

中国东北黑龙江杂岩体蓝闪石片岩岩石学研究

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摘要: 黑龙江杂岩主要由蓝闪石片岩构成, 蓝闪石片岩主要包括绿帘石、绿泥石、钠长石、钠质角闪石、多硅白云母和石英以及为数不多的榍石、钛铁矿和黑硬绿泥石。其中, 钠质角闪石包括蓝闪石和镁质钠闪石。变质条件的压力(P)-温度(T)评价条件为 $400\sim 425\text{ }^{\circ}\text{C}$ 和 $0.69\sim 0.86\text{ MPa}$, 对应岩相为绿帘-蓝闪石片岩相。黑龙江杂岩蓝闪石片岩的地球化学研究表明, 其原岩是可与洋岛型(OIB)玄武岩和一些洋中脊型(E-MORB)玄武岩相对比的大洋玄武岩, 这说明黑龙江杂岩蓝闪石片岩的玄武岩原岩是在海底山或者在大洋隆起条件下由富集源形成的; 具有洋岛型玄武岩地球化学特征的变质玄武岩以及富锰的变质燧石、大理石、变质硬砂岩和蛇绿岩鳞片的加入证明黑龙江杂岩是消减-增生杂岩, 它含有变形洋壳的碎块和在改造的前震旦纪佳木斯岩体西边缘上形成于侏罗纪的增生楔岩石; 黑龙江杂岩在原岩成分上可与活动大陆边缘许多增生的杂岩相当。

关键词: 蓝闪石片岩; 岩石学; 黑龙江杂岩; 洋岛型; 洋中脊型

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Petrology of Blueschists of Heilongjiang Complex in Northeast China

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Abstract The Heilongjiang Complex contains blueschists composing of epidote, chlorite, albite, sodic amphibole, phengite, quartz, with minor amounts of titanite, ilmenite, and staurolite. Sodic amphiboles are glaucophane to magnesioriebeckite. The Pressure(P)-Temperature(T) metamorphic conditions are estimated to be $400\sim 425\text{ }^{\circ}\text{C}$ and $0.69\sim 0.86\text{ MPa}$, which correspond to epidote-blueschist facies. Geochemical study of blueschists from the Heilongjiang Complex showed that their protoliths were oceanic basalts, which were comparable with oceanic island basalt(OIB) or some types of basalts from plume-influenced regions(E-MORB). This suggests the formation of basalt protolith of the Heilongjiang blueschists from enriched source in seamount or oceanic uplift setting. The presence of metabasalts with geochemical features typical of ocean island basalts, as well as Mn-rich metacherts, marbles, metagraywackes and ophiolite slices, indicates that the Heilongjiang Complex is a subduction-accretionary complex, containing fragments of deformed oceanic crust and rocks of an accretionary wedge, which was formed at the western part of reworked Pre-Sinian Jiamusi Massif in the Jurassic. The complex is comparable in protolith compositions with many accretionary complexes of active continental margins.

Key words: blueschist; petrology; Heilongjiang Complex; OIB; E-MORB

0 Introduction

Blueschists are widespread in orogenic belts

and meaningful indicators of the former subduction zones. They attract attention because knowledge of their formation and exhumation conditions

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allows us to decipher a sequence and character of subduction-accretionary events taking place at the convergent boundaries^[1-3]. As blueschists are generally believed to be exhumed fragments of subducted oceanic lithosphere plates, their petrological and geochemical research can give some information on protoliths nature and thermal evolution of ancient subduction zones. In this paper, the mineralogical and geochemical features of blueschist-facies rocks from the Heilongjiang Complex in Northeast China, which were sampled during Fourth Workshop IGCP-420 in 2002, are examined in detail.

1 Geological Setting

The Heilongjiang Complex located at the western margin of the Jiamusi Massif (Fig. 1^[4]). It is closely associated to the Mashan Complex, and distributed in Mudanjiang, Yilan and Luobei areas. The Heilongjiang Complex was previously considered as metamorphosed Early Precambrian strata^[5]. In the last decades, it is realized that the Heilongjiang Complex is different lithologically from those of the Mashan Complex, composing of granulite facies rocks^[4,6]. The major rock types of the Heilongjiang Complex include serpentized ultramafic rocks, blueschist, greenschist, mica schist and marble, with some radiolarian-bearing metacherts. The blueschists, occurring as small tectonic lenses in greenschist facies country rocks, were considered as tholeiitic basalt undergone blueschist facies metamorphism^[7].

