Vol. 82 No. 6 pp. 1194–1200 ACTA GEOLOGICA SINICA Dec. 2008

Cretaceous Volcanic Events in Southeastern Jilin Province, China: Evidence from Single Zircon U-Pb Ages

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Abstract: Mesozoic volcanic rocks in southeastern Jilin Province are an important component of the huge Mesozoic volcanic belt in the northeastern area. Study of the age of their formation is of great significance to recognize Mesozoic volcanic rule in northeastern China. Along with the research of rare Mesozoic biota and extensive Mesozoic mineralization in western Liaoning, a number of researchers have focused on Mesozoic volcanic events. The authors studied the ages of the Cretaceous volcanic rocks in southeastern Jilin Province using single Zircon U-Pb. The result shows that the Sankeyushu Formation volcanic rocks in the Tonghua area are 119.2 Ma in age, the Yingcheng Formation in the Jiutai area 113.4±3.1 Ma, the Jinjiatun Formation in Pinggang Town of Liaoyuan City and the Wufeng volcanic rocks in the Yanji area 103.2±4.7 Ma and 103.6±1 Ma, respectively. Combined with the data of recent publication on volcanic rocks ages; the Cretaceous volcanic events in southeastern Jilin Province can be tentatively subdivided into three eruption periods: 119 Ma, 113 Ma and 103 Ma. The result not only provides important chronology data for subdividing Mesozoic strata in southeastern Jilin Province, establishing Mesozoic volcanic event sequence, discussing geological tectonic background, and surveying the relation between noble metals to the Cretaceous volcanic rocks, but also offers important information of Mesozoic volcanism in northeastern China.

Key words: age of zircon U-Pb, volcanic event, Cretaceous, Jilin Province

1 Introduction

As an important part of the huge volcanic intrusive rocks belt in East China, the Mesozoic volcanic rocks in southeastern Jilin Province has received numerous attention due to its multiple phases of formation, great intensity and its relation to mineralization (Li, 1994; 2003; Wu and Sun, 1999; Lin et al., 1998; Yin et al., 2000; Hua and Mao, 1999; Tao et al., 1999; Deng et al., 1999; 2000; Mao et al., 2003; Du et al., 2000; Hu et al., 1994; Meng and Zhou, 1996; Liu et al., 2000; Zhang et al., 1998; Zhang et al., 2006; Jiang et al., 2006). Mesozoic volcanic rocks in southeastern Jilin Province consist of the Triassic, Jurassic and Cretaceous. Though the Nanloushan Formation in central Jilin has been accepted to be Early Jurassic in age by plant fossils from sediments and volcanic rocks dating (BGMRJP, 1988; 1997; Sun, 1993; Wang et al., 1997), K-Ar, Ar-Ar and Rb-Sr methods (Xue, 1997; Shen, 1987; Wu, 1987; Liu et al., 1992; Zhu et al., 1997; Pei, 2005; Chen, 1999) were mostly used to study the ages of widely-distributed volcanic rocks in the area. Dating methods and analysis precision, and absence of the fossils in the volcanic rocks strata are all attributed to the debate on forming age of the volcanic rocks in the area. This has not only restricted the classification of the volcanic rocks, but also limited the understanding of the Mesozoic volcanic events in the area. Using single zircon (U-Pb) dating, the authors researched the ages of the Mesozoic volcanic rocks in southeastern Jilin Province, and put forward a new viewpoint based on the stratrum classification, and defined the ages of the volcanic events and mineralization age of the Wufeng gold mine in the Yanbian area.

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2 Geological Background

Mesozoic volcanic rocks are distributed widely in southeastern Jilin Province, and can be divided into three parts, Later Triassic, Jurassic and Cretaceous. The rocks are located mostly in an NE-trending belt at the Mesozoic volcanic-sediment basin in the eastern Yanbian, middle and southern Jilin areas. Thereinto, the Later Triassic

