The SHRIMP U-Pb isotope dating of Mesozoic volcanic from Zhangwu-Heishan Area, West Liaoning Province, China

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ABSTRACT

The Zhangwu-Heishan area is located in the east of the Fuxin-Yixian basin. Besides the Quaternary soil, the study area is mostly covered with volcanic rock. The horizon and age of volcanic rock play an essential role in understanding fossil beds, structures, and sedimentary evolution of West Liaoning Province and coal seeking. During this work, 11 volcanic rock samples were measured by SHRIMP U-Pb isotope analysis. Based on the reported data on the age of the Mesozoic volcanic rock in West Liaoning Province, in combination with new measurement data, Cretaceous volcanic activities in West Liaoning Province can be divided into five stages, namely 132±1 Ma, 126±1 Ma, 122±2 Ma, 115±2 Ma, and 100±5 Ma. Based on statistical results, this paper concluded that the thinning time of the crust in Northeast China is from 132±1 Ma to 115±2 Ma.

RESUMEN

El área Zhangwu-Heishan se ubica en el este de la cuenca Fuxin-Yixian. El suelo del Cuaternario en el área de estudio está cubierto por rocas volcánicas. El horizonte y la edad de la roca volcánica juegan un rol esencial en la comprensión de las capas fósiles, las estructuras y la evolución sedimentaria de la Provincia Liaoning, en el occidente de China, y en la búsqueda de carbón. En este trabajo se estudiaron 11 muestras de roca volcánica a través del análisis isotópico SHRIMP U-Pb (Datación U-Pb a través de la Microsonda de Iones de Alta-Resolución). De acuerdo con la información reportada en las rocas volcánicas de edad del Mesozoico al oriente de la provincia Liaoning, en combinación con información de nuevas mediciones, las actividades volcánicas del Cretácico en la zona se pueden dividir en cinco etapas: 132±1 Ma, 126±1 Ma, 122±2 Ma, 115±2 Ma, y 100±5 Ma. Con base en los resultados estadísticos, este estudio concluyó que el tiempo de adelgazamiento de la corteza en el noroeste de China está entre 132±1 Ma y 115±2 Ma.
Introduction

Due to the discovery of precious fossils, West Liaoning Province has been drawing extensive interests in recent years (Chen et al., 1998; Sun, 1998; Swisher, 1999; Xu, 2001; Zhou, 2003; Zhou, 2003). Meanwhile, the researches on the stratigraphy, paleo-geography, paleoclimatic, and paleomagnetism of the Mesozoic volcano-sedimentary basin in west Liaoning Province are gradually performed (Pan et al., 2001; Zhang et al., 2002; Zhu et al., 2001 & 2002; Gong et al., 2007; Li et al., 2002; Ren, 1997). As an essential terrane in North China where Meso-Cenozoic volcanic activities were developed, outstanding achievements have also been made in the researches on the chronology (Figure 1) and geochemistry of volcanic rock in west Liaoning Province (Jia et al., 1999; Zhou, 2001; Zhang & Zheng, 2003; Yang, 2007; Wu et al., 2003). Whereas SHRIMP Zircon U-Pb isotopic dating of volcanic rock in west Liaoning Province mainly concentrates on Yixian Basin, there are only sporadic isotopic reports dating of volcanic rock in Zhangwu-Heishan Area (Chen et al., 1997; Huang, 2006 & 2007; Xiao, 2008).

West Liaoning Province is located in the east section of the Yanshan Platformal Fold Belt in the north of Sino Korean Paraplatform and belongs to the east extension of Yanshan Orogenic Belt (Figure 1). Yanshan Orogenic Belt lies inside the North China Platform and has experienced intense tectonic deformation, magmatic and volcanic activities, and syn-orogenic sedimentation Jurassic-Cretaceous Yanshan Movement, and finally becomes a typical intraplate orogenic belt (Zhang CH, 1999) far away from any contemporary plate boundary. The subduction of the Pacific Plate has resulted in NE-trending thrust nappe structure of late Jurassic Epoch and extensional structure of the early Cretaceous Epoch. Before the Mesozoic Period, the study area is a large tectonic uplift area. At the first stage of the Yanshan Movement, the fault-folding formed lower-middle Jurassic Series in the NNE-trending depression area, including coal-bearing strata - Beipiao Formation. At the Yanshan Movement’s medium setting, a large-scale fracture occurred and was accompanied by a magmatic eruption, and then a Mesozoic tectonic framework was formed.