The Heilongjiang Complex was firstly considered as Paleoproterozoic or Mesoproterozoic, even Archean strata^[5]. The discovery of *Ordovician Chitinozoa* suggested that at least some part of the Heilongjiang Complex is of Paleozoic^[8]. That is the reason why the first published Ar-Ar isotopic data (155 Ma^[9]; 175, 166 Ma^[8]) indicating the Mesozoic age of blueschist metamorphism in Mudanjiang, are regarded as the age of the later tectonic movements along the Dunhua-Mishan fault. However, recently Wu et al^[10] reported phengite

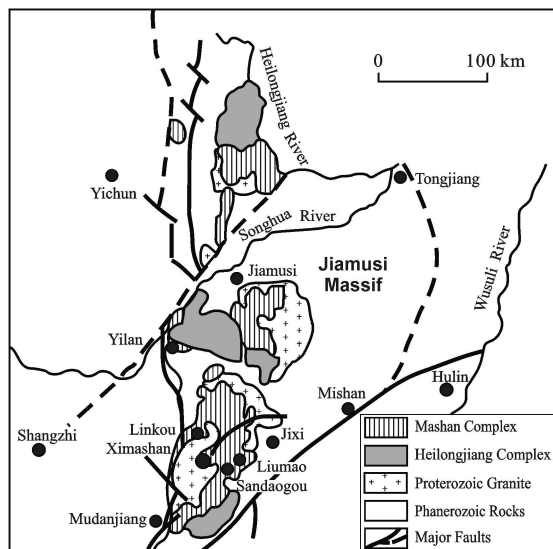
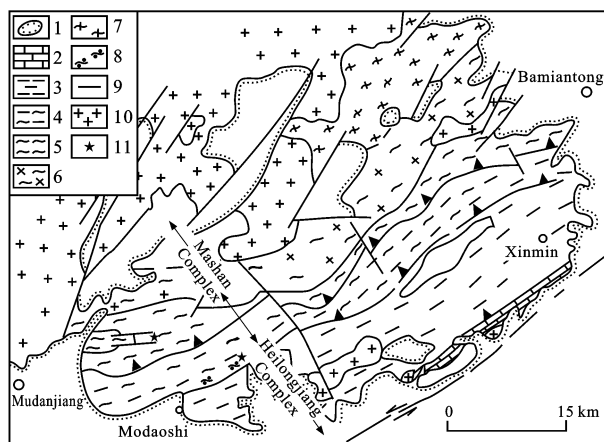


Fig. 1 Major Geological Subdivisions of the Jiamusi Block
Ar-Ar plateau ages of 184–174 Ma from mica schist, indicating that blueschist metamorphism occurred in the Early Jurassic, not in the Early Paleozoic as previously thought. The Jurassic ages were obtained also on phengites from metapelites and blueschists of the Heilongjiang Complex: 171–165 Ma and 146–145 Ma, correspondingly^[11]. U-Pb SHRIMP dating of zircons of blueschists from Jilan [(258 ± 2), (259 ± 4) Ma] and Mudanjiang [(213 ± 2), (224 ± 7) Ma] allowed to constrain their basalt protolith age as the Late Permian and Late Triassic, respectively^[12]. So, the Heilongjiang Complex is a Jurassic accretionary-collisional complex, formed as a result of subduction of westward-directed Pacific Ocean plate, and can not be related to the Central Asian Orogenic belt^[10,12].

2 Sample Description

Five blueschist samples from the Heilongjiang Complex were collected near Modaoshi village in the vicinity of Mudanjiang during Fourth Workshop IGCP-420. Here the Heilongjiang Complex occurs as a SW-NE trending tectonic unit made of imbricated slices of blueschist, greenschist, serpentinite, mica schist, marble, and metachert, and is tectonically contacted with the Mashan Complex as shown in the simplified geological map (Fig. 2^[8]). The unit has been strongly deformed



1— Mesozoic-Cenozoic Cover; 2— Marble; 3, 4— Mylonite;
5-7— Gneiss with Increasing Degree of Anatexis; 8— Blueschist;
9— Ultramafic Rock; 10— Late Paleozoic Granite; 11— Sample
Location

Fig. 2 Simplified Geological Map of the Mudanjiang Area with folding thrust imbrication and generation of foliation. Regional metamorphism in the unit is generally transitional blueschist/greenschist facies.

The blueschist samples are medium to fine-grained rock, composed of epidote, chlorite, albite, blue amphibole, phengite, and quartz, with accessory ilmenite, apatite and iron oxide. Metamorphism is pervasive and no primary relict phases exist. The rock consists of subhedral to euhedral, pale yellow-green epidote and anhedral quartz and albite set in a moderately-well foliated matrix of chlorite, amphibole, and phengite. No textural evidence of disequilibrium was noted and the six-phase assemblage is considered to have equilibrated during blueschist metamorphism.