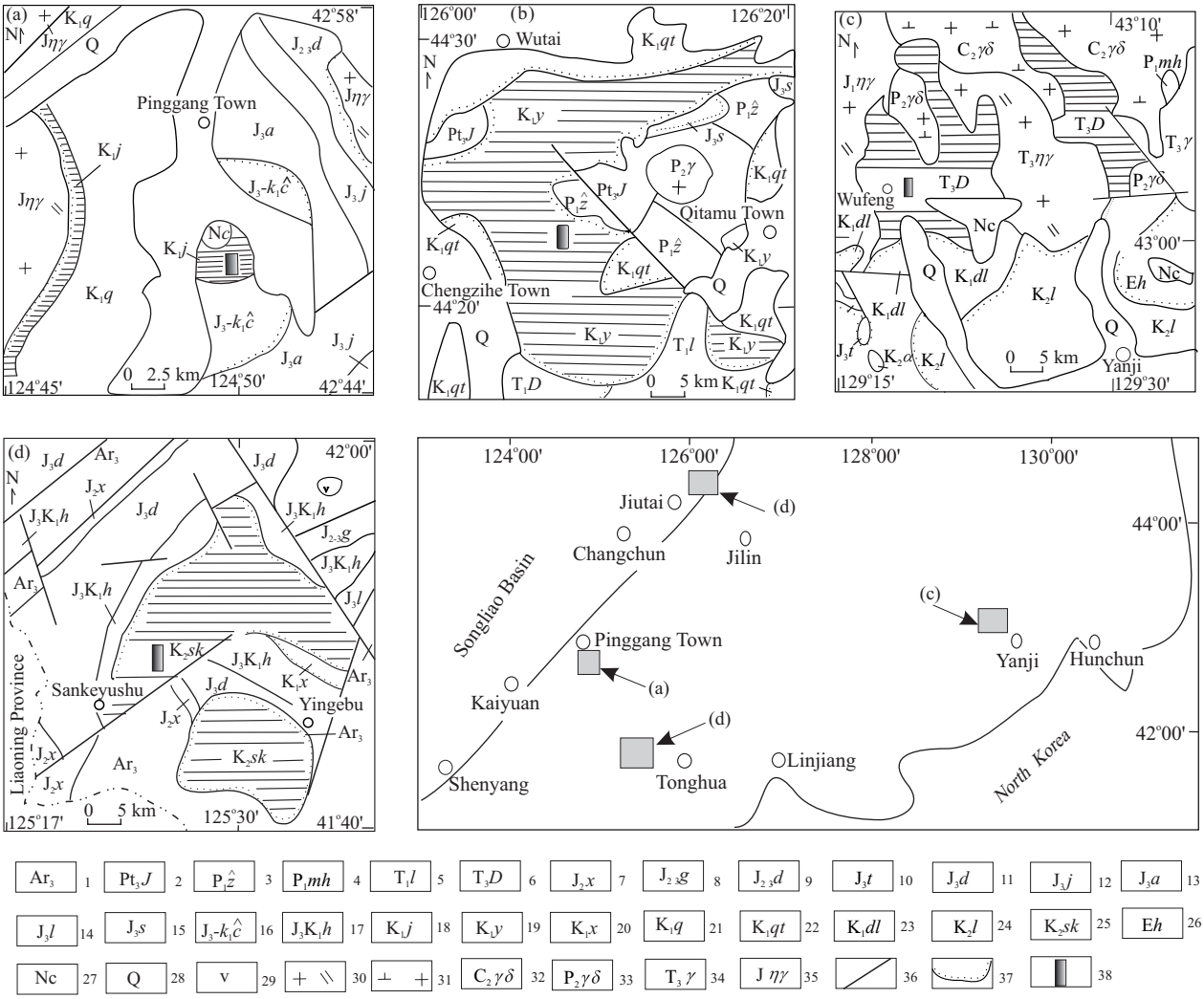

Fig. 1. Structural location and geological maps showing the position of isotope samples. (a from the geological map of Liaoyuan City in scale of 1:250000, 2004; the others from the digital geological map of Jilin Province in scale of 1:500000, 1998).
(1. Late Archaean; 2. Neoproterozoic Jifanggou Complex Group; 3. Lower Permian Zhesi Formation; 4. Lower Permian Manhe Formation; 5. Lower Triassic Lujiatun Formation; 6. Upper Triassic Daxinggou Group; 7. Middle Jurassic Xiaodonggou Formation; 8. Middle-Upper Jurassic Guosong Formation ; 9. Middle-Upper Jurassic Deren Formation ; 10. Upper Jurassic Tuntianying Formation; 11. Upper Jurassic Dashatan Formation; 12. Upper Jurassic Jiuda Formation; 13. Upper Jurassic Anmin Formation; 14. Upper Jurassic Linzitou Formation; 15. Upper Jurassic Shiren Formation; 16. Upper Jurassic-Early Cretaceous Changcai Formation; 17. Upper Jurassic-Lower Cretaceous Hengtongshan Formation; 18. Lower Cretaceous Jinjiatun Formation; 19. Lower Cretaceous Yingcheng Formation; 20. Lower Cretaceous Xiaonangou Formation; 21. Lower Cretaceous Quanshuicun Formation; 22. Lower Cretaceous Quantou Formation; 23. Lower Cretaceous Dalazi Formation; 24. Lower Cretaceous Longjing Formation; 25. Upper Cretaceous Sankeyushu Formation; 26. Paleocene Hunchun Formation; 27. Pliocene Chuandishan Formation; 28. Quaternary alluvium; 29. Gabbro; 30. Monzonitic granite; 31. Granodiorite; 32. Middle Carboniferous Granodiorite; 33. Later Permian Granodiorite; 34. Later Triassic granite; 35. Jurassic Monzonitic granite; 36. Fault; 37. Boundary of unconformity; 38. Location of isotope samples.

volcanic rocks consists of the Daxinggou Group in the Yanbian area, the Xiaofengmidingzi Formation in central Jilin and the Changbai Formation in southern Jilin; the Early Jurassic mainly of the Nanloushan Formation, the Middle-Later Jurassic the Tuntianying Formation in the Yanbian; and the Guosong Formation in the Tonghua and the Deren Formation in the Liaoyuan areas. Due to lack of reliable dating data, the ages of the volcanic rocks are still debatable. (Wang, 1996; BGMRJP, 1989; 1997; Li and Dong, 1986; Sun and Zheng, 2000; Peng et al., 1995; Peng and Su, 1997; Cheng et al., 1997) (Fig. 1).

