: Plagioclase; Al: Alkali feldspar

4 Analytical methods

4.1 U-Pb Zircon dating
The samples used for zircon U-Pb dating were crushed using conventional crushing and were separated using heavy liquids and a magnetic separator at the Langfang Regional Geological Survey, Hebei Province, China. Laser ablation inductively coupled plasma mass spectrometry (LA–ICP–MS) U–Pb analyses were conducted using the Agilent 7500a ICP-MS instrument equipped with ComPex102 ArF (193 nm) at the State Key Laboratory of Continental Dynamics, Northwestern University, Xi'an, China, using a 30 μm spot diameter. Details of the analytical technique are described in Yuan et al. (2004)[1], common Pb concentrations were evaluated following Andersen (2002)[2], and ISOPLOT version 3.0 (Ludwig, 2003)[3] was used for age calculations and for constructing concordia diagrams.

4.2 Whole-rock geochemistry determination
For geochemical analysis, whole-rock samples, after the removal of altered surfaces, were crushed in an agate mill to ~200 mesh. X-ray fluorescence (XRF; PW1401/10) using fused-glass
disks and ICP-MS (Agilent 7500a with a shield torch) were used to measure the major and trace elements compositions, respectively, at the Testing Center of Jilin University, after acid digestion of samples in Teflon bombs.

5 Results

5.1 U-Pb Zircon ages
The analytical results of U-Pb zircon dating in the Late Ordovician monzonitic granites are listed in Table 1. Zircons CL images from monzonitic granite (samples XXL-N2) reveal that the zircons display typical magmatic oscillatory zoning and rhythmically zoned textures (Fig.3) euhedral-subhedral in shape and the Th/U ratios of 0.22–0.69. The 12 analytical sites show that the ages range from 443 to 461 Ma, and the majority of ages are centralized at around 450 Ma. The weighted mean age is 451±5 Ma (1σ, MSWD= 0.43, n=12; Fig. 4).

Table.1 LA-ICPMS zircon U-Pb data of the monzonitic granite

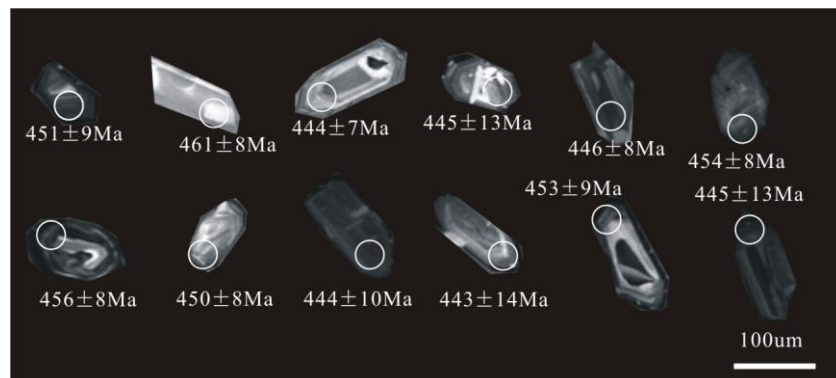| Sample	Th/U	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{206}Pb/^{238}U$	1σ
XXL-N2-01	0.47	0.05824	0.00654	0.57043	0.06134	0.07121	0.0024	443	14
XXL-N2-02	0.35	0.05544	0.0024	0.546	0.01951	0.07158	0.00136	446	8
XXL-N2-03	0.22	0.05593	0.00177	0.54915	0.01152	0.07134	0.00123	444	7
XXL-N2-04	0.69	0.056	0.00553	0.55127	0.05176	0.07152	0.00215	445	13
XXL-N2-05	0.52	0.05542	0.00535	0.54517	0.05002	0.07145	0.0021	445	13
XXL-N2-06	0.42	0.05693	0.00298	0.57109	0.02612	0.07285	0.00149	453	9
XXL-N2-07	0.45	0.05659	0.00317	0.56444	0.0281	0.07243	0.00152	451	9
XXL-N2-08	0.40	0.05597	0.00218	0.56451	0.01713	0.07323	0.00133	456	8
XXL-N2-09	0.69	0.05926	0.00227	0.59659	0.01755	0.07304	0.00131	454	8
XXL-N2-10	0.26	0.05632	0.00185	0.57556	0.01271	0.07412	0.00126	461	8
XXL-N2-11	0.36	0.05634	0.0026	0.56178	0.0217	0.07231	0.00137	450	8
XXL-N2-12	0.42	0.05589	0.00379	0.54911	0.03411	0.07124	0.00163	444	10