Photomicrographs of the analyzed blueschist samples from the Heilongjiang Complex, showing their textural relationships are given in Figure 3. Epidote occurs as large porphyroblasts (about 5 mm) and as clusters of small matrix grains. Some epidote grains are elongate laths, which appear to be pseudomorphs after lawsonite. Chlorite is generally the predominant phase occurring as subhedral crystals arranged parallel to the schistosity. Na-amphibole occurs as minor needles together with chlorite. Larger euhedral blue amphibole occurs as inclusions within albite and epidote

porphyroblasts, as well as in calcite veinlets. Grain size is less than 100 μ m in most samples and commonly between 1 μ m and 50 μ m. Albite forms poikiloblasts with numerous inclusions of all matrix phases. Calcite occurs as small veinlets and is also overgrown by blue amphibole and chlorite. Titanite is ubiquitous and occurs as very fine grained clusters in the matrix.

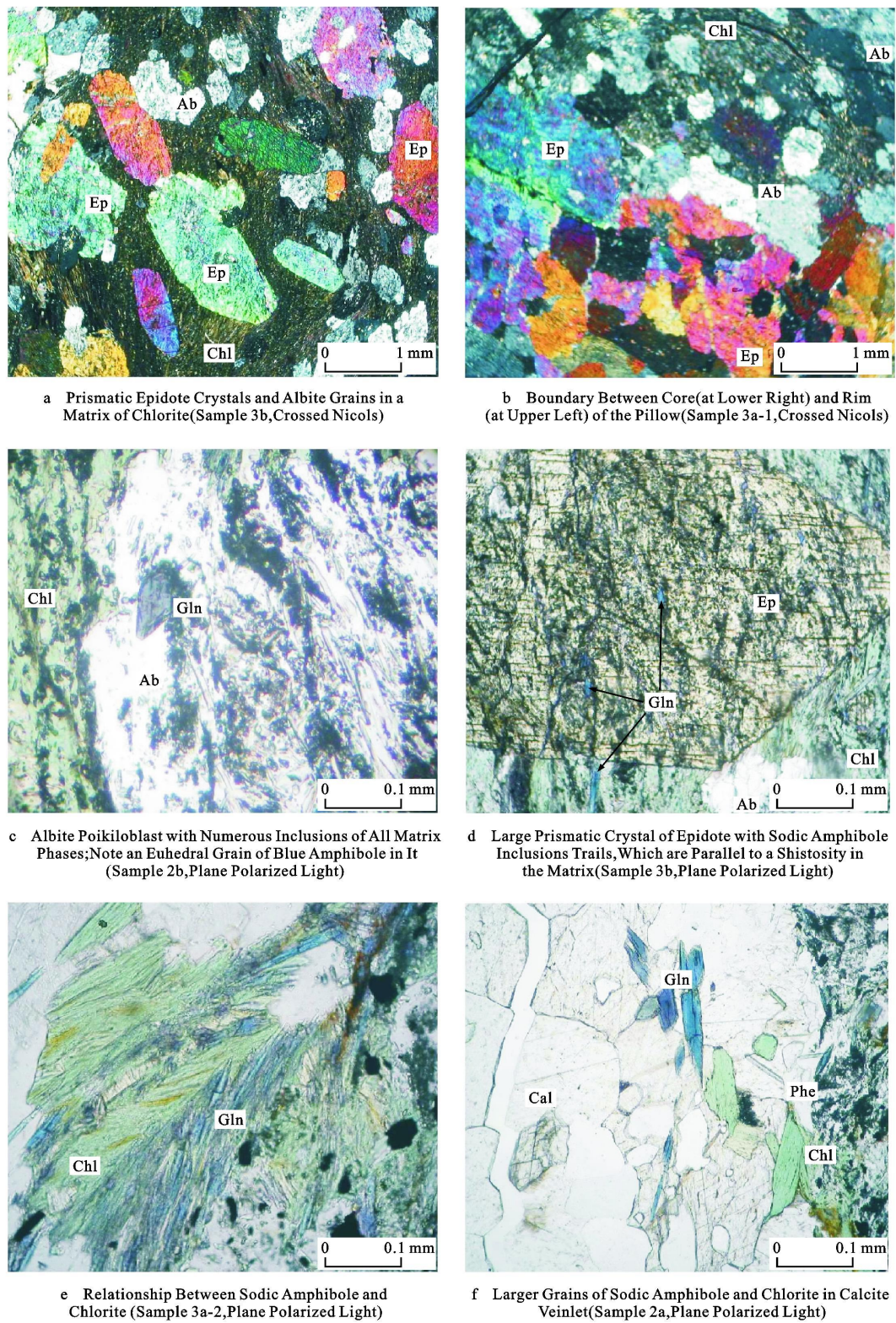
Although most mafic rocks are massive in structure, occasional pillow structures have been preserved. Having a similar mineral assemblage, the central parts of pillows are characterized by prevalence of prismatic epidote crystals and albite grains, and their rims are enriched in chlorite.