Denomination and Age of Volcanic Rocks

Although numerous detailed stratigraphic researches have been carried out in West Liaoning Province, the knowledge of stratigraphic sequence, the horizon of volcanic rock, and volcanic eruption periods are unified yet. For instance, whether volcanic rock in Yixian Formation is of late Jurassic Epoch (Wang, 1987; Ren et al., 1997; Wang, 1998; Luo et al., 1999), late Jurassic to early Cretaceous Epoch (Zhang et al., 1992; Chen et al., 1998; Ji et al., 1998; Sun & Zheng, 2000; Jiang et al., 2000; Wang et al., 2002) or early Cretaceous Epoch (Li et al., 2001; Wang et al., 1999; Wang et al., 2001; Xu et al., 1999; Ji et al., 2002; Wang et al., 2005; Zhang et al., 2006) is an open question. For more details of the stratigraphic division in this area and volcanic rock’s denomination, see the references Wang et al., 2004; Cai, 2009). It should be noted that the Scientific Research Institute of Liaoning Bureau of Coalfield Geological Exploration (1970) advocates that extensive volcanic rock in this area belongs to Dalinghe Formation and is of Cretaceous Epoch and concluded that there might be coal seams of Fuxin Formation under this suite of volcanic rock. Likewise, the 107th Coalfield Geological Brigade of Liaoning Province held in 1974 suggested that coal-bearing series of Badaohao Formation could not be correlated with Shahai Formation or Fuxin Formation in Fuxin Basin, and Gangtaishan volcanic rock overlies Badaohao Formation and also drew the conclusion that the coal possibly could be found below those volcanic rocks.

Isotopic Dating and Eruption Period of Volcanic Rock

Isotopic dating of volcanic rock in west Liaoning Province starts in the 1980s (Diao, 1983; Wang, 1984 & 1985). Some fundamental findings have been made since the 1990s (For the data on isotopic dating, see Figure 2). By far, over 120 pieces of data derived from various dating methods have been published. These data are systematically collected, and the distribution map (see Figure 2) was plotted in this work. From the figure, the age of volcanic rock
which crops out in west Liaoning Province varies between 56 Ma and 147 Ma. Yixian Formation of early Cretaceous Epoch in the Xixian Basin contains four suites of volcanic rock and sedimentary rock (Ji, 2004), which represent four volcanic-sedimentary activities. As shown in Table 1, the periods of volcanic activities are 132±1 Ma, 126±1 Ma, 122±2 Ma, and 115±2 Ma. Also, a suite of alkaline basalt was formed in the period of 90-105 Ma. This is identical to the east part of North China (Zhai et al., 2003). There is also a Paleogene olivine-inclusion-bearing basalt suit with the age of about 56Ma in the Zhangwu-Heishan Area. In 2008 the International Commission on Stratigraphy adjusted the Jurassic-Cretaceous boundary from originally 135 Ma (140 Ma) to 145 Ma to 14 Ma and the age of lower Cretaceous-upper Cretaceous limit from 95 Ma to 99.6 Ma. Therefore, previously delineated volcanic rock of late Jurassic Epoch is now of early Cretaceous Epoch, and the peak period of volcanic activities is the medium stage (130 Ma-122 Ma or so) of early Cretaceous Epoch, namely Barremian to Aptian stage.

It is an indisputable fact that the lithospheric mantle in North China Craton was thinned on a large scale in the Mesozoic and Cenozoic Periods (Gao et al., 2004; Liu et al., 2004). The earth’s crust in west Liaoning Province was also thinned when volcanic rock in the Xixian Formation was formed (Zhang, 2003; Zhang, 2005). The time when Xixian Formation was formed is also the critical period when the earth’s crust (lithosphere) in Northeast China was thinned, so the age of top and bottom boundaries of volcanic rock in Xixian Formation is the critical period when the earth’s crust (lithosphere) in west Liaoning Province, even Northeast China, was thinned.