3 Samples and Analysis Method

The volcanic rock samples (Cy-086) in the Wufeng area were collected from the Wufeng gold mine of Yanji City, Jilin Province, northeastern China (44°23′13″N, 126°08′9″ E). Purple andesite with porphyritic texture (porphyritic crystals up to 20%–25%) consists mostly of plagioclase, minor amount of dark minerals and quartzs; 75%–80% of matrix is aphanitic.

The Yingcheng Formation volcanic rock sample (Cy-070) was collected from the Guanma Mountain in Jiutai City, Jilin Province, northeastern China (44°23′13″N, 126°

Table 1 Chemical composition of the Cretaceous volcanic rocks in southeastern Jilin

Sample No.	Cy-086	Cy-070	Cy-083	Cy-056
Lithology	andesite	rhyolite	dacite	augite andesite
Major (%)	(%)			
SiO_2	61.34	79.66	65.07	55.57
TiO_2	0.88	0.06	0.81	1.02
Al_2O_3	16.69	9.2	16.81	15.76
Fe_2O_3	3.47	0.29	2.93	6.76
FeO	2.24	0.55	0.37	2.65
MnO	0.11	0.01	0.01	0.11
MgO	1.49	0.22	1.31	3.51
CaO	3.72	0.23	4.47	5.98
Na_2O	4.4	4.51	2.59	3.78
K_2O	3.14	4.41	2.59	2.64
P_2O_5	0.35	0.03	0.28	0.98
LOS	1.26	0.71	2.46	0.87
Trace	($\times10^{-6}$)			
Rb	14	205.8	72.5	48.7
Ba	870	75	1086	1287
Th	0.95	14.8	4	6.5
Nb	10	37.6	13.6	23.2
Ta	0.95	2.3	0.5	0.9
Sr	410	12	721	1208
Zr	77.3	358	187	267
Cr	5	2.5	24	46.5
La	45.7	26.9	32.2	84.4
Ce	73.1	58.5	57.3	158
Pr	9.26	7.35	7.83	19
Nd	42.6	23.5	30	65.9
Sm	8.03	5.47	5.18	10.45
Eu	2.03	0.03	1.44	2.63
Gd	8.98	4.65	4.63	6.67
Tb	1.14	0.81	0.66	0.95
Dy	5.73	4.99	3.55	4.25
Ho	1.14	1.14	0.7	0.76
Tm	0.4	0.55	0.3	0.26
Yb	2.61	3.78	1.87	1.61
Lu	0.34	0.57	0.27	0.25
Y	23.2	30.05	19.53	17.96
TREE	172	141.6	148	357.3
(La/Yb)n	11.643	4.979	10.927	33.064
Eu^*/Eu	0.735	0.018	0.889	0.902

Note: The samples from Yingcheng, Jinjiatun and Sankeyushu formations were analyzed at the geological laboratory of Bureau of Geology and Mineral Rresources of Hubei Province; The sample from the Wufeng volcanic rocks was analyzed the the Labouratory of Geology and Mineral Research Institute of Yichang City, Hubei Province, China.