3 Methods

The bulk rock compositions of 5 samples of blueschists were obtained by X-ray fluorescence (XRF) spectroscopy with X-ray analyzer VRA-20R. Losses on ignition were determined by standard chemical method. For the majority of rock-forming components the detection limits were at a level of 0.02%-0.005%. Content of Rb, Sr, Nb, Zr and Y were analyzed by energy-dispersive XRF with an accuracy of 5%-10% and precision of 1%-2%. Contents of Cs, Hf, Ta, U, Th, Cr, Co, REE were determined by instrumental neutron-activation analysis (INAA) with an accuracy of 5%-10%. Mineral compositions were determined using a Camebax-micro microprobe analyzer. An operating voltage of 20 kV, a beam current of 40 nA, counting time of 10 s and a beam diameter of 2-3 μ m were employed for most analyses. Natural and synthetic standards were used and the data were processed by the PAP routine. The determination error for all components was less than 2%. All analyses were performed in the Institute of Geology and Mineralogy, Novosibirsk, Russia.

4 Mineral Chemistry and Estimates of Pressure and Temperature

Representative analyses of amphiboles are listed in Table 1, and all analyses are plotted in



Ab—Albite; Cal—Calcite; Chl—Chlorite; Ep—Epidote; Gln—Glaucofane; Phe—Phengite

Fig. 3 Photomicrographs of the Analyzed Blueschist Samples from the Heilongjiang Complex

Figure 4. The Fe^{3+}/Fe^{2+} of amphibole is calculated assuming 13 total cations (exclusive of K, Na, and Ca) and 23 oxygens. Blue sodic amphiboles plot in a band from glaucophane to magnesioriebeckite (Fig.3), according to the current classification^[13]. $Na_{(B)}$ content in these amphiboles is

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Tab. 1

Representative Analyses of Sodic Amphiboles from Blueschists of the Heilongjiang Complex

%

Sample	2a	2b	3a-1				3a-2		3b			
Mineral	Gln	Gln	Gln-c	MR-r	MR-c	MR-r	MR-r	MR-c	Gln-c	MR-r	Gln-c	MR-r
SiO ₂	55.83	56.26	56.05	55.84	56.11	56.60	56.00	55.78	56.56	55.61	56.05	56.13
TiO ₂	0.01	0.20	0.11	0.04	0.03	0.04	0.01	0.02	0.18	0.08	0.01	0.02
Al ₂ O ₃	7.04	6.41	6.97	6.51	5.88	5.33	5.36	6.64	6.63	5.79	6.84	5.17
Cr ₂ O ₃	0.04	0.04	0.05	0.03	0.05	0.02	0.03	0.01	0.04	0.05	0.00	0.04
FeO	16.93	17.69	16.49	17.78	18.50	19.08	19.24	18.20	17.05	18.80	17.43	18.85
MnO	0.16	0.14	0.08	0.14	0.12	0.10	0.13	0.13	0.16	0.17	0.14	0.14
MgO	9.11	9.09	9.83	9.33	9.18	9.69	8.85	9.20	9.18	9.20	8.83	9.41
CaO	0.26	0.52	0.94	0.30	0.34	0.36	0.16	0.31	0.71	0.71	0.48	0.61
Na ₂ O	7.19	7.06	6.89	6.96	6.72	7.17	7.09	7.30	6.79	6.55	6.97	6.90
K ₂ O	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.03	0.02	0.02
Total	96.57	97.42	97.42	96.93	96.93	98.40	96.87	97.59	97.31	96.98	96.77	97.29
Si	7.889	7.914	7.847	7.855	7.901	7.880	7.939	7.828	7.942	7.852	7.925	7.919
Ti	0.001	0.021	0.012	0.004	0.003	0.004	0.001	0.002	0.019	0.008	0.001	0.002
Al	1.172	1.062	1.150	1.079	0.976	0.874	0.895	1.098	1.097	0.963	1.140	0.859
Cr	0.005	0.004	0.005	0.003	0.005	0.003	0.004	0.001	0.004	0.005	0.000	0.005
Fe ²⁺	1.002	1.094	0.953	0.874	0.901	0.905	1.052	0.971	1.084	0.916	1.107	0.999
Fe ³⁺	0.995	0.983	0.974	1.214	1.274	1.313	1.225	1.162	0.914	1.301	0.951	1.221
Mn	0.019	0.017	0.009	0.016	0.015	0.012	0.015	0.016	0.019	0.020	0.017	0.017
Mg	1.917	1.905	2.050	1.955	1.926	2.009	1.869	1.923	1.920	1.935	1.860	1.977
Ca	0.039	0.078	0.142	0.045	0.052	0.053	0.024	0.047	0.107	0.107	0.072	0.092
Na	1.969	1.924	1.869	1.897	1.833	1.934	1.947	1.985	1.847	1.792	1.910	1.886
K	0.001	0.001	0.002	0.000	0.000	0.002	0.000	0.000	0.001	0.005	0.003	0.003
Mg [#]	0.657	0.635	0.683	0.691	0.681	0.689	0.640	0.665	0.639	0.679	0.627	0.664