Fig.3 CL images of representative zircons from the monzonitic granite
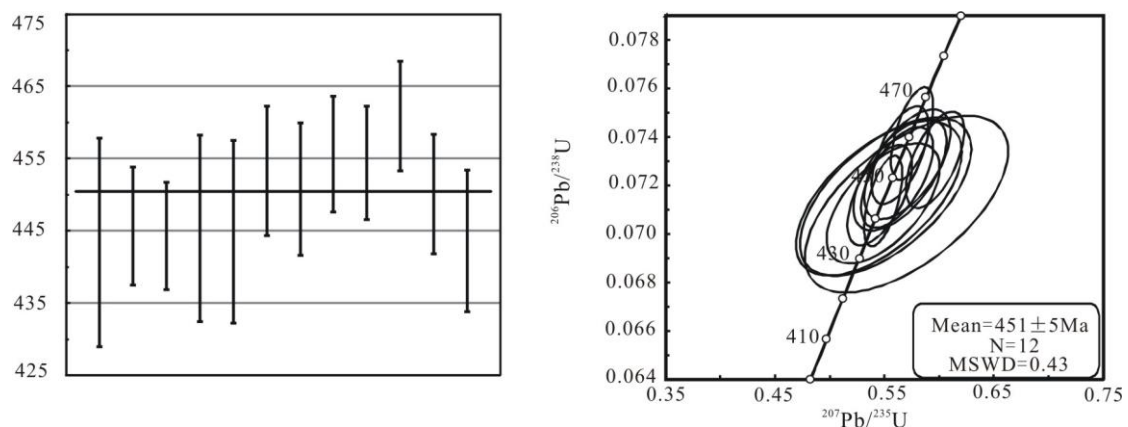

Fig. 4 Zircon U-Pb concordia diagram and weighted average ages diagram from the monzonitic granite

5.2 Geochemistry characteristics

The analytical results of major and trace elements in the Late Ordovician monzonitic granites are listed in Table 2. The monzonitic granite in Xiaoxilin area have SiO_2 of 66.45%~72.93%, Na_2O of 2.41%~3.93%, K_2O of 3.09%~5.58%,CaO of 2.02%～3.76%, ALK of 6.56%～7.99% and A/CNK=0.97~1.02. They are classified as granite in a total subalkalic versus SiO_2 (Fig.5a) diagram and are classified as high-K and calc-alkaline in a K_2O versus SiO_2 diagram(Fig.5b).

