2011-2014

China National Report on Volcanology and Chemistry of the Earth's Interior

For

The 26th General Assembly of IUGG

Prague, Czech Republic, 22 June - 2 July 2015

Prepared by Chinese National Committee for International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI)

CONTENTS

The Research Progress for the Petrogenesis of Basalts from NE, China

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The Cenozoic volcanism produced quantity of alkaline basalts, widely distributed along the eastern China. Among them, Xiaogulihe-Keluo-Wudalianchi-Erkeshan (XKWE for short) potassic volcanic rock belt, between Lesser Hinggan Mountains and Greater Hinggan Mountains and in the north rim of Songliao basin, located in Heilongjiang province, northeastern China. The XKWE potassic volcanoes are one of the best preserved Quaternary volcanic clusters in China, and the unique eruptions of ultrapotassic volcanic rocks in eastern China so far took place in the Xiaogulihe area. Potassic and ultrapotassic volcanism receive much attention in recent years because of their special geological setting and characteristic geochemistry. However, the origin of these alkali basalts has been the subject of considerable debate.

The high content of K_2O and negative correlation between $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{204}Pb$ of Xiaogulihe ultrapotassic rocks indicate the presence of a potassic phase, mostly phlogopite, in their mantle source. The strong fractionation of REE and lack of Nd-Hf isotopic decouple imply a low-degree partial melting of garnet-bearing source rocks. In addition, the low CaO and Al_2O_3 contents of whole-rock compositions and low Fe/Mn ratios of olivine phenocryst chemistries suggest peridotites rather than pyroxenites as dominant source rocks for the Xiaogulihe ultrapotassic rocks. Sun et al. (2014) then propose that the mantle source of these ultrapotassic rocks is phlogopite-bearing garnet peridotite within the lower part of the SCLM that had been metasomatized by potassium-rich silicate melts.

Kuritani et al. (2013) investigated the origin of Wudalianchi volcanic field and estimated the temperature of the magmas shortly before eruption. Because the estimated temperatures are significantly higher than the projected maximum temperature of the lithospheric mantle beneath the Wudalianchi volcanic field, they concluded the magmas were likely derived from the asthenospheric mantle. They also suggested that both the potassic- and EMI-like natures of the basalts originated from the mantle transition zone, metasomatized by K-rich sediment fluids ~1.5 Ga ago through a stagnation of an ancient slab. They inferred that the Wudalianchi magmatism was caused by an upwelling of a hydrous mantle plume from the mantle transition zone, which was hydrated through the stagnant of the ancient subducted slab and the recent Pacific slab. While Chu et al. (2013) suggested that the Wudalianchi-Erkeshan basalts mainly originated from phlogopite-bearing garnet-peridotite in the SCLM which had been metasomatized by delaminated old, lower continental curst. Zhang et al. (2011) proposed the ancient mantle beneath the Keluo region is extraneous and had been emplaced from other locations.

Quaternary volcanism also distribute pervasively from middle to east Innor Mongolia. The Nuomin volcanic field (NM for short) in northern Greater Xing'An Mountains is dominated by Quaternary monogenetic eruptions, forming lava flows covering an area of about 600 km^2. The lavas range from tephrite and basanite to trachybasalts, with K_2O contents between 2.6 wt.% and 4.3 wt.%, and K_2O/Na_2O between 0.78 and 1.08. The NM lavas are characterized by relatively high $(La/Yb)_N$ (21.6-41.9) and enrichments in LILEs, but low in HSFE concentrations. The incompatible elements patterns for the NM lava show features apparently different from melt from asthenosphere such as the Halaha-Chaoer lava, strongly supporting the possibility of involvement of lithosphere mantle in the origin of primitive magma. Isotopic data of NM lava are located between Wudalianchi lava and Halaha-Chaoer lava, indicating source mixing for NM lava origin. Zhao et al. (2014) concluded that the delamination of K-rich lithosphere mantle triggered the mixing of melts derived from asthenosphere and delaminated lithospheric block which contributed the Quaternary potassic volcanism of Northeastern China.

The Wulanhada basalts, located in northern Jining, Innor Mongolia, at the northern margin of the North China Craton, are associated with the well-known Hannuoba basalts. According to the characteristics of trace elements and Sr-Nd-Pb-Hf isotopic compositions, the Wulanhada magmas were mainly derived from garnet-bearing peridotite within the asthenosphere and underwent fractional crystallization of olivine and clinopyroxene without significant crustal contamination. Their elevated values of Na, Al, Sr/Sm, Sm/Hf, Zr/Hf, and Nb/Ta, positive Ba, K, Pb and Sr anomalies and negative Zr, Hf anomalies, combined with a negative correlation between $^{176}Hf/^{177}Hf$ and $^{143}Nd/^{144}Nd$ and relatively low $^{87}Sr/^{86}Sr$, suggested that the magma source may be a mixture of garnet peridotites and carbonated melts. The presence of carbonated melts is likely associated with the sediments or fluids carried by the subducted or stagnant Pacific Plate (Fan et al., 2014).