Conclusions

The horizon and age of volcanic rock play an essential role in understanding fossil beds, structures, and sedimentary evolution of West Liaoning Province and coal seeking. During this work, 11 volcanic rock samples were measured by SHRIMP U-Pb isotope analysis. Based on the reported data on the age of the Mesozoic volcanic rock in West Liaoning Province, in combination with new measurement data, Cretaceous volcanic activities in West Liaoning Province can be divided into five stages, namely 132±1 Ma, 126±1 Ma, 122±2 Ma, 115±2 Ma, and 100±5 Ma. Based on the statistical result, this paper concluded that the thinning time of the crust in Northeast China is from 132±1 Ma to 115±2 Ma.
| NO | Sample Location                  | Lithology       | Test method | Age/Ma  | Data source |
|----|----------------------------------|-----------------|-------------|---------|-------------|
| 1  | Zhuanchengzi in Yixian           | andesite, basalt| K-Ar        | 139.2±6.1| Diao et al. |
| 2  | Zhuanchengzi in Yixian           | andesite, rhyolite| K-Ar       | 117.1±5 | Diao et al. |
| 3  | Zhuanchengzi in Yixian           | andesite        | Rb-Sr       | 125.9±5.3| Wang et al. |
| 4  | Zhuanchengzi in Yixian           | basalt-basaltic andesite | K-Ar | 136.9 | Wang et al. |
| 5  | Zhuanchengzi in Yixian           | rhyolite        | Rb-Sr       | 142.5±4 | Wang et al. |
| 6  | Wendi Countryside                | rhyolite        | Rb-Sr       | 126±5  | Wang et al. |
| 7  |                                  | rhyolite, andesite | Rb-Sr | 127±3 | Guo et al. |
| 8  | Dakangbo in Yixian               | andesite, dacite| Ar-Ar       | 121.2±0.3| Smith et al|
| 9  | Jingangshan in Yixian            | dolerite        | Ar-Ar       | 120.8-121| Smith et al|
| 10 | Jiashangou in Beipiao            | basalt          | Ar-Ar       | 121.2±0.3| Smith et al|
| 11 | Huanghuashan in Yixian           | volcanic breccia| Ar-Ar       | 121.5±0.9| Smith et al|
| 12 | Zoujiagou in Yixian              | basalt          | Ar-Ar       | 121.6±0.4| Smith et al|
| 13 | Central Yixian Formation         | zircon         | U-Pb        | 136.7   | Luo et al. |
| 14 | Yixian                           | andesite        | Ar-Ar       | 129.2   | Chen et al.|
| 15 | Zhuanchengzi in Yixian           | phosphorite     | U-Pb        | 136±7   | Chen et al.|
| 16 | Hejiagou in Yixian               | andesite        | Ar-Ar       | 119.0±10.0 | Chen et al.|
| 17 | Zhujiaogou in Yixian             | andesite        | Ar-Ar       | 124.5±4.9 | Chen et al.|
| 18 | Dehuiyingzi in Zhangwu           | trachyandensite, dacite | Ar-Ar | 123.7±4.4 | Chen et al.|
| 19 | Dingjiafang in Zhangwu           | andesite        | Ar-Ar       | 125.9±2.0 | Chen et al.|
| 20 | Yemaotai in Zhangwu              | dacite          | Ar-Ar       | 112.0±0.9 | Chen et al.|
| 21 | Yemaotai in Zhangwu              | andesite        | Ar-Ar       | 115.0±0.5 | Chen et al.|
| 22 | Paozi in Fuxin County            | Hyalinite andesite | U-Pb  | 116     | Chen et al.|
| 23 | Sihetun, Jiashangou              | tuff            | Ar-Ar       | 145.3±4.4 | Luo et al.|
| 24 | Sihetun, Jiashangou              | tuff            | Ar-Ar       | 144.8±1.5 | Luo et al.|
| 25 | Sihetun, Jiashangou              | tuff            | Ar-Ar       | 147.1±1.8 | Luo et al.|
| 26 | Fuxin                            | basalt          | K-Ar        | 84.76±1.6 | Zheng et al.|
| 27 | Sihetun                          | Tuff permeates feldspar | Ar-Ar | 124.6±0.3 | Swisher et al|
| 28 | Sihetun                          | Tuff permeates feldspar | Ar-Ar | 125.0±0.18 | Swisher et al|
| 29 | Hengdaoozi                       | sanidine        | Ar-Ar       | 125.0±0.19 | Swisher et al|
| 30 | Dijiaogou                        | trachyte        | Ar-Ar       | 147.3±0.6 | Li et al.|
| 31 | Dijiaogou                        | trachyandensite | Ar-Ar | 140.4±0.4 | Li et al.|
| 32 | Xijieshany Section               | andesite        | Ar-Ar       | 121.9±0.6 | Li et al.|
| 33 | Xijianshan Section               | dolerite        | K-Ar        | 116.7±2.3 | Li et al.|
| 34 | Jingangshan in Yixian            | andesite        | K-Ar        | 120.1±2.0 | Li et al.|
| 35 | Xiaoyiuntan in Yixian            | basalt          | K-Ar        | 91.8±2.13 | Li et al.|
| 36 | Xiaoyiuntan in Yixian            | andesite        | K-Ar        | 125.6±0.4 | Li et al.|

(Continued)
Table 1. Rock samples and dating results of volcanic in Fuxin and Heishan-Zhangwu area

| NO | Sample Location          | Lithology     | Test method | Age/Ma            | Data source   |
|----|--------------------------|---------------|-------------|-------------------|---------------|
| 37 | Dijiagou—Zhuanchengzi    | basalt        | K-Ar        | 131.2±2.6         | Wang et al.   |
| 38 | Sihetun                  | tuff          | U-Pb        | 125.2±0.9         | Wang et al.   |
| 39 | Sihetun                  | basaltic andesite | Ar-Ar   | 128.2±0.8         | Wang et al.   |
| 40 | Sihetun                  | basaltic andesite | Ar-Ar   | 128.4±1.4         | Wang et al.   |
| 41 | Sihetun                  | basaltic andesite | Ar-Ar   | 128.4±0.2         | Wang et al.   |
| 42 | Sihetun                  | dolerite      | Ar-Ar       | 122.3±0.5         | Wang et al.   |
| 43 | Sihetun                  | dolerite      | Ar-Ar       | 122.1±1.2         | Wang et al.   |
| 44 | Sihetun                  | dolerite      | Ar-Ar       | 121.8±1.3         | Wang et al.   |
| 45 | Paishanlou in Fuxin      | dioritic porphyrite | U-Pb | 126±2             | Luo et al.    |
| 46 | Paishanlou in Fuxin      | granite porphyry | U-Pb     | 124±1             | Luo et al.    |
| 47 | Paishanlou in Fuxin      | dioritic porphyrite | U-Pb | 125±1             | Luo et al.    |
| 48 | Dashitougou in Fuxin     | biotite granite | U-Pb     | 124±1             | Luo et al.    |
| 49 | Jianguo in Fuxin         | basalt        | K-Ar        | 92.12±2.08        | Wang et al.   |
| 50 | Sihetun                  | basalt        | K-Ar        | 124.16-133.59     | Zhu et al.    |
| 51 | Zhuanchengzi             | andesite      | K-Ar        | 120.42-122.31     | Zhu et al.    |
| 52 | Zhuanchengzi in Yixian   | andesite      | K-Ar        | 122.31-120.42     | Zhu et al.    |
| 53 | Jianguo in Fuxin         | basalt        | Ar-Ar       | 105.5±0.5         | Zhu et al.    |
| 54 | Jianguo in Fuxin         | andesite      | Ar-Ar       | 100.4±1.6         | Zhu et al.    |
| 55 | Songjia                  | andesite      | Rb-Sr       | 140±6             | Zhu et al.    |
| 56 | Yiwulvshan               | miliolite     | Ar-Ar       | 219±4             | Zhang et al.  |
| 57 | Yiwulvshan               | miliolite     | Ar-Ar       | 116±2             | Zhang et al.  |
| 58 | Yiwulvshan               | miliolite     | Ar-Ar       | 127±3             | Zhang et al.  |
| 59 | Sihetun                  | olivine basalt | Ar-Ar   | 132.9±1.5         | Peng et al.   |
| 60 | Huangbanjigou            | liparitic tuff | Ar-Ar   | 127.4±1.3         | Peng et al.   |
| 61 | Sihetun                  | ellipsoidal lava | Ar-Ar | 126.1±1.7         | Peng et al.   |
| 62 | Sihetun                  | olivine basalt | K-Ar     | 133.3±2.6         | Peng et al.   |
| 63 | Sihetun                  | olivine basalt | K-Ar     | 133.6±2.6         | Peng et al.   |
| 64 | Sihetun                  | olivine basalt | K-Ar     | 124.16±2.4        | Peng et al.   |
| 65 | Sihetun                  | olivine basalt | K-Ar     | 124.42±2.4        | Peng et al.   |
| 66 | Sihetun                  | olivine basalt | K-Ar     | 124.91±2.4        | Peng et al.   |
| 67 | Houyanzigou              | olivine basalt | Ar-Ar   | 130.6±0.5         | Peng et al.   |
| 68 | Sihetun                  | olivine basalt | Ar-Ar   | 127.7±0.2         | Peng et al.   |
| 69 | Jianguo                  | basalt        | K-Ar        | 107.3±1.6         | Zhang et al.  |
| 70 | Jianguo                  | ring tephrite  | K-Ar        | 94.2±1.4          | Zhang et al.  |
| 71 | Jianguo                  | basalt        | K-Ar        | 97.1±1.4          | Zheng et al.  |
| 72 | Jianguo                  | basalt        | K-Ar        | 98.0±1.4          | Zheng et al.  |
| 73 | Zaocishan                | dacite porphyry | Ar-Ar   | 122.09±0.29       | Wang et al.   |

(Continued)
Table 1. Rock samples and dating results of volcanic in Fuxin and Heishan-Zhangwu area

| NO | Sample Location             | Lithology          | Test method | Age/Ma     | Data source       |
|----|-----------------------------|---------------------|-------------|------------|-------------------|
| 74 | Zaocishan                   | dacite porphyry     | Ar-Ar       | 122.36     | Wang et al.       |
| 75 | Zaocishan                   | dacite porphyry     | Ar-Ar       | 121.80±1.36| Wang et al.       |
| 76 | Sihetun                     | basalt              | U-Pb        | 112±3      | Ji et al.         |
| 77 | Zhuanchengzi in Yixian      | basalt              | U-Pb        | 120±2      | Ji et al.         |
| 78 | Jingangshan in Yixian       | dacite porphyry     | U-Pb        | 126±0.5    | Ji et al.         |
| 79 | Zhuanchengzi in Yixian      | andesite            | U-Pb        | 132±1      | Ji et al.         |
| 80 | Sihetun                     | tuff                | U-Pb        | 124.4±1.6  | Yang et al.       |
| 81 | Huangbanjigou               | tuff                | U-Pb        | 123.1±2.1  | Yang et al.       |
| 82 | Huangbanjigou               | tuff                | U-Pb        | 122.1±1.4  | Yang et al.       |
| 83 | Jianguo                     | basalttrachyandensite | Ar-Ar    | 116.8±3.0  | Zhu et al.        |
| 84 | Fanjiagou in Yixian         | rhyolite            | U-Pb        | 118.9±1.4  | Zhang et al.      |
| 85 | Fanjiagou in Yixian         | rhyolite            | U-Pb        | 119.8±1.9  | Zhang et al.      |
| 86 | Huanghuashan breccia        | dacite porphyry     | Ar-Ar       | 122.1±0.3  | Zhang et al.      |
| 87 | Huanghuashan breccia        | dacite porphyry     | Ar-Ar       | 121.8±1.4  | Zhang et al.      |
| 88 | Sihetun                     | basaltic andesite   | Ar-Ar       | 126.1±0.4  | Zhang et al.      |
| 89 | Sihetun                     | basalt              | K-Ar        | 124.2±2.4  | Li et al.         |
| 90 | Sihetun                     | basalt              | K-Ar        | 124.4±2.4  | Li et al.         |
| 91 | Sihetun                     | basalt              | K-Ar        | 125.0±2.4  | Li et al.         |
| 92 | Sihetun                     | basalt              | K-Ar        | 124.6±2.5  | Li et al.         |
| 93 | Sihetun                     | basalt              | K-Ar        | 124.8±2.3  | Li et al.         |
| 94 | Sihetun                     | basalt              | K-Ar        | 125.1±2.4  | Li et al.         |
| 95 | Sihetun                     | basalt              | K-Ar        | 124.9±2.4  | Li et al.         |
| 96 | Sihetun                     | basalt              | K-Ar        | 126.1±2.6  | Li et al.         |
| 97 | Sihetun                     | basalt              | K-Ar        | 129.3±2.5  | Li et al.         |
| 98 | Sihetun                     | basalt              | K-Ar        | 129.2±2.6  | Li et al.         |
| 99 | Sihetun                     | basalt              | K-Ar        | 133.3±2.6  | Li et al.         |
| 100| Sihetun                     | basalt              | K-Ar        | 133.6±2.6  | Li et al.         |
| 101| Sihetun                     | basalt              | K-Ar        | 133.1±2.6  | Li et al.         |
| 102| Maozishan in Lingyuan       | tuff                | U-Pb        | 125.4±0.9  | Zhang et al.      |
| 103| Maozishan in Lingyuan       | rhyolite            | U-Pb        | 125.3±0.9  | Zhang et al.      |
| 104| Maozishan in Lingyuan       | rhyolite            | U-Pb        | 124.4±1.1  | Zhang et al.      |
| 105| Guojiagou in Lingyuan       | tuff                | U-Pb        | 122.3±2.1  | Zhang et al.      |
| 106| Dawangzhangzi in Lingyuan   | rhyolite            | U-Pb        | 123.1±1.7  | Zhang et al.      |
| 107| Zhangwu                     | andesite            | U-Pb        | 126±2      | Huang et al.      |
| 108| Lihenggou in Yixian         | rhyolite            | Ar-Ar       | 113.2±1.6  | Shao et al.       |
| 109| Daxingzhuang in Linghai     | amphibole andesite  | U-Pb        | 114.9±2.5  | Shao et al.       |
| 110| Dasijiazi in Zhangwu        | rhyolite            | U-Pb        | 122.4±0.4 Ma| Xiao et al.       |
Table 1. Rock samples and dating results of volcanic in Fuxin and Heishan-Zhangwu area

| NO  | Sample Location     | Lithology       | Test method | Age/Ma         | Data source          |
|-----|---------------------|-----------------|-------------|----------------|----------------------|
| 111 | Kazuo butte         | andesite        | K-Ar        | 125.7 ± 4.3   | Wang et al.          |
| 112 | Kazuo butte         | andesite        | U-Pb        | 126.0 ± 1.5   | Wang et al.          |
| 113 | Lingyuan            | rhyolite        | U-Pb        | 124.4 ± 1.4   | Meng et al.          |
| 114 | Badao hao in Heishan| trachyandesite  | U-Pb        | 125.7 ± 1.7   | This Paper           |
| 115 | Zhangluo tun in Heishan | rhyolite    | U-Pb        | 124.9 ± 2.9   | This Paper           |
| 116 | Yaocangtu in Heishan | coloradoite  | U-Pb        | 115.5 ± 1.5   | This Paper           |
| 117 | Nalishan in Yaocangtu | basalt          | U-Pb        | 56 ± 2.9      | This Paper           |
| 118 | Liangshan in Heishan | trachyandesite | U-Pb        | 129.7 ± 1.6   | This Paper           |
| 119 | Beizhuanchengzi     | andesite        | U-Pb        | 132.3 ± 2.3   | This Paper           |
| 120 | Huanghuashan in Yixian | dacite      | U-Pb        | 126.3 ± 1.7   | This Paper           |
| 121 | Juliangtun in Yixian | trachyandesite | U-Pb        | 125.8 ± 1.9   | This Paper           |
| 122 | Lijiatai            | andesite        | U-Pb        | 127.0 ± 5.1   | This Paper           |
| 123 | Xinglonggou in Yixian | andesite    | U-Pb        | 122.3 ± 4.5   | This Paper           |
| 124 | Songbahu in Yixian  | andesite        | U-Pb        | 129.0 ± 2.4   | This Paper           |

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