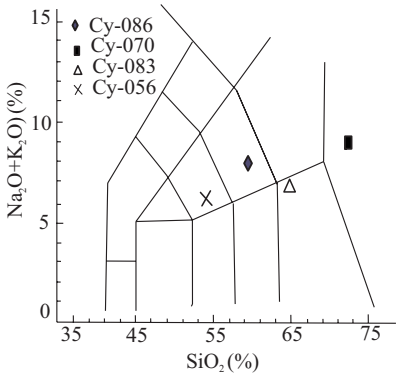

Fig. 2. TAS diagram of the Cretaceous volcanic rocks in southeastern Jilin.

08′9″E). Purple spherulite rhyolite with porphyritic texture (porphyritic crystals accounting for 3%–4%) consists of quartz and alkali-feldspar; the matrix is of fibrous

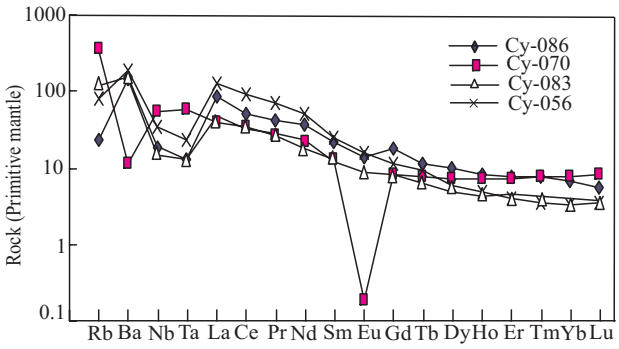

Fig. 3. Spidergram of the Cretaceous volcanic rocks in southeastern Jilin.

spherulite texture.

The Jinjiatun Formation sample (Cy-083) was collected from the Yuquandong Mountain in Pinggang Town of Liaoyuan City, Jilin Province, China (41°44′46″N, 125°24′28″E). Buff dacite with porphyritic texture (porphyritic crystals up to 8%–10%) consists mainly of plagioclase and alkali-feldspar and minor amount of quartz. Matrix accounts for more than 90% and minor air holes and others are full of subglaucophane.

The Sankeyushu Formation sample (Cy-056) was collected from Sankeyushu Town of Tonghua City, southern Jilin Province, China (42°52′50″N, 124°52′36″E). Pyroxene-andesite consists of pilotaxitic matrix. Chemical composition of the sample is listed in Table 1.

Fig. 2 shows that the Sankeyushu samples are distributed around boundary, indicating alkalescence, and other samples are sub-alkalescence. Fig. 3 displays that the samples are enriched in light lanthanon and deplete in heavy lanthanon, but the Yingchengzi Formation is distinctly deplete in Eu, indicating that the magma experienced strong differentiation. Chemical analysis of zircons refers to the literature (Lu and Li, 1991), isotope dating was performed in an apparatus of VG-354 in the Tianjing Institute of Geological and Mineral Resources, Chinese Academy of Geological Science. Four to five Zircons were tested in every sample, with data reliability up to 95%. The results are listed in Table 2 and Fig. 4.

4 Results

Volcanic rocks (Cy-086) from Wufeng of the Yanji area: zircons are long transparent column, which shows that they were crystallized from the crest of magma chamber. Four grains of zircon were tested. $^{206}Pb/^{238}U$ ages are between 100–107 Ma (averaging 103.2±4.7 Ma), and should represent forming time of the tested rock.