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Variations in the Geochemical Structure of the Mantle Wedge Beneath the Northeast Asian Marginal Region from Pre- to Post-opening of the Japan Sea

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Deep asthenospheric processes and the dynamic mechanism of magmatism in the northeast Asian marginal region are of significant interest but have been difficult to study in detail. We completed comprehensive studies on Japan Sea basalts including petrography, whole-rock major and trace elements, Sr-Nd-Pb isotopic compositions, and K-Ar geochronology, then combined our results with previous research to study the tectonic evolution of northeast Asia. The Japan Sea basalts, divided into Upper and Lower layers of Site 794 (US794, LS794), and Upper and Lower layers of Site 797 (US797, LS797) based on their stratigraphic level, belong to the calc-alkalic series and are characterized by flat HREE with significantly positive anomalies of Ba, Sr, and Pb, and slight anomalies of Eu (δEu=0.81–1.21). The US797 sample group has lower LREE, LILE and relatively depleted radioactive isotope ratios ($^{87}Sr/^{86}Sr$ = 0.704051–0.704254; $^{143}Nd/^{144}Nd$ = 0.513035–0.513139; $^{206}Pb/^{204}Pb$ = 17.758–18.223), whereas the sample groups LS797, US794, and LS794 have relatively higher incompatible elements and slightly enriched isotopic values ($^{87}Sr/^{86}Sr$ = 0.704248–0.705222; $^{143}Nd/^{144}Nd$ = 0.512705–0.512917; $^{206}Pb/^{204}Pb$ = 18.077–18.377) due to the involvement of Pacific subducted fluid and sediments. K-Ar and ^{40}Ar-^{39}Ar geochronlogical data indicate age ranges of LS797, US794, and LS794 samples of 17.7 ± 0.5–21.2 ± 0.8 Ma, significantly older than those of US797 (15.1 ± 0.9–17.2 ± 0.7 Ma). Our data compiled with other data show sharply defined Sr-Nd isotopic variations of the Cenozoic basalts from Sikhote-Alin, the Japan Sea, the back-arc side of NE Japan and SW Hokkaido, and north Hokkaido from a slightly enriched to a depleted isotopic signature at 23–24 Ma, 17 ± 2 Ma (15–19 Ma), 15 Ma, and >12 Ma, respectively, indicating that the upwelling asthenosphere beneath northeast Asia progressed eastward relative to the lithosphere. We conclude that the temporal and spatial variation of basaltic magma sources in the northeast Asian marginal region is closely associated with the extension of the Japan Sea.

Research Progress of Geophysical Exploration the Magma Chamber of Changbai Mountains

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Changbaishan Tianchi volcano is a multi-causes Stratovolcano, a dormant volcano, with a potential risk of eruption. Over the years, many scholars and units conducted geological, geophysical, geochemical and other exploration works. Let's focus on the geophysical exploration.

Jin et al. (1994) draw the main faults of Changbai Mountains based on the complete bourger anomaly and its horizontal gradient data. At the same time, get the magma chamber models in different eruption periods based on geochemical data. But the confidence level of models is lower they written at the end of their book, because of the lack of the temperature and pressures data.

Guo et al. (1995, 1996), study the magma chambers of Changbai Mountains based on seismic CT technology by using of seismograph station data. The result shows that there is low velocity zone (LVZ) under the Changbai Tianchi, with depth 38-65km, distribution 100-200km. it could be the magma chamber.

Zhang et al. (2000, 2002) inverse the 2D and 3D velocity structure in Changbai Mountains based on the seismic exploration data, and the result shows that there several low velocity zones during the depth from 9-15km to the lower crust, and they regard that the LVZs are magma chambers, and a shallow small LVZ should be active magma pocket. While Song (2007) regard it as true that the magma chambers must be under the place at least 20km-north from Tianchi based Zhang's data.

Tang et al. (2001) inverse the electrical resistivity section structure in Changbai Mountains based on the 5 profiles, 61 MT data measured very close to the Changbaishan Tianchi. The resistivity contour section shows that there is a low apparent resistivity zone with the depth of 12km, under the northeast place of Tianchi, and they think it must be the Changbai Tianchi volcano magma chamber.

Duan et al. (2003) analysis 4 seismic profiles and one 3D seismic stations data, and get the basement structure of the Changbai Mountains, the result shows generally the depth of the basements is 2.0-3.0km.

Zhao et al. (2004) analysis 19 seismic stations for short time and 3 digital seismic stations data by using of seismic tomography, the P-wave velocity shows that the LVZs with 400km-length, 200km-width from the crust to mantle. And they regard it is true that Changbai Mountains is back-arc intraplate volcano.

Hetland et al. (2004) presented the crustal structure in the Changbaishan region based on modeling teleseismic receiver functions. They compare their result with Zhang's & Tang's. And their results show that below 3.7–7 km depth should exit partial melt body.

Wu et al. (2007) analysis the naturel seismic events during 2002-2003 in Changbai Mountains, they think that at the depth of 5km there is a active magma pocket and the pressure is growing.

Qiu et al. (2014) inverse the electrical resistivity profile structure in Changbai Mountains based on the South-north 103km-length MT profile. It is similar to Tang's result. But Qiu's result is deeper and longer, and it shows more electrical resistivity structure in details. The result shows that near the north entrance gate of protection zone, there are two obvious nearly vertical low resistivity zones existing in the depth of about 7-17km; north to the position of 20km south from Tianchi volcano, the low resistivity zone is in the depth of 13-30km. And they consider that the low resistivity zone should be active magma chambers.

The geophysical exploration results can only show the current structure of the volcano if we don't do 4D survey or monitor, different geophysical method can just present different physical parameter distribution. So we need multiple geophysical methods, or even other geoscience method to study the magma chambers of the volcano.

We conclude that the magma chamber of Changbai mountains exist both at crust and mantle. And there several magma Chambers under the volcano or a little more north direction from Tianchi. The evidence can be found from the other geoscience results such as geochemistry results, Liu et.al. (1998), study the geochemical data in Changbai

Mountains, and draw a conclusion that there are crustal and mantle magma chambers under Changbaishan Tianchi volcano based on the phenomenon of the co-eruption of the basaltic thick magma and basic lava flow.

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Advances and Petrogenesis of the Paleozoic and Mesozoic Volcanic Rocks in Northwest China

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The main achievements of the Paleozoic volcanic rocks in northwest China show in two aspects: one is the establishment and the research on the causes of the Late Paleozoic large igneous province of Xinjiang, and the other is that the new advance in petrogenesis of the late Paleozoic volcanic rocks from Tianshan.