Table 2. Major and trace element compositions of the monzonitic granite

Sample	XXL-B1	XXL-B2	XXL-B3	XXL-B4
SiO_2	72.93	68.02	66.62	66.45
TiO_2	0.27	0.42	0.46	0.47
Al_2O_3	13.49	15.76	15.9	15.88
Fe_2O_3	1.16	1.55	1.79	1.7
MnO	0.08	0.17	0.15	0.16
MgO	0.44	1.33	1.21	1.29
CaO	2.02	2.99	3.59	3.76
Na_2O	3.93	2.41	3.3	3.47
K_2O	3.43	5.58	3.76	3.09
P_2O_5	0.1	0.18	0.23	0.24
LOI	0.64	0.46	1.08	1.14
Total	98.49	98.87	98.09	97.65
K_2O/Na_2O	0.87	2.32	1.14	0.89
K_2O+Na_2O	7.36	7.99	7.06	6.56
A/CNK	0.97	1.02	0.99	1
La	15.98	41.41	23.57	11.02
Ce	24.04	71.14	55.17	21.42
Pr	2.68	9.11	6.45	2.7
Nd	9.09	32.92	24.18	9.52
Sm	1.61	6.4	5.15	1.9
Eu	0.52	1.01	1.02	0.35
Gd	1.31	6.14	5.03	1.8
Tb	0.16	0.96	0.84	0.29
Dy	0.89	6.1	5.35	1.82
Ho	0.18	1.36	1.19	0.41
Er	0.52	4.4	3.79	1.29
Tm	0.08	0.73	0.62	0.21
Yb	0.59	5.08	4.43	1.5
Lu	0.11	0.78	0.69	0.23
Cr	8.94	10.91	4.92	4.68
Ni	5.08	6.2	3.96	2.22
V	21.86	31.56	45.39	10.85
Rb	112.7	222.7	54.56	44.19
Sr	294.4	201.4	202.8	81.52
Ba	296.9	935.5	605.2	192.1
Pb	32.76	237.3	68.92	18.19
Ga	16.82	19.77	19.09	5.48
Y	4.45	37.99	28.2	11.39

Zr	123.3	262.3	173.6	56.57
Nb	5.19	18.26	13.83	3.81
Ta	0.49	1.57	1.21	0.36
Hf	4	7.53	5.05	1.62
Th	11.84	14.99	11.12	5.08
ΣREE	57.74	187.54	137.48	54.45
ΣLREE	53.92	161.99	115.54	46.91
ΣHREE	3.84	25.55	21.94	7.55
LREE/HREE	14.03	6.34	5.27	6.22
（La/Yb）$_N$	18.3	5.49	3.58	4.97
ΔEu	1.09	0.49	0.61	0.59

$A/CNK=Al_2O_3/(CaO+Na_2O+K_2O)$; $\delta Eu=2\times(Eu/0.0735)/(Gd/0.259+Sm/0.195)$；$LREE=La+Ce+Pr+Nd+Sm+ Eu$; $HREE=Gd+Tb+Dy+Ho+Er+Tm+Yb+Lu$; $(La/Yb)_N=(La/0.310)/(Yb/0.209)$。
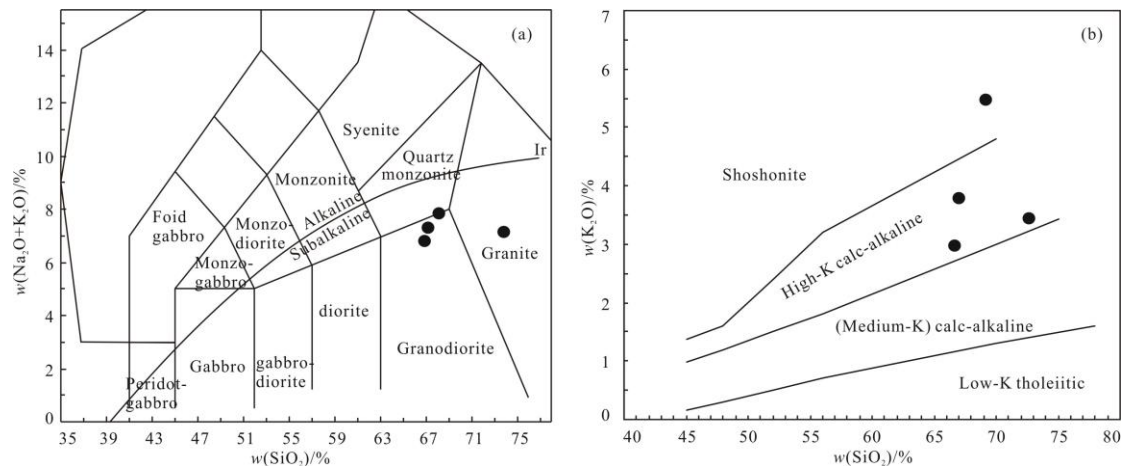