Volcanic rocks from the Yingcheng Formation: all the zircons are transparent to translucent buff crystals with a

Table 2 U-Pb dating data of Zircons from the Cretaceous volcanic rocks in southeastern Jilin

Sample No.	Weight μg	U μg/g	Pb μg/g	Content ng	Isotopic ratios $^{206}Pb/^{204}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Age（Ma） $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
cy-086												
1	15	1078	39	0.2	73	0.2257	0.01575 <12>	0.1016 <140>	0.04677 <643>	100.7	98.2	37.4
2	15	966	54	0.3	45	0.2353	0.01585 <17>	0.1045 <198>	0.04782 <851>	101.4	100.9	90.5
3	10	752	28	0.097	71	0.2452	0.06121 <25>	0.1112 <297>	0.04977 <1254>	103.6	107.1	184.1
4	15	638	24	0.12	77	0.2288	0.0168 <29>	0.1107 <339>	0.04778 <1396>	107.4	106.6	88.2
cy-070												
1	15	1144	50	0.27	64	0.1992	0.01744 <12>	0.117 <137>	0.04866 <535>	111.4	112.3	131.4
2	15	1777	63	0.32	86	0.1806	0.01767 <7>	0.1152 <180>	0.04727 <310>	112.9	110.7	62.5
3	15	1613	63	0.33	75	0.2143	0.01772 <9>	0.1145 <99>	0.04687 <537>	113.2	110.1	42.9
4	15	1856	56	0.21	119	0.1603	0.01817 <9>	0.1165 <83>	0.04651 <313>	116.1	111.9	24.1
cy-083												
1	15	751	25	0.27	86	0.2015	0.01621 <17>	0.1071 <194>	0.04792 <819>	103.6	103.3	95.5
2	15	260	13	0.097	49	0.165	0.01622 <44>	0.1094 <520>	0.04893 <2192>	103.7	105.4	144.3
3	15	313	29	0.22	34	0.1829	0.01748 <41>	0.1171 <485>	0.04856 <1899>	111.7	112.4	126.8
4	15	462	19	0.092	74	0.2688	0.0177 <58>	0.1112 <691>	0.04557 <2684>	113.1	107.1	-25.2
5	10	1177	47	0.14	90	0.2274	0.02007 <17>	0.1343 <197>	0.04852 <674>	128.1	127.9	124.6
cy-056												
1	10	1003	56	0.11	88	1.354	0.01867 <20>	0.1239 <229>	0.04814 <842>	119.2	118.6	106.3
2	15	613	32	0.1	96	1.007	0.02033 <21>	0.1351 <243>	0.0482 <824>	129.8	128.7	108.9
3	15	995	58	0.11	112	1.459	0.02052 <16>	0.1363 <183>	0.04815 <612>	131	129.7	106.6
4	15	1014	60	0.16	102	1.226	0.02197 <10>	0.1686 <146>	0.05567 <459>	140.1	158.2	439.1
5	15	601	59	0.27	81	0.5864	0.04134 <18>	0.4287 <226>	0.07521 <372>	261.2	362.3	107.4

$^{206}Pb/^{204}Pb$ had been corrected to test blank (Pb=0.050 ng, U=0.002 ng) and thinner. Pb isotopes from the others rates are radioactivity and the absolute error is 2σ.

shape of puncheon, and four grains were tested. $^{206}Pb/^{238}U$ ages are between 111–116 Ma (averaging 113.4±3.1 Ma). Thus, the Yingcheng Formation rhyolite formed at 113.4 ±3.1 Ma.

Volcanic rocks (cy-083) from the Jinjiatun Formation: all the zircons are transparent to translucent buff crystals with a shape of puncheon, only a few grains are buff dollop. Five grains were tested, and the result shows that the ages of all the zircons are on concordant line. Thus the points on concordant line represent crystal ages of the tested zircons.

$^{206}Pb/^{238}U$ age (128.1±1.1 Ma) of the fifth grain may represent the earliest volcanic event in Cretaceous (about 130 Ma). The average age (112.2±2.1 Ma） of the third and the fourth grains shows the medium term of the volcanic activity (113 Ma) in which these grains were captured. Therefore, the averaging age (103.6±1.0 Ma) of the first and second grains showed the exact time of the Jinjiatun volcanic event.

Volcanic rocks (cy-056) from the Sankeyushu Formation: five zircon grains were tested; the zircons are long transparent column. Dating data of the second and third grains are very close, with an average age of 130.5±5.6 Ma, and the lower point of intersection age on the concordant line is 125.2±8.4 Ma. The fifth grain was not at concordant, suggesting a loss of Pb; the age was of insignificance. The age of the first point is 119.2 Ma, indicating the forming time of the tested rock. The average age of the second and third points and lower point of intersection reflect the early information of the volcanic events.