Residual distribution area of Tarim large igneous province (TLIP) is greater than 250000km^2, whose maximum residual thickness is to 780m. Huge amounts of basalt erupt at the early stage (290 Ma), which belongs to the rapid eruption of LIP magmatic events. But the late stage (280 Ma) is the ultrabasic-basic and felsic rocks, dyke swarm and felsic volcano rocks. Trace element characteristics of the most developed basalt and diabase dyke is similar to that of oceanic island basalts (OIB), the major of which is highly titanium content. Isotopic characteristics can be obviously divided into two categories: one is the Keping basalt derived from enriched mantle with negative εNd value, and relatively higher heavy rare earth element (HREE); the other is north Tarim basalt and diabase derived from depleted mantle with positive εNd value and relatively low HREE value. However, another view is that the two significantly distinct mafic magmatism is result of that the difference of plume lateral flow cause the differences of spatial and temporal distribution and geochemistry characteristic of two group magma.

The Carboniferous volcano rocks in East Tianshan are calc-alkaline basalt-andesite-rhyolite construction. The basalt including N-MORB and IAT two types, which indicates the existence of a inter-arc basin in Carboniferous in East Tianshan. The Carboniferous volcanic rocks from north to south in East Tianshan has obvious ingredient zoning, which may be the result of that the Paleo-Asian Ocean oblique subducted to the southeast Junggar-Turpan-Hami terrane in the Carboniferous. It provides some information for exploring tectonic evolution between the Junggar and Tianshan.

The West Tianshan Mountains developed two sets of volcanic rocks in the early and late Carboniferous, the previous mainstream view is that is the product of the rift valley. In recent years, more and more researchers believe that the tectonic setting of West Tianshan was volcanic arc in Early Carboniferous, but converted to intra-continental rift setting in Late Carboniferous. Meanwhile, the Songhu, Beizhan, Dongde, Zhibo and other iron ores were found in the Early Carboniferous volcanic rocks in the Awulale area of the east part of West Tianshan, and all of them formed in volcanic arc tectonic setting.

In recent years, the adakites, Nb-rich basalts and sanukitoids related subduction were distinguished from late Paleozoic magmatic events in Tianshan, Junggar, Aletai and other place in northern Xinjiang, confirmed that Junggar ancient ocean basin was the arc tectonic setting from Devonian to Carboniferous, and enriched the genetic types of volcanic rocks in the northwest China. In addition, the new progress was made in reservoir lithology and lithofacies model in Carboniferous volcanic rocks from Junggar basin.

The volcanic rocks of Permian in north of Xinjiang have the bimodal characteristics, which is the important evidence of extensional tectonic system that the Junggar ancient ocean and Tianshan ocean has been completely closed.

It should be focus the middle and late Ordovician bimodal volcanic rocks which was found in Wushaoling area from north Qilian.

Compared with the Paleozoic, the Mesozoic volcanic rocks generally undeveloped in northwest China. The latest report is that the two periods volcanic rocks found in Western Qinling with the age of 245～234 Ma and 225～205 Ma, respectively. Moreover, the rock assemblages are mainly rhyolites with trachytes and dacites.

The Recent Progress of Volcano Monitoring in Changbaishan Mountain

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Changbaishan volcano observatory was set up in 1999. Over 14 years of continuous monitoring of volcanic seismicity, ground deformation and gas geochemistry, we find clear evidence that this volcano has experienced an magmatic unrest period between 2002 and 2005(Liu, 2011; Xu, 2012). In May 2010, the temperature of both of Julong hot spring increased 3℃ together. Meanwhile, the vertical displacement of the northern slope of this mountain changed its uplift status and declined up to 12.44 mm in 1 year. We speculate both of these 2 anomaly maybe related to the 2011 Tohoku Japan earthquake.

1, Seismic monitoring

We have 11 seismic stations in total (Fig. 1). 3 of them use short period seismometers and the other 8 use broadband seismometers. Using this seismic network, we record more than 3000 volcanic events from 1999 to 2014. The seismic activity during this time can be divided into 3 distinct periods: During the "inactive period" from July 1999 to June 2002 and from July 2005 till now, there were about 7 volcanic events per month, this can be considered as background seismicity rate. During the "active period" from July 2002 to June 2005, the number of volcanic events increased to 72 per month (Xu, 2012).