Fig.5   Total alkali versus SiO$_2$ diagram and SiO$_2$ versus K$_2$O diagram for the monzonitic granite
(a: base map modified after reference[4]; b:base map base map modified after reference[5])

The monzonitic granites in the Xiaoxilin area are weak enrichment in LREE (Fig.) and the (La/Yb)$_N$ values of 3.58–18.30, with the weak Eu anomalies (Eu/Eu*=0.49～1.09). The monzonitic granite is characterized by the enrichment of LILEs (e.g., Rb and K) and incompatible elements(e.g., Th and U), and depletion of HFSEs(e.g., Nb, Ta, Sr, P and Ti).(Fig.6),
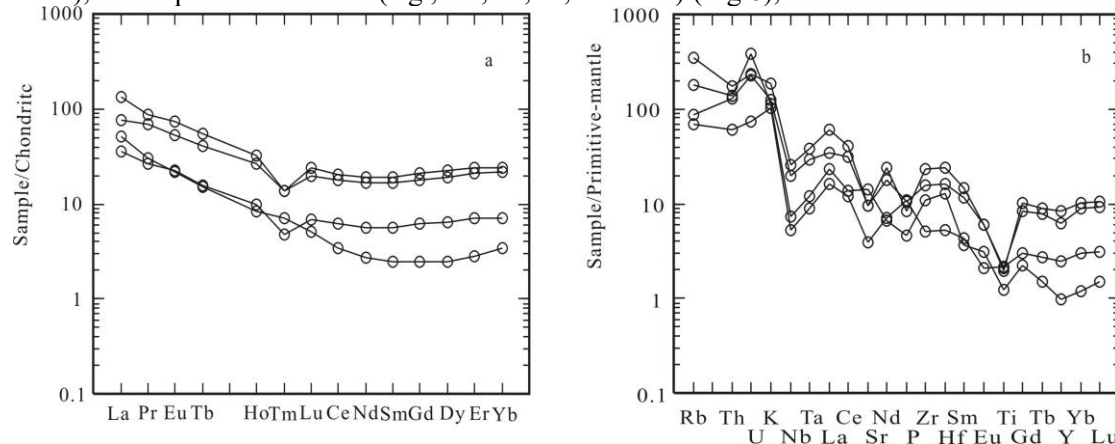

Fig.6 Chondrite-normalized REE distribution patternsand primitive mantle-normalized trace element spider diagramsof the monzonitic granite (a: base map modified after reference[6]; b:base map base map modified after reference[7])