Note: Gln—Glaucophane; MR—Magnesioriebeckite; c—Core; r—Rim; FeO—Total Fe

1.83-1.96 per formula and Mg[#] number is 0.63 to 0.69. Most grains of Na-amphibole are too fine-grained to analyze for compositional zoning. Where core and rim analyses were obtained, they display an increase of Fe³⁺/(Fe³⁺+Al^{VI}) and to a less extent, Mg[#] number from core to rim. However, the amphiboles of the selected samples generally fall within the Na-amphibole range (Fig. 4).

In all analyzed samples, a single population of *phengite* is observed. Mica occurs in small quantities as fine to very fine crystals. It contains appreciable amounts of celadonite component (Tab. 2), with Si ranging from 3.29 to 3.43 per formula (11 Oxygens). There is no regular zonation in most phengites. However, compositional scanning of

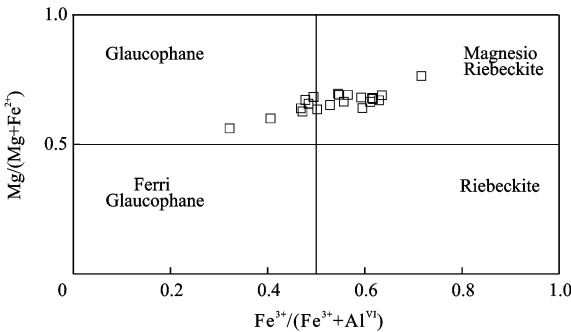


Fig. 4

Sodic Amphibole Compositions from Blueschists of the Heilongjiang Complex

some phengite crystals in blueschists indicates a decrease of Al and an increase of Si and Fe from core to rim. Rarely, a slight decrease of Si from core to rim was found.

Tab. 2 Representative Analyses of Phengite Chlorite Epidote and Albite from the Heilongjiang Blueschists %

Sample	2a		2b			3a-1				3a-2				3b			
Mineral	Phe	Chl	Phe	Ep	Pl	Phe	Ep	Chl	Pl	Phe	Chl	Ep	Pl	Phe	Chl	Ep	Pl
SiO ₂	48.01	27.69	49.39	37.52	68.05	50.07	38.10	27.39	68.12	49.24	29.27	37.39	68.67	48.19	28.22	37.83	68.54
TiO ₂	0.11	0.00	0.07	0.02	0.00	0.12	0.18	0.05	0.00	0.07	0.04	0.20	0.02	0.11	0.00	0.06	0.00
Al ₂ O ₃	27.71	18.39	26.42	21.94	19.41	25.10	22.11	18.76	19.10	26.78	19.93	23.18	19.24	28.47	18.58	22.23	19.49
Cr ₂ O ₃	0.12	0.04	0.07	0.07	0.00	0.03	0.04	0.06	0.02	0.09	0.05	0.02	0.01	0.05	0.08	0.03	0.00
FeO	4.48	19.55	4.90	13.68	0.10	4.45	13.12	19.30	0.15	4.77	18.71	12.84	0.02	5.23	19.51	13.65	0.06
MnO	0.01	0.18	0.06	0.43	0.01	0.05	0.25	0.21	0.00	0.05	0.24	0.73	0.03	0.00	0.16	0.48	0.01
MgO	2.30	20.52	2.78	0.03	0.01	3.21	0.03	20.91	0.01	2.80	18.84	0.05	0.01	1.85	20.04	0.02	0.01
CaO	0.04	0.02	0.04	22.91	0.00	0.03	22.78	0.09	0.14	0.21	0.04	22.81	0.10	0.01	0.05	23.01	0.05
Na ₂ O	0.58	0.04	0.38	0.02	12.03	0.33	0.01	0.02	12.29	0.54	0.00	0.03	11.82	0.44	0.03	0.02	12.02
K ₂ O	10.35	0.01	10.76	0.01	0.02	11.23	0.00	0.01	0.00	10.61	0.63	0.00	0.01	10.47	0.02	0.01	0.01
Total	93.71	86.44	94.87	96.63	99.63	94.62	96.62	86.80	99.83	95.16	87.75	97.25	99.93	94.82	86.69	97.34	100.19
Si	3.307	2.871	3.370	3.009	2.988	3.426	3.042	2.827	2.990	3.349	2.965	2.973	3.001	3.289	2.910	3.008	2.991
Ti	0.006	0.000	0.004	0.001	0.000	0.006	0.011	0.004	0.000	0.004	0.003	0.012	0.001	0.005	0.000	0.003	0.000
Al	2.249	2.246	2.124	2.074	1.004	2.024	2.081	2.282	0.988	2.146	2.379	2.173	0.991	2.290	2.258	2.084	1.002
Cr	0.007	0.004	0.004	0.005	0.000	0.001	0.003	0.005	0.001	0.005	0.004	0.002	0.000	0.003	0.007	0.002	0.000
Fe	0.258	1.692	0.279	0.917	0.003	0.254	0.876	1.663	0.006	0.271	1.582	0.854	0.001	0.298	1.680	0.908	0.002
Mn	0.000	0.016	0.003	0.029	0.000	0.003	0.017	0.018	0.000	0.003	0.020	0.049	0.001	0.000	0.014	0.032	0.000
Mg	0.236	3.169	0.283	0.004	0.000	0.327	0.004	3.215	0.001	0.284	2.843	0.006	0.000	0.188	3.079	0.003	0.001
Ca	0.003	0.003	0.003	1.968	0.000	0.002	1.949	0.010	0.007	0.015	0.004	1.943	0.005	0.001	0.006	1.961	0.002
Na	0.077	0.009	0.051	0.003	1.024	0.044	0.001	0.003	1.046	0.071	0.000	0.005	1.002	0.059	0.006	0.003	1.017
K	0.909	0.001	0.936	0.001	0.001	0.980	0.000	0.001	0.000	0.920	0.082	0.000	0.001	0.911	0.002	0.001	0.001
Sum	7.052	10.009	7.056	8.011	5.022	7.067	7.984	10.028	5.038	7.068	9.882	8.017	5.003	7.044	9.961	8.005	5.017
O	11	14	11	12.5	8	11	12.5	14	8	11	14	12.5	8	11	14	12.5	8

Note: Phe—Phengite; Chl—Chlorite; Ep—Epidote; Ab—Albite; FeO—Total Fe

The Mg[#] number of chlorite varies from 64% to 66% (Tab. 2). Pistacite content of epidote varies from 32.4% to 26.9%. All analyzed plagioclase grains are nearly pure albite, containing less than 0.01 mol anorthite (Tab. 2).

Estimations of Pressure(*P*) and Temperature (*T*) parameters of metamorphism for mineral assemblage Gln+Phe+Ep+Chl+Ab+Qtz+Ttn of blueschists from the Heilongjiang Complex were calculated using the THERMOCALC program^[14]. They are the following: *T*=400-425 °C, *P*=0.69-0.86 MPa, and are corresponded to epidote-blueschist facies conditions.

5 Whole-rock Chemistry: Major and Trace Elements

Common blueschists have basaltic to picrobasalt composition (Tab. 3) with weight content of

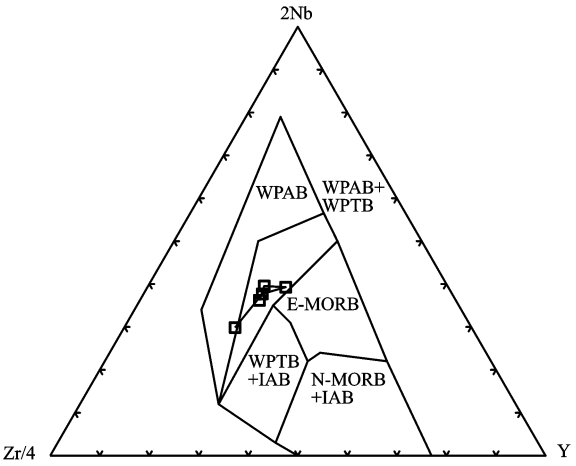
SiO₂ ranging from 40.6% to 48.3% and are characterized by increased contents of titanium (2.52%-2.97%), and phosphorus (0.35%-0.45%). The geochemistry of major and trace elements suggests that the blueschist protoliths were oceanic intraplate basalts rather than that of N-MORB.