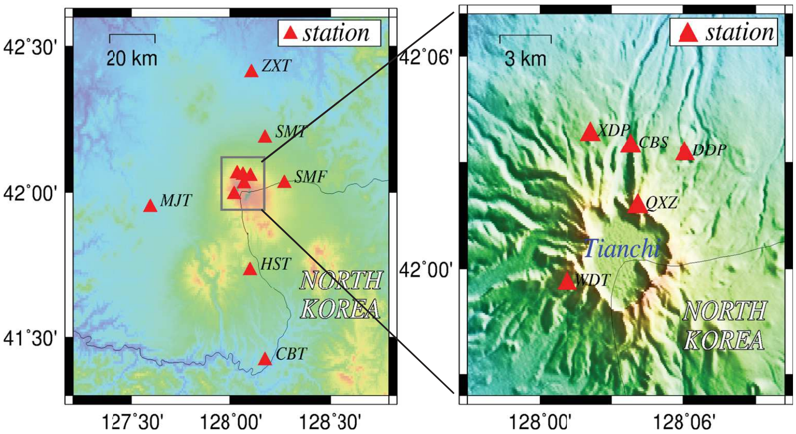

Figure 1. Seismic network in Changbaishan volcano

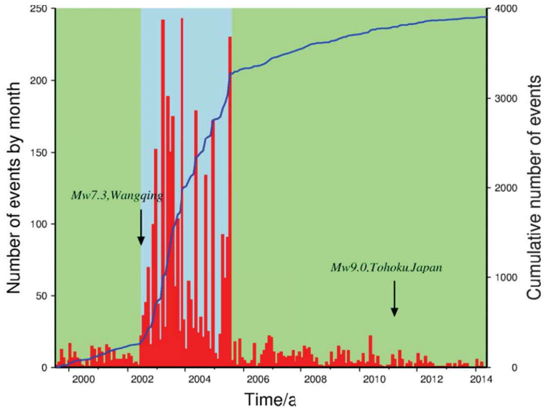

Figure 2. Seismic activity of Changbaishan volcano from 1999 to 2014

2, Ground deformation monitoring

The GPS network consists of 15 sites, 8 of them were set up in 1999 and started to work in 2000. The other 7 were set up in 2006 and started to work in 2007. The leveling survey has been conducted since 2000 with 2 routes, one is on the northern slope and the other is on the western slope. Fig. 3 shows the horizontal displacements observed by campaign GPS network from 2000 to 2014. In this figure, we can see that during the so-called "active period" during 2002-2005, the mountain shows clear inflation status, corresponding with the seismic activity in this area.

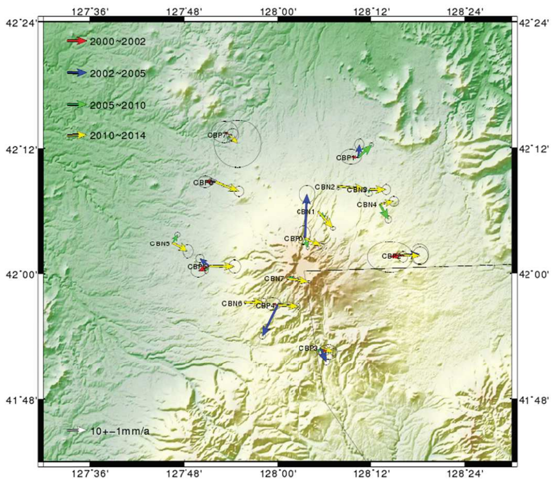

Figure 3. horizontal displacements observed by campaign GPS

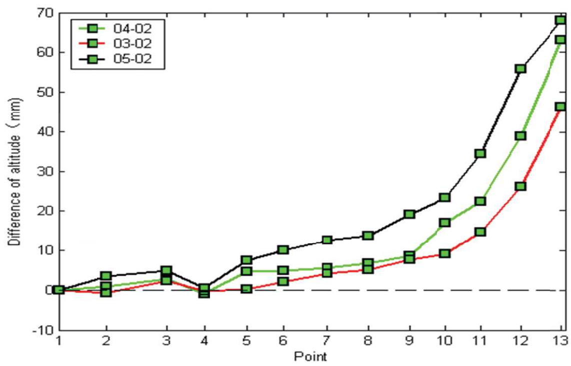

Figure 4. Vertical movements on the northern slope from 2002 to 2005

Fig. 4 shows the vertical movements observed by leveling survey on the northern slope from 2002 to 2005. The normal movements can be considered as 4 mm/a, so during the active period, a total of 68.12 mm of uplift was detected, about 3 times than the background level.

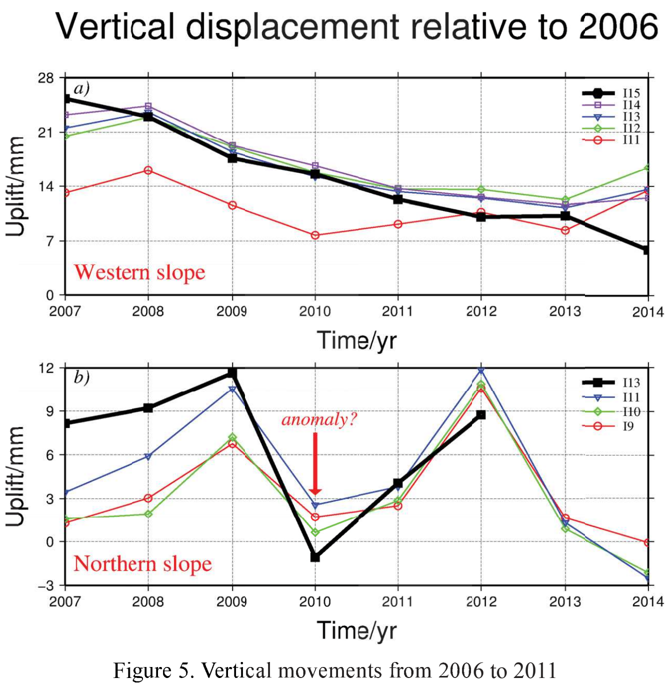

Figure 5. Vertical movements from 2006 to 2011

In 2006, we began to use an electronic leveling instrument to conduct the leveling survey, instead of the optical one and a new leveling route was established on the western slope. To avoid the systematic errors, we plot the leveling results separately (Fig. 5 and Fig. 5).

Vertical displacements on the northern slope gradually became slow and weak since 2006 (Fig. 5b). It is worth noting, a transition from uplift to subsidence was detected with vertical displacement of ~12.44 mm/a on the northern slope between 2009 and 2010 and then recovered to its normal uplift state and level. Perhaps this transition related to the 2011 Tohoku Japan earthquake.

The vertical displacements on the western slope show steadily subsidence state within the background level from 2006 to 2011 (Fig. 5a).

3, Gas geochemistry

Composition and temperature of gases from 3 hot springs have been measured since 1999. A high value anomaly of contents of He and H_2 was detected simultaneously in 3 hot springs, also corresponding with the seismic activity (Fig. 6). Besides, a small high value anomaly was detected in 2011, perhaps related to the 2011 Tohoku Japan earthquake.