6 Discussion

The monzonitic granites are high-k calc alkaline granites, which are mainly formed in the tectonic setting of the continental arc and the collision of the plate after the collision of the two. In the Rb-(Y+Nb) tectonic discriminant diagrams (Fig.7a), all the samples fall into the volcanic arc granite area. The ratio of Zr/Y (4.97～27.70), with an average value of 11.43, three in the four ratios are from 4.97 to 6.90, the scope of the main continental margin between the andesite (Zr/Y ratio ranged from 4 to 12, Condie 1989), shows the characteristics of active continental margin arc. The average La/Nb ratio (1.70～3.08) is 2.49, which is that of active continental margin La/Nb ratio (>2). In the R1-R2 diagram of granite (Fig.7b), the samples mainly fall into the zone of granite from the subduction zone before the collision, which is equivalent to the active plate margin. The above characteristics indicate that the late Ordovician granite is mainly formed in the tectonic environment of active continental margin.
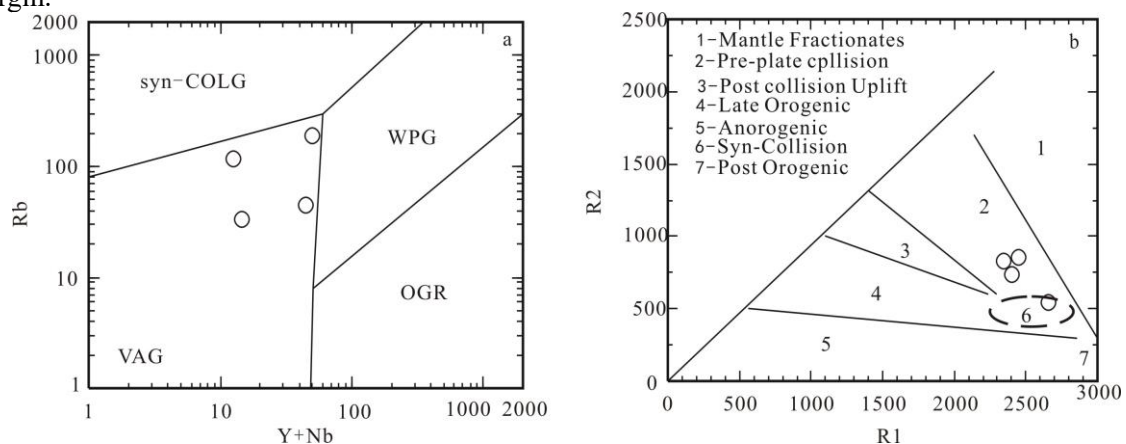

Fig. 7 Tectonic setting discrimination diagrams of the monzonitic granite
(ORG–ocean ridge granites; VAG–volcanic arc granites; WPG–within plate granites;
syn-COLG–syn-collision granites)

The Northeast orogenic belt is composed of many micro plates (XingKai Massif、Jiamusi Massif、Songnen-Zhangguangcai Massif、Erguna Massif and Xingan Massif).There are two points about the time of the Jiamusi Massif associated with Songnen-Zhangguangcai Massif. Some studies suggest that the Jiamusi Massif was associated with Songnen-Zhangguangcai Massif in Ordovician and the others suggest the time is Silurian.The monzonitic granite in study area formed at 451±5 Ma, it belongs to Late Ordovician. The above characteristics indicate that the late Ordovician granite is mainly formed in the tectonic environment of active continental margin. We conclude, therefore, that the the Jiamusi Massif was not yet associated with Songnen-Zhangguangcai Massif in in Late Ordovician.

Based on the research result and the previous studies, we summarize the evolution of the Northeast China Orogenic belt. In the Late Proterozoic, the Northeast China had been affected by the Rodinic Super-continent breakup. From the Late Mesoproterozoic to the Late Proterozoic, the Paleo Asian ocean basin formd in the Northeast China. From the Late Proterozoic to the Early Cambrian, there are many small oceans in the micro plates (XingKai Massif 、 Jiamusi Massif 、 Songnen-Zhangguangcai Massif、 Erguna Massif and Xingan Massif). In the Ordovician, The Jiamusi Massif and Songnen-Zhangguangcailing Massif had not yet joined. In the Silurian, the Jiamusi Massif was associated with the Songnen-Zhangguangcailing Massif.

7 Conclusions

Based on the U-Pb zircon ages and geochemical data presented in this paper, we draw the following conclusions:

1. U-Pb zircon dating results demonstrate that the monzonitic granites formed in Late Ordovician (451±5 Ma).

2. These monzonitic granites are characterized have SiO_2 of 66.45%~72.93%, Na_2O of 2.41%~3.93%, k_2O of 3.09%~5.58%, CaO of 2.02%～3.76%, ALK of 6.56%～7.99% and A/CNK=0.97~1.02, belonging to the high-K calc-alkaline series

3. The late Ordovician monzonitic granites is mainly formed in the tectonic environment of active continental margin.

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