5 Discussions

The Tuntianying Formation profile to the north of the Wufeng gold mine in Yanji City, which is often used to classify sequences, was previously regarded as the volcanic rocks of Middle-Late Jurassic Tuntianying Formation. But because of lacking fossil and dating data, it was once defined as the Late Triassic Daxinggou Group

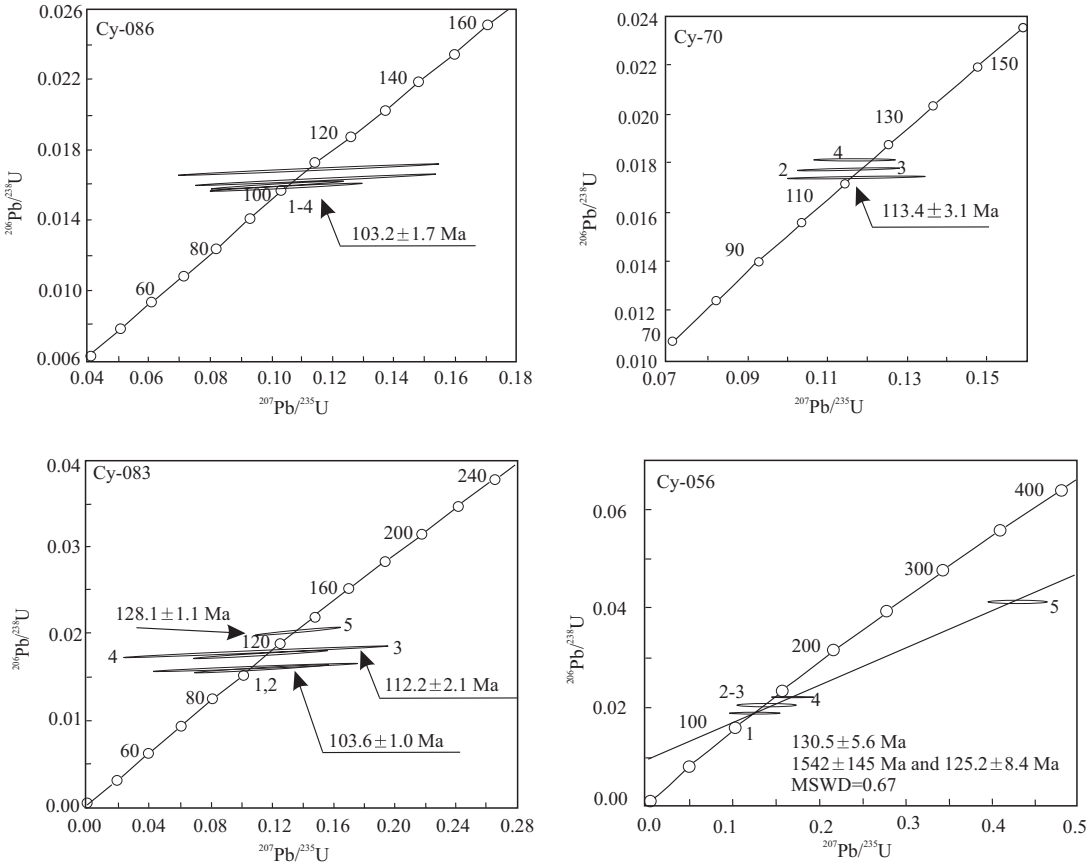

Fig. 4. Zircon U-Pb Concordia diagram of the Cretaceous volcanic rocks in southeastern Jilin.

again (BGMRJP, 1988). Some geologists (BGMRJP, 1987; Wang et al., 1995) believed that the Wufeng gold mine formed in Indo-Chinese epoch. Therefore, the gold mine has long been regarded as a mode of Late Jurassic supergene hydrothermal deposit (Mao et al., 2003).

Based on the new zircon U-Pb ages (Chen, 2003), it can be referred that at least one volcanic event occurred in the volcano-sedimentary basin during Late Cretaceous (103 Ma). This provides new important information for subdividing volcanic events and gold mineralization time in the Wufeng area. Meanwhile, it will broaden the thought on exploration in the whole Yanbian area, especially gold deposits forming at the late stage of Early Cretaceous (103 Ma).

Volcanic rocks of the Sankeyushu Formation have been believed to be Late Cretaceous in age (BGMRJP, 1988; 1997). Chen (1999) gained 8 K-Ar dating data ranging from 100.9 Ma to 115.9 Ma, with an average of 107.0±4.7 Ma, and believed that the $^{40}Ar/^{36}Ar$ and K-Ar ages for the Sankeyushu Formation is 100±1.3 Ma and 101±1.9 Ma. It is very likely that the age represents the last time of the Sankeyushu Formation volcanic event. This age is basically in agreement with that of volcanic rocks of Wufeng (103.2±4.7 Ma) and Jinjiatun formations (103 .6±1.0 Ma), suggesting one volcanic event occurring at the end of Early Cretaceous.

A suit of medium-basic volcanic rocks at Qidaogou in southeastern Tonghua City, Jilin Province was identified by Xue (1997) and named the Sankeyushu Formation with 112.8 Ma of K-Ar age, overlying unconformably the Late Jurassic Jinzitou Formation. This age is in accordance with that (113.4±3.1 Ma) of the Middle Yingcheng Formation purple rhyolites in the Jiutai area, showing medium-term activity time of the volcanic event. Furthermore, a 3- or 4-points weighted average U-Pb dating of single-grained zircon from the Jinjiatun Formation volcanic rock yields an age of 112.2±2.1 Ma, which also provides important evidence for the medium-term volcanic activity.

A surface age of 119 Ma for the first point from the Sankeushu Formation volcanic rocks is basically consistent with that (118.3±1.87 Ma (K-Ar)) of the Sankeyushu Formation (Pei, 2005), showing the earlier time of the Sankeyushu volcanic rocks. It is obvious that the Sankeyushu volcanic rocks were not formed by one eruption but at least three eruptive events.

Besides, the age of rhyolite in the lower Yingchneg Formation is 132±2 Ma (BGMRJP, 1988), 125–131 Ma (K-Ar) (Wang et al, 1995) and 130.5±5.6 Ma–125.2±8.4 Ma (zircon U-Pb age) (Wang et al., 1995), which, along

with 130.5±5.6Ma and 125.2±8.4Ma for the lower Sankeyushu Formation and 128.1±1.1 Ma for No. 5 point of the Jinjiatun Formation (by this study), all reflecting the information of volcanic eruption events in Early Cretaceous or earlier than Early Cretaceous.

Regionally, almost all chronological data of the Yixian Formation in western Liaoning Province are between 130–120 Ma (Peng et al., 2003; Wang et al., 2001a, 2001b, 2001c), with a concentration of about 125 Ma. Viewed from chronology, the Yixian volcanic event corresponds to the earliest volcanic event in Mesozoic Early Cretaceous in Jilin Province.

To sum up, the Mesozoic Early Cretaceous volcanic events in Jilin Province broke through at least three times, but on the scale of one lithostratigraphic unit, it is obvious that this sequence such as the Yingcheng and Sankeyushu formations all formed in Early Cretaceous (K_1).

6 Conclusion

Cretaceous volcanic events in southeastern Jilin Province may have been the result of multiple eruptions, at least three periods, namely 119 Ma (Sankeyushu period), 113 Ma (Yingcheng period), and 103 Ma (Jinjiatun period). Earlier events are likely to occur in 130–125 Ma.

The Sankeyushu Formation in the Tonghua area in southeastern Jilin Province, China, was revised to be Early Crectaceous. The widely distributed volcanic rocks were not come into being by one activity, but at least three activities, which corresponded to the early Cretaceous volcanic events in the area.

A volcanic event in Early Cretaceous (Jinjiatun period: 130 Ma) likely result in the formation of the Wufeng volcanic rocks at Yanji, previously considered as the Upper Triassic Daxinggou Group or the (Middle) Upper Jurassic Tuntianying Formation. Although the age (103 Ma) of the widely distributed volcanic rocks can not be currently confirmed, it suggests that the age of adjoining rocks in the Wufeng gold mine needs to be readdressed. This study also put forward a new multiple-phase mineralization for this area, with the major mineralization occurring at the end of Early Cretaceous. Therefore, the volcanic rocks could be the target for future exploration.

Acknowledgements

This research was supported by the National Natural Science Foundation of China (No. 30670138). The authors are grateful to Professor Peng Yujing from the Regional Geological and Mineral Resources Survey of Jilin Province, China for his guidance in field work.

Manuscript received Jan. 12, 2007
accepted Jan. 30, 2008
edited by Fei Hongcai

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