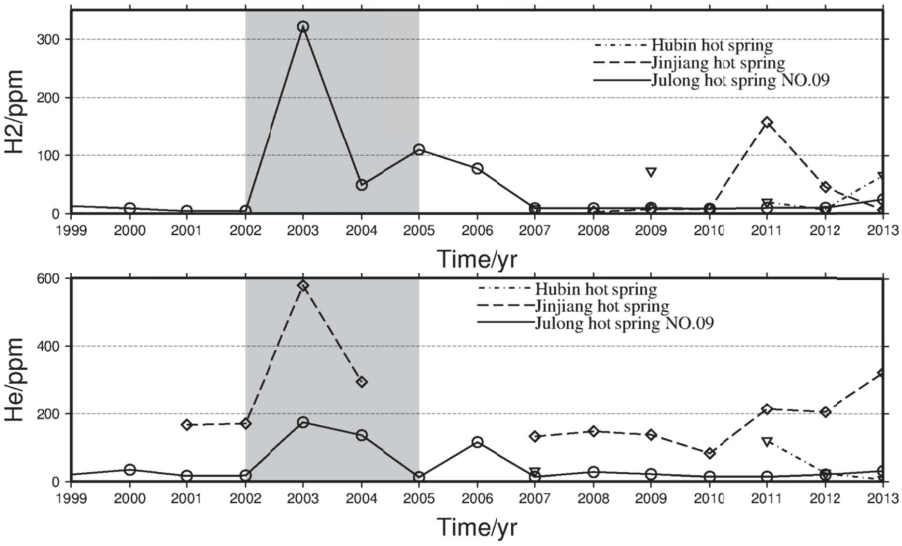

Figure 6. Contents of Helium and H_2 in 3 hot springs

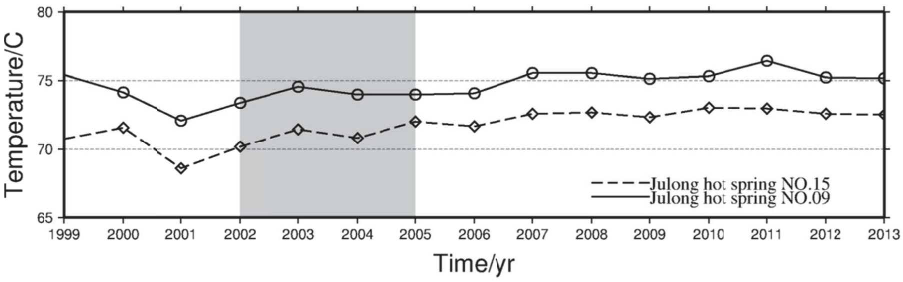

Figure 7. Temperature in 3 hot springs

In Julong hot spring area, we get samples from 2 hot springs, they are NO.09 and NO.15 respectively. During the active period from 2002 to 2005, the temperature in both hot springs rose about 2 ^{o}C. And in 2011, the temperature show high value again, about 3^{o}C higher than the background level (Fig. 7). We speculate that the anomaly of temperature detected in 2011 relate with the 2011 Tohoku Japan earthquake.

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Distribution and Characteristic of Active Volcano Research Progresses in China

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The distribution area of Cenozoic volcanics is about 186000 square kilometers in China. The volcanic geological survey of about 63000 square kilometers in eastern China and south-western China has been completed preliminary in last 20 years. Active volcanoes in western and eastern of Mongolia have been studied by volcanologist in last 4 years. Volcanic geological maps about some of the volcano groups in different size have been accomplished. Number, scale, eruption type and time-space distribution characteristics of Cenozoic active volcanoes have been further determined and improved. Active volcanoes mainly distribute around the Qinghai-Xizang Plateau and eastern China. The determined active volcanoes in China include Tianchi volcano area in Changbai mountain in Jilin province, Jinlongdingzi volcano of Longgang volcanic swarm, Jingpohu volcano in Heilongjiang province, Laohei volcano and Huoshao volcano in Wudalianchi area, Keluo-Erke volcano, Ma'an-Leihu volcano in northern Hainan, Weizhou island volcano, Tengchong volcano in Yunnan province, Tulufan volcano, western Tianshan volcano, and Hoh xil volcano. In the latest years, we have determined some volcanoes in Greater Hinggan mountains in eastern Mongolia, that include Ma'anshan, Dalaibinhutong, 371 and 358 highland volcanoes in valley around Erlunchunbila river, Yanshan, Gaoshan, Shihaogou basin, Xiaodonggou and Zigongshan volcano in Chaihe-Aershan volcano group, Gezishan volcano in Xilinhaote volcano group, Liandanlu volcao in Wulanhada volcano group. This discovery laid a solid foundation for the geological underlying database of active volcanoes in China. The eruption type , the tiny eruption sequence, volcanic lithofacies-phase sequence and facies model, volcanic chronology, high-resolution volcanic institutional framework, volcanic petrology and geochemistry, the source and evolution of volcano magma, volcanic eruption physical process, volcanism and neotectonics, volcanic eruption dynamic background, volcanic resources, volcanic disasters and some other aspects have great improvement. According to the high resolution volcanic structure map of Tianchi volcano area in Changbai mountain, Nuominhe-Maanshan, Chaihe-Aershan Yanshan, Xilinhaote Gezishan, Wulanhada

Liandanlu in eastern of Inner Mongolia, Tengchong Yunnan, Ashikule western Kunlun, we confirmed the genetic type and distribution range of the eruptive material, revealed the factors that limit the length different lava flow, built fine volcanic eruption sequence, acquired geometric parameter and forming process kinetic parameter of volcanic debris, offered necessary multidimensional volcanic edifice structure for volcanic disaster warning research.