In discriminant diagram Zr/4-Nb-Y^[15], permitting to estimate geodynamic formation conditions of basalt protoliths, figurative points of the Heilongjiang Complex blueschists lie within the field of within-plate basalts (Fig. 5^[15]). The REE patterns (Fig. 6) of the Heilongjiang blueschists demonstrate a noticeable negative slope with La_N/Yb_N= 3.3-5.1 and La_N=62-91. On the one hand, they are similar to oceanic island basalt (OIB) patterns, but differ from them in increased HREE contents and more flattened spectra, and on the

Tab. 3 Chemical Composition of Blueschists from the Heilongjiang Complex

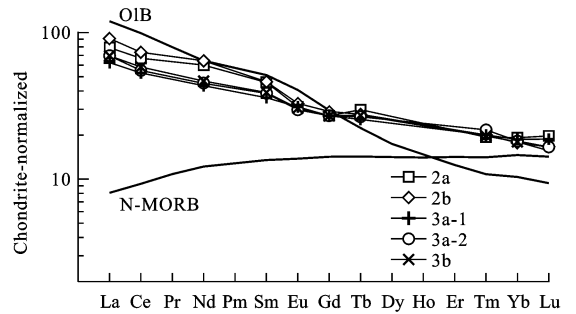
Sample	4-2a	4-2b	4-3a-1	4-3a-2	4-3b
SiO ₂	48.31	42.85	40.62	44.91	41.08
TiO ₂	2.52	2.61	2.53	2.97	2.68
Al ₂ O ₃	15.85	16.31	17.57	16.39	17.60
Fe ₂ O ₃	13.24	13.11	13.11	14.40	13.74
MnO	0.17	0.19	0.20	0.15	0.21
MgO	4.52	6.05	5.23	5.63	6.60
CaO	7.52	11.49	13.58	6.08	12.36
Na ₂ O	3.62	1.88	1.67	4.47	1.18
K ₂ O	1.12	0.55	0.29	1.21	0.20
P ₂ O ₅	0.43	0.40	0.35	0.45	0.35
LOI	2.62	4.48	4.73	3.23	3.96
Total	99.91	99.92	99.89	99.89	99.95
Rb	30.6	16.7	8.1	29.2	7.5
Cs	1.57	0.40	1.40	2.02	0.40
Sr	202	319	388	101	356
Ba	121	71	42	128	51
U	1.0	1.0	0.5	0.4	0.5
Th	1.5	2.1	1.5	2.0	1.8
Zr	335	224	163	212	248
Hf	6.5	6.0	5.5	5.8	6.2
Y	39.3	35.1	34.7	33.6	37.7
Nb	26.2	27.6	24.4	28.3	28.3
Ta	1.20	1.28	1.20	1.30	1.36
La	24.43	28.22	19.30	21.51	21.50
Ce	53.9	59.2	42.8	44.5	47.0
Nd	36.0	38.5	26.0	27.0	28.0
Sm	8.90	9.00	7.00	7.50	7.60
Eu	2.30	2.43	2.30	2.20	2.25
Gd	7.0	7.5	7.0	7.0	7.0
Tb	1.40	1.30	1.20	1.25	1.28
Tm	0.58	0.60	0.60	0.65	0.59
Yb	4.00	3.70	3.90	3.80	3.75
Lu	0.63	0.53	0.60	0.53	0.50
Cu	69	59	54	42	60
Zn	155	171	150	146	188
Cr	223	271	230	293	275
Ni	190	259	233	225	263
Co	62	75	63	72	78
V	321	367	294	378	340

Note: Fe₂O₃— Total Fe; Weight Content of Major Element/%;
Weight Content of Trace Element/10⁻⁶



WPAB— Within-plate Alkali Basalts; WPTB— Within-plate Tholeiitic Basalts; E-MORB— Basalts from Plume-influenced Regions (P-type MORB); IAB— Island Arc Basalts; N-MORB— “Normal” Mid-ocean Basalts

Fig. 5 Zr-Nb-Y Ternary Diagram for Blueschists from the Heilongjiang Complex

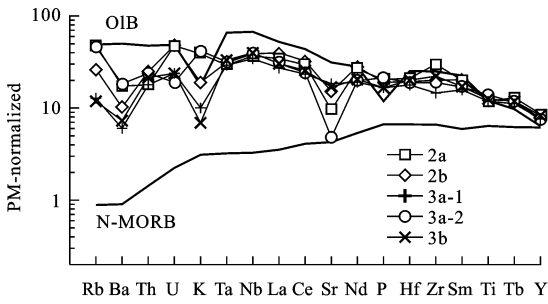


Values of Chondrite, OIB and N-MORB Basalts are from Reference [16]

Fig. 6 Chondrite normalized REE Diagram for Blueschists from the Heilongjiang Complex

other hand, to some enriched MORB (E-MORB or P-MORB), occurring in oceanic uplift setting. The spidergrams of the Heilongjiang blueschists (Fig. 7) also show a pronounced negative slope, and are characterized by increased contents of U, Th, Nb, Ta, and light REE, depletion in LILE (Rb and Ba), and distinct K and Sr minima. Such spectra bear a resemblance to OIB, or to some types of E-MORB.

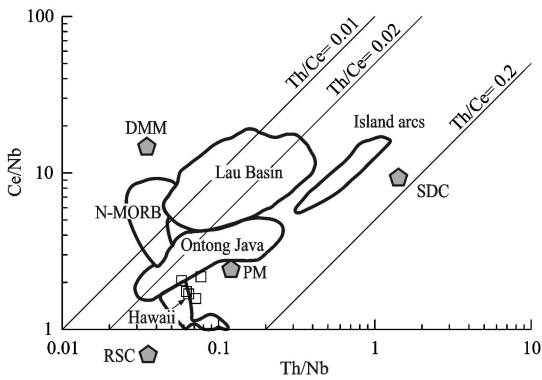
In a Ce/Nb versus Th/Nb diagram^[17], the mantle sources of oceanic basalts are described by mixing of the depleted (DMM; high Ce/Nb and low Th/Nb), recycled (RSC; low Th/Nb and Ce/Nb), and subducted (SDC; high Th/Nb) and Ce/Nb



Compositions of Primitive Mantle OIB and N-MORB Basalts are from Reference [16]

Fig. 7 Spidergrams for Blueschists from the Heilongjiang Complex

Nb) components(Fig. 8^[17]). The data points of the Heilongjiang blueschists plot mostly near the field of the oceanic island basalts and exhibit the mixing of the DMM and RSC components, with the presence of the subducted component in their source being unlikely.



PM—Primitive Mantle; DMM— Depleted Mantle Material; RSC— Recycled Slab Component (Material of Oceanic Crust Dehydrated in a Subduction Zone); SDC— Subduction-derived Component

Fig. 8 Blueschists of the Heilongjiang Complex in the Diagram Ce/ Nb- Th/ Nb

6 Discussion

The presence of metabasalts with geochemical features typical of ocean island basalts, as well as Mn-rich metacherts, marbles, metagraywackes, and ophiolite slices^[8, 10, 18], indicates that the Heilongjiang Complex is a subduction-accretionary complex, containing fragments of deformed oceanic crust and rocks of an accretionary wedge, which was formed at the western part of reworked Pre-Sinian Jiamusi Massif. The complex is comparable

in protolith compositions with many accretionary complexes of active continental margins^[19-20].

Based on U-Pb SH RIMP ages of 259 to 213 Ma for basalt protoliths of the Heilongjiang blueschists^[12], we can suggest that in the Late Permian to Late Triassic there existed a marginal sea with a chain of seamounts or small oceanic islands between the Jiamusi Block and the western blocks. The presence of continental-derived clastic rocks^[10] implies formation within a marginal sea, close to terrigenous sources. It should be noted that the final closure of the Paleo-Asian Ocean is dated as the end of the Permian^[21-22]. So, on the hills of Li^[22], Wu et al^[10] and Zhou et al^[12], we believe that the formation of the Heilongjiang blueschists was connected with subduction of Paleo-Pacific oceanic plate. This is confirmed by recent geochronological data^[10-12], suggesting the Jurassic age of high-pressure/ low-temperature metamorphism of the rocks.

7 Conclusion

The Heilongjiang subduction-accretionary complex contains blueschists composing of epidote, chlorite, albite, sodic amphibole, phengite, and quartz, with minor amounts of titanite, ilmenite, and stilpnomelane. Sodic amphiboles are glaucophane to magnesioriebeckite. The *P-T* metamorphic conditions are estimated to be 400-425 °C and 0.69-0.86 MPa, which correspond to epidote-blueschist facies.

Geochemical study of blueschists from the Heilongjiang Complex showed that their protoliths were oceanic basalts, which are comparable with OIB or some types of E-MORB. This suggests the formation of basalt protolith of the Heilongjiang blueschists from enriched source in seamount or oceanic uplift setting.

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