Geochemical Characteristics and Genesis of Volcanic Rocks of Yixian Formation in Jianping, Western Liaoning

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Abstract: The volcanic rocks distributed in Pingzhuang-Machang basin of Jianping country should belong to Yixian Formation, the volcanism may be divided into two subcycles. The volcanic rocks mainly consist of rhyolites, trachyte and trachyandesites. The geochemical characteristics indicate that the volcanic rocks belong to the high-K calc-alkaline magmatic series. The volcanic rocks are obviously enriched in large ion lithophile elements (K, Rb, Sr, Zr, Ba, Pb, Li), and depleted in high field-strength elements (HFSE) (Nb, Ti, P, Th, U, HREE) as well as compatible elements (Co, Ni, Cr, V). The volcanic rocks are rich in LREE. There is a slight negative Eu anomaly, no Ce anomaly. A detailed geochemical discrimination of selected elements allowed us to identify that the volcanic rocks of Yixian Formation mainly derived from the partial melting of lower crust materials, but has been contaminated by upper crustal materials during its ascent process in some degree. The volcanic rocks of Yixian volcanic cycle were generated in response to lithosphere inhomogeneous extension in the continental intra-plate orogenic belt. They have the basic characteristics of continental intra-plate volcanic rocks.

Introduction

Large-scale Mesozoic volcanic rocks are developed in the Northern Hebei-Western Liaoning-Southern Inner Mongolia area. Yixian Formation is a typical representative of the Mesozoic volcanic rocks. Many geologists have been paying attention to it in the past ten years and number of important achievements had been obtained [1-4]. The research were mainly concentrated in the Northern Hebei-Western Liaoning area. Study on volcanic rocks in Pingzhuang-Machang basin is relatively weak. Thus, study on Yixian Formation has the vital significance. In recent years, the author has taken detailed field investigation and indoor research on Yixian Formation developed in the area. This paper mainly summarizes the geochemical characteristics and genesis of volcanic rocks of Yixian Formation in the Pingzhuang-Machang basin of Jianping country.

Geological Setting

The area is located in the northern margin of North China platform. Pingzhuang-Machang basin of Jianping country is one of the typical continental-volcanic sedimentary basins in western Liaoning province in which the volcanic rocks of Yixian Formation are exposed widely. Yixian volcanic cycle may be divided into two subcycles. The volcanic rocks of the first subcycle are rhyolites which directly cover the Yixian Formation basal conglomerate. The volcanic rocks of the second subcycle are trachyte and trachyandesite; The volcanic rock facies types mainly include eruption facies,

overflowfacies, subvolcanicfacies, the volcano channel phase and volcano-sedimentaryfacies. Lithology combination reflects the regularity of magma evolution from acidto intermediate-acid(alkaline). Volcanicactivitymigrate from northwest to southeast in the region.

Geochemical Characteristics

The major elements, trace elements and rare earth elements abundance of volcanic rocks of Yixian Formation are listed in table 1.

Table 1Chemical compositions of volcanic rock of Yixian Formation

cycle lithology	first subcycle rhyolites						second subcycle trachvandesit			
samples	P109-2-1	P109-8-1	D1034-1	D2081-1	D2099-1	D2062-1	D3007-1	D4071-1	D2059-1	D2060-1
SiO ₂	71.52	70.57	70.32	70.22	70.33	68.07	68.34	67.77	62.15	63.43
TiO ₂	0.26	0.29	0.29	0.33	0.35	0.38	0.35	0.41	0.66	0.66
Al ₂ O ₃	14.08	14.66	14.02	14.11	13.95	14.87	14.55	14.86	16.42	16.35
Fe ₂ O ₃	1.79	1.41	2.73	2.04	1.73	2.19	2.47	2.22	3.92	3.22
FeO	0.77	1.02	0.29	0.65	0.90	0.79	0.65	1.11	0.83	1.17
MnO	0.03	0.04	0.05	0.05	0.04	0.05	0.03	0.05	0.07	0.06
MgO	0.44	0.48	0.37	0.52	0.81	0.61	0.53	0.77	1.11	0.91
CaO	1.43	1.64	0.99	1.58	1.63	2.06	2.05	2.25	2.45	2.46
Na ₂ O	3.17	3.50	3.51	3.54	3.60	3.86	3.95	4.02	4.50	4.63
K ₂ O	5.36	5.19	5.64	5.15	5.05	5.09	5.11	4.85	5.21	4.97
P ₂ O ₅	0.07	0.09	0.10	0.12	0.13	0.24	0.18	0.29	0.47	0.46
LOS	0.89	0.78	1.33	1.46	1.21	1.55	1.54	1.22	1.96	1.25
Y	12.83	16.40	10.79	12.50	12.33	10.94	10.05	9.97	14.76	15.92
Hf	4.81	6.60	5.27	5.68	6.05	5.62	5.56	5.53	9.07	9.06
Ta	4.38	5.25	1.28	1.52	1.41	1.28	1.16	1.08	1.33	1.18
Rb	185.82	180.46	186.47	133.97	77.31	95.98	30.72	39.02	78.98	102.48
Ba	822.19	996.30	971.28	924.05	894.52	1065.82	1122.40	1010.72	1359.65	1417.74
Sr	223.58	339.64	274.90	277.36	264.57	441.36	389.42	448.73	659.59	641.55
Li	16.77	27.04	16.36	25.48	26.80	15.76	12.98	20.65	16.57	16.92
Be	2.49	2.64	2.22	2.58	2.70	2.50	2.68	2.61	2.70	2.46
Sc	5.76	6.45	6.34	6.11	7.01	7.76	6.59	7.12	9.12	7.18
Th	5.53	7.09	13.71	15.60	15.24	11.34	12.95	11.04	10.89	8.28
U	1.38	1.25	2.08	1.54	2.01	2.13	1.66	1.80	1.38	1.38
Nb	10.30	12.96	13.48	13.80	13.10	12.70	10.80	12.35	19.16	19.40
Co	3.74	2.84	4.50	3.14	4.07	4.41	5.34	6.37	5.14	5.26
Cr	20.94	13.01	8.20	11.17	9.64	17.39	15.10	18.48	7.45	7.56
Ni	4.77	3.85	5.56	4.51	6.07	7.99	8.19	11.19	4.05	3.88
V	24.19	19.24	20.03	22.50	18.11	25.43	19.44	26.82	32.15	35.36
Zr	182.45	201.66	196.90	193.18	193.85	233.17	201.96	213.05	400.13	400.89
La	55.24	49.09	52.13	59.48	56.09	60.47	55.87	53.44	77.58	75.42
Ce	88.48	83.89	102.18	115.57	118.51	136.92	111.85	104.83	143.87	136.51
Pr	10.10	9.44	9.33	11.05	10.14	11.03	9.94	10.04	14.93	14.60
Nd	32.72	30.74	29.72	35.62	33.81	36.94	32.84	34.10	50.69	50.37
Sm	4.86	4.94	4.20	5.35	4.90	5.22	4.76	5.19	7.29	7.38
Eu	0.72	0.84	1.09	1.37	1.26	1.35	1.32	1.31	1.96	2.07
Gd	4.79	4.72	3.69	4.37	4.16	4.49	4.14	4.37	6.03	6.21
Tb	0.57	0.58	0.41	0.51	0.52	0.52	0.44	0.50	0.71	0.72
Dy	2.40	2.76	2.07	2.40	2.41	2.22	1.97	2.12	3.07	3.31
Ho	0.49	0.55	0.41	0.45	0.45	0.40	0.37	0.38	0.59	0.59
Er	1.37	1.52	1.08	1.24	1.27	1.13	1.03	1.09	1.55	1.63
Tm	0.26	0.25	0.17	0.19	0.19	0.16	0.15	0.16	0.22	0.25
Yb	1.33	1.70	1.13	1.26	1.20	0.96	0.92	0.99	1.37	1.51
Lu	0.26	0.42	0.18	0.18	0.18	0.15	0.13	0.14	0.20	0.23

Analyzed by Shenyang Institute of Geology and Mineral Resources (2011)

Characteristics of major elements.

Volcanic rock of first subcycle (K_1Y^1). Rhyolites have SiO_2 content of 70.22%-71.52%, Al_2O_3 content of 13.95%-14.66%, K_2O+Na_2O content of 8.87-9.7%. Na_2O/K_2O is 0.59-0.71. $FeO_t/(FeO_t+MgO)$ is 0.77-0.89, and their average is 0.84. The index δ is 2.55-3.06, and their average is 2.77. The chemical characteristics of the rocks indicate that they belong to calc-alkaline series.

Volcanic rock of second subcycle (K_1Y^2). Trachyte and trachyandesites have SiO_2 content of 62.15%-68.34%, Al_2O_3 content of 14.55%-16.42%, K_2O+Na_2O content of 6.59%-8.57%. Na_2O/K_2O ratio is 0.76-0.93. $FeO_t/(FeO_t+MgO)$ is 0.81-0.86, and their average is 0.83. The index δ of trachyandesites is in the range of 3.17-3.24, and their average is 3.22. The index δ of trachyte is in the range of 4.51-4.92, and their average is 4.72. The chemical characteristics of the rocks indicate that they belong to alkaline series.

On the diagram of AFM (diagram is omitted), all samples of volcanic rocks cast point in the calc-alkaline series area. On the diagram of SiO_2-K_2O (diagram is omitted), most of the dots of volcanic rocks are in the area of shoshonite series area. Thus, volcanic rocks of Yixian Formation belong to high-K calc-alkaline series.

Characteristics of trace elements. Volcanic rocks of Yixian Formation are rich in incompatible elements as a whole, whereas the contents of compatible elements such as Cr, Co, Ni, etc. are lower. The primitive mantle-normalized patterns of trace elements show that the contents of large ionic lithophile elements such as K, Rb, Li and LREE of volcanic rocks of first subcycle are high, whereas the contents of High field strength elements (HFSE) such as Nb, Ti and P are lower. The contents of large ionic lithophile elements such as Rb, Li, Y and LREE of volcanic rocks of second subcycle are high, whereas the contents of High field strength elements (HFSE) such as Nb, Ti and P are lower. The features show that magma derived from crust, rather than the mantle. The crust material involved in volcanic magma activity process.

Characteristics of rare earth elements. The total amounts of REE of rocks from the first subcycle are in the range of 191.45-239.04. LREE/HREE ratios of rocks are 14.3-21.74. $(La/Yb)_N$, $(Ce/Yb)_N$, La/Sm, Gd/Yb ratios are in the range of 19.55-31.95, 12.81-25.54, 9.94-12.42, and 2.78-3.6 respectively. The values of δEu are 0.45-0.84, and its average is 0.70, which is more obviously negative anomaly. The values of δCe are 0.82-1.09, and its average is 0.96, Ce anomaly is not obvious. The chondrite-normalized REE patterns are all the right-inclination ones.

The total amounts of REE of volcanic rocks from the second subcycle are in the range of 218.65-310.08. LREE/HREE ratios of volcanic rocks are 19.81-25.10. $(La/Yb)_N$, $(Ce/Yb)_N$, La/Sm and Gd/Yb ratios are in the range of 33.70-40.92, 23.39-34.90, 10.22-11.73 and 4.11-4.49 respectively. The values of δEu are 0.82-0.92, and its average is 0.88, which is weak negative. The values of δCe are 0.91-1.15, and its average is 1.01, which almost no Ce anomaly.

Genesis analysis of volcanic rocks

Volcanic rocks of Yixian Formation with low contents of TiO_2 (0.26-0.66), the mean value of TiO_2 is 0.41, $TiO_2 < 1.75$ is an important indicator of orogenic andesite (Gill, 1981). The total amounts of REE of volcanic rocks of Yixian Formation are higher and rich in LREE. The chondrite-normalized REE patterns are the right-inclination ones. Volcanic rocks are characterized by negative Eu anomalies in general, as well as no Ce anomaly. It is significantly different from general mantle-derived rocks (e.g. ocean ridge basalt) [5]. This indicates that its source area is not normal primitive mantle or depleted mantle.

Volcanic rocks of Yixian Formation enriched in incompatible elements K, Rb, Li etc, whereas the contents of compatible elements such as Nb, Ti, Cr, Co, Ni, P, etc are lower, and with low content of U, Th. Nb/La of volcanic rocks is 0.19-0.26, and Nb/La of the primitive mantle and mid-ocean ridge basalt is greater than 1. The Nb/Ta of volcanic rocks is 2.35-16.5, the mean value is 9.53, far below the Nb/Ta value of mantle (17.5 ± 2). Th/Ta of volcanic rocks is 1.26-10.83, the mean value is 7.99 which is higher than the Th/Ta of mantle (2.3), and close to the Th/Ta of continental crust (10). The ratio Ba/La of island arc volcanic rocks related to plate subduction is greater than 30 generally [6], while the mean value of rhyolite in research area is 17.06, the mean value of trachyte and trachyandesites in research area is 18.59, the difference is very big. The ratio Rb/Sr of volcanic rocks is 0.08-0.83, the mean value is 0.35 which is higher than that of the primitive mantle (0.029); The ratio Rb/Ba of volcanic rocks is 0.03-0.19, the mean value is 0.112 which is higher than that of the primitive mantle (0.088) also.

The average of Gottignies index τ of volcanic rocks is 30.1, volcanic rocks with value of τ higher than 10 are usually in orogenic belts. All samples plot in the orogenic belts area (B area) and its derivative of alkali, alkaline volcanic rocks area (C area) on the $\log \tau$ - $\log \sigma$ diagram (diagram is omitted).

At Mesozoic era, the horizontal distance from the studied area to Pacific plate subduction zone is larger than 1200 km, which is much more than the maximum horizontal distance of modern plate subduction zone (600 km) [7], therefore, the Mesozoic volcanism in the studied area is not resulted from the underthrust of Pacific Plate to Eurasian Plate directly.

Conclusion

The volcanic rocks of Yixian Formation in Pingzhuang-Machang basin of Jianping country mainly consists of rhyolites, trachyte and trachyandesites. The research results indicate that the volcanic rocks of Yixian Formation belong to the high-K calc-alkaline magmatic series. The volcanic rocks of Yixian Formation mainly derived from the partial melting of lower crust materials, but has been contaminated by upper crustal materials during its ascent process in some degree. The results show that volcanic rocks of Yixian Formation, having the basic characteristics of volcanic rocks of continental intraplate orogenic belt, were generated in response to lithosphere extension in the continent intraplate orogenic belt.

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