The distribution of active volcanoes is the direct symbol of neotectonics. The NE Datong-Great Khingan Cenozoic volcanic active belt in eastern China has Holocene volcanic activities in different volcanic groups, and formed alkali basalt belt as long as more than 1000 kilometers. Active volcano and alkali basalt belt indicate this area is in early rift stage.

According to observing and researching of some active volcanoes, we extract deformation field in active volcano area technology and detect the mobility of volcanoes with InSAR. The main active risk level and mobility are carried on the preliminary classification research.

On-going Study of Greenhouse Gas Emission from Fault Zones in China

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Because of special tectonic surroundings, there are numerous active fault zones occurred throughout of China, which are closely related to local geological situations. For example, the major fault zones in eastern China are mainly extensional ones closely related to the westward subduction of the Pacific plate under the Eurasia plate whereas the thrust and transition fault zones are widely distributed in central and western China controlled by the uplift of Tibet plateau and the compression of India plate to Eurasia plate. Although great number of geochemical researches on geo-fluids from fault zones, there are recently only few publications available about greenhouse gas emission from fault zones in China, probably due to shortage of suitable measuring methods and knowledge about carbon circulation inside of the Earth. Along with the rise of interest in deep carbon observation, recently renewed focus on greenhouse gas emission from no-volcanic regions is attractive to many scientists including some Chinese geochemists. The on-going investigation and studies in China are mainly related to gas emission from some mud volcanoes in western China and fault zones in eastern China with several publications, mainly including the followings:

1, CO_2-rich bubbling gases discharging from cold springs in Wudalianchi intra-plate volcanic area, NE China.

Observed $^3He/^4He$ ratios (2 ~ 3 RA) and $\delta^{13}C$ values of CO_2 (-5 ~ -3 ‰) indicate the occurrence of a mantle component released and transferred to the surface by the Cenozoic extension-related magmatic activities. The $CO_2/^3He$ ratios are in a wide range of (0.4 ~ 97×10^9). Based on the apparent mixing trend in a $^3He/^4He$ and $\delta^{13}C$ of CO_2 diagram from all published data, the extracted magmatic end-member in the Wudalianchi volcano has $^3He/^4He$, $\delta^{13}C$ and $CO_2/^3He$ value of 3.2±0.1 RA, -4.6±0.8 ‰ and ~6×10^{10}, respectively. These values suggest that the volatiles originate from the sub-continental lithospheric mantle (SCLM) in NE China and represent ancient fluids captured by prior metasomatic events, as revealed by geothermal He and CO_2 from the adjacent Changbaishan volcanic area.

2, Natural gases near the NNE trending Tancheng-Lujiang Fault Zones (TLFZ) at Liaoning Province, NE China.

The gas samples are collected and measured for He-CO_2 systems including hydrocarbon-rich natural gases from Liaohe basin (121ºE-124ºE, 40.5ºN-42ºN) and nitrogen-rich geothermal gases from the eastern Liaoning Mountains. Observed $^3He/^4He$ ratios show two orders of magnitude variability from 0.04 RA to 3.5 RA where RA is atmospheric $^3He/^4He$ ratio 1.4×10^{-6}. The following geochemical observations are noted: (1) at Liaohe basin and the adjacent geothermal fields, $^3He/^4He$ ratios show positive correlations with Helium contents; (2) in Liaohe basin, the $^3He/^4He$ ratios are largely variable (0.04 ~ 3.5 RA), generally high in the eastern depress and low in the western depress; (3) in the eastern Liaoning mountains, geothermal $^3He/^4He$ ratios are generally low (0.2 ~ 0.7 RA) but have closed relationship with distribution of seismic activity and heat flow; and (4) overall there is a spatial distribution pattern that $^3He/^4He$ ratios gradually decrease from the TLFZ eastwards and westwards. Such a $^3He/^4He$ distribution feature shows strong evidence that the TLFZ played an important role on mantle-derived helium transformation from mantle upwards and groundwater circulation along the deep major faults.

3, N_2-He-rich bubbling gases discharging from hot springs in the Hainan Island, Southern China.

Observed $^3He/^4He$ ratios (0.1 ~ 1.3 RA) indicate the occurrence of a mantle component throughout the island which has been highly diluted by a crustal radiogenic ^4He component. The occurrence of mantle-derived helium is high in the northern island (12 ~ 16 % of total He) and gradually decreases towards southern coast (1 ~ 3 % of total He). Such a distribution pattern is most likely controlled by the Paleocene-Quaternary volcanic activities in the northern island and groundwater circulation along the deep major faults. The $^{40}Ar/^{36}Ar$ and N_2/Ar ratios suggest that N_2 and Ar of the hot spring gases are mostly meteoric. Although $\delta^{13}C$ values of CO_2 (-20 ~ -27 ‰) with low concentrations are consistent with the biogenic origin, the combination of $^3He/^4He$ and $\delta^{13}C_{CO2}$ suggests a two end-member mixing of mantle and crustal components with $CO_2/^3He$ ratios of 2×10^9 and 8×10^{11} respectively. However, the low $CO_2/^3He$ ratios (1 ~ 22×10^6) cannot be ascribed in terms of the simple mixing but has to be explained by the addition of radiogenic ^4He and loss of CO_2 by calcite precipitation in hydrothermal system, which is most likely controlled by the degree of gas-water-rock interaction.

4, Hydrocarbon-rich natural gases from the Tarim, Junggar, Turpan-Hami and Santanghu basins in Xinjiang, Northwest China.

The observed $^3He/^4He$ ratios from 0.01 Ra to 0.6 Ra (where Ra is atmospheric $^3He/^4He$ 1.4×10^{-6}) indicate 0 ~ 7 % 4He from mantle and 93 ~ 100 % from crust. The $^3He/^4He$ ratios are relatively high (>0.1 Ra) in foreland basins associated with Tianshan, Kunlun and Zhayier-Halalate orogenic mountains, but low towards the center of basins. Such a spatial distribution suggests that the mantle-derived helium originates from magmatic reservoirs, which are probably located in the mid-low crust or boundary layer between the mantle and crust, and becomes focused into the root zones of the faults, which subsequently traverses the crust via permeable fault zones. When transported upwards to the near surface, the mantle-derived helium has been significantly diluted by radiogenic helium produced in the crust. Despite the lack of Cenozoic magmatic activities and extension tectonics, this pattern shows strong evidence that the major faults played an important role on mantle-derived components degassing from the mantle to the surface.

5, Gas emission from mud volcanoes in Xinjiang, NW China

There are many mud volcanoes occurred in the southern Junggar Basin, Northwest China, of which the Dushanzi area is one of the most typical and active one, emitting large amount of greenhouse gases. The emitted gas is dominated by methane with an average content of 90.1% and other gases including ethane (4.95 ~ 5.46%), propane (0.06 ~ 0.90%), CO_2 (0.70 ~ 1.5%) and N_2 (2.8 ~ 3.3%). Carbon and hydrogen isotopic ratios of methane are in the $\delta^{13}C_1$ and δD ranges of -40.6‰ to -43.2‰ and -221‰ to -249‰, respectively, whereas carbon isotope ratios of ethane ($\delta^{13}C_2$) are -25.2‰ to -27.6‰. Based on $C_1/(C_2+C_3)$ and $\delta^{13}C$ values, the released gas is characterized as a thermogenic coal-type and possibly originated from the middle-low Jurassic coal-bearing layers according to the gas-source correlation tracing. Helium isotopes showed a crust source. Methane flux of Dushanzi mud volcanoes from both craters/vents (macro-seepage) and invisible exhalation from the soil (micro-seepage) was ranged within the orders of magnitude of 78.2 ~ 378 g d^{-1} in macro-seeps, and the average value of 4.0 ~ 10.8 g m^{-2} d^{-1} from micro-seepage in a measured area. Positive CH_4 fluxes from dry soil land were widespread throughout the investigated areas (about 9400 m^2). Total CH_4 emission from Dushanzi mud volcanoes was estimated to be at least 16.6 ton a^{-1}, of which more than 99% was from invisible seepage surrounding the mud volcano vents.

6, Gas Emission from the Qingzhu River after the 2008 Wenchuan Earthquake, Southwest China

Four gas and six water samples were collected from the Qingzhu River in Qingchuan County, one of the regions affected by the 2008 *Ms*8.0 giant Wenchuan Earthquake. Gases were discharged soon after the earthquake, but such emissions ceased in October 2008. The predominant gases are CH_4, CO_2, N_2 and O_2. The N_2, O_2 and noble gases are of atmospheric origin. In contrast, the CH_4 and CO_2 have typical biogenic signatures, with high $C_1/(C_2+C_3)$, $\delta^{13}C_{CH4}$ (-56.1 to -56.6‰); δD_{CH4} (-328 to -345‰); and $\delta^{13}C_{CO2}$ (-6.7 to -4.9‰). These measurements indicate that the gases are discharged from a shallow reservoir through faults or fractures caused by the earthquake. The discharging gases are significantly distinct from the natural gas fields nearby, suggesting that there are no direct pathways, such as faults or fractures, between the surface and the natural gas reservoir.

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Cenozoic Volcanism and Geothermal Resource

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One of the recent developments in Chinese volcanology study over the past years is associated with the growing interest in geothermal energy.

The rapid economic growth of Chinese economy over the last three decades casted a deep footprint in the nation's carbon emission. The country is anxious for low-carbon energy to help sustain economic development and social stability. Geothermal energy is now on the table as a means to mitigate global warming and air pollution.

The Earth encompasses an enormous amount of thermal energy generated from the original formation of the planet, and from the decay of radioactive elements such as U, Th, and K. This internal energy is transferred outward slowly through heat conduction of crustal rocks，and dramatically through magma ascending from mantle and lower crust. As a direct consequence of the steady thermal energy flux from greater depths, on global average ground temperature increases around 3°C with every 100 m increase in depth. Whereas in young volcanic areas, the gradient could be several folds higher than the average, making geothermal energy exploitation much more economically attractive (Huang and Liu, 2010). Worldwide, therefore, most geothermal energy projects are located in volcanic zones.

However, this has not been the case in China. So far, the great geothermal potential of Chinese Cenozoic volcanoes remains largely untapped (Huang, 2012). This has been recognized as part of the reason China being behind most geothermal countries in geothermal power development (Huang, 2014). Efforts are making to change the status quo. Figure 1 shows several volcanic areas currently under investigation for geothermal energy.

1, Tengchong volcano-geothermal tectonic zone in Yunnan Province in SW China:

A geochemical thermometry study (Zhao, 2011) inferred three magma chambers at shallower depths. Sponsored by the national crustal exploration program SinoProbe, a scientific drilling project was conducted to drill a hole of 1,222 m with a core sampling rate of 89% in this area (Liu and Qi, 2014). The borehole drilled through thick volcanic and sedimentary strata and penetrated 300 m into the granite basement, reaching a temperature of 74 ^{o}C at the bottom.

2, Leizhou - Hainan volcanic cluster across the provincial boundary of Guangdong and Hainan Provinces in south China:

The cluster includes more than 40 Quaternary volcano calderas. Sinopec Star Company, the largest geothermal company in China, is developing a hot dry rock project in this area. It is estimated that temperature could be around 150 ^{o}C at a depth of 4 km in this area (Liao et al., 2015).

3, Longhai volcanic area in Zhangpu and Longhai Counties of Zhangzhou Municipality of Fujian Province in SE China:

Temperature of 128 ^{o}C within a borehole of less than 100 m was reported and a high heat flow up to 368.72 mW/m^2 has been estimated for this area (Zeng et al., 2012). China Geological Survey, in conjunction of the local government, is currently exploring the area for an enhanced geothermal system (EGS) demonstration project.

4, Changbaishan-Longgang volcanic zone in Jilin Province, NE China:

This is probably the most active volcanic area in China that is of a high possibility of eruption in near future. Earlier studies (Fan et al., 2007) show that magma chambers exist at several depths and a recent MT survey (Qiu et al., 2014) indicates a magma channel lying right beneath the Tianchi caldera. A research proposal is currently under review to address the volcanism and thermo-tectonic evolution of this region from a geothermal perspective.

5, Wudalianchi volcanic field in Heilongjiang Province, NE China:

This volcanic field is named after five interconnected caldera lakes formed after the eruption in 1720-21. Despite of the absence of significant hydrothermal features, geological evidences (Gao et al., 2013; Xu et al., 2013) suggest that the recent volcanism is well connected with deep heat source. The area has become another candidate for China Geological Survey's EGS demonstration project.

6, Abaga basaltic volcanic zone in the Xilinhot of the Inner Mongolia in northern China:

Cenozoic volcanism resulted in the formation of three major basalt fields and about 300 volcanic cones in this area. A project sponsored by the China Natural Science Foundation is evaluating the geothermal resource potential and its causal relationship with the Cenozoic volcanism in this region (Peng et al., 2014).

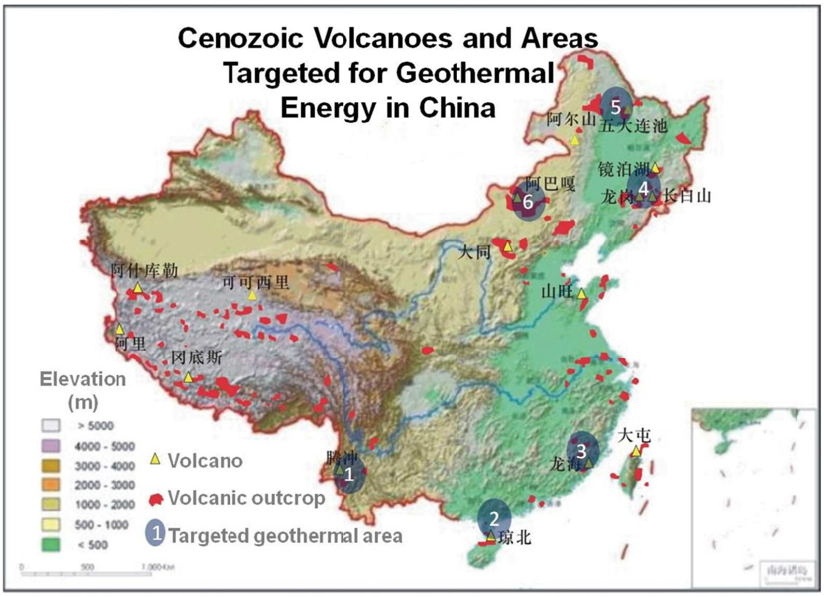

Figure 1 Cenozoic volcanoes and areas selected for volcano-geothermal study. See the main text for the marked areas.

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Tephrochronological Studies in China

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Volcanic ash (tephra), produced by explosive eruptions, is deposited rapidly; hence, it can serve as a distinctive and widespread synchronous marker horizon, correlating terrestrial, marine and ice core records (Lowe 2011). Therefore, tephra layers can be used to correlate geological events among such sedimentary archives and the ages of such events can also be constrained once the age of tephra layers were determined. Tephra and cryptotephra studies have advanced the developments of high-resolution time scales for the Quaternary science and volcanology. China is near to the active volcanic regions, such as, far east of Russia, Japan, Philippine and Indonesia and there are also numerous volcanic fields in China, for examples, Wudalianchi, Changbaishan, Tengchong, Hainan, Datong and Taiwan Datun. Additionally, there are lots of sedimentary contexts close to such volcanoes in China, such as, maar lakes in Longgang volcanic field, loess deposits, maar lakes in south China, and widely marine environments. A lot of projects related to tephrochronology have been carried out in Europe and other regions (Lowe, 2008; Davies et al. 2012), while the tephrochronological studies in China are relative deficient not only proximal but also distal tephra records.

Tephra layers visible to eyes are more easier to be obtained, for examples, tephra layers sourced from the three basaltic explosive eruptions in the Longgang volcanic field were identified in lake sediments from maar lakes while no corresponding proximal tephra layers were compared except the most recent eruption 1600 a BP (Liu et al. 2009; Zhao and Hall 2015). Loess and lacustrine sediments from Shanxi province also record some tephra layers from Datong volcanic field (Wu et al. 2013). Tephra layers sourced from Toba volcano in Indonesia have been found in the sediments from South China Sea (Bühring et al 2000; Song et al. 2000; Liang et al. 2001; Lee et al. 2004; Liu et al. 2006), while the age uncertainties and the similar glass geochemistry between YYT, MTT and OTT (only limited MTT can be distinguised) have made many troubles to precisely trace each layer and correlate climatic events (Pearce et al. 2014; Shane et al. 2004; Smith et al. 2011; Wetgate et al. 2014). Other tephra layers from surrounding volcanoes also can be detected in the sediments from South China Sea (e.g. Wiesner et al. 2004; Chen et al. 2005; Yan et al. 2007; Ku et al. 2008, 2009).

Cryptotephra can be transported to far more regions than the tephra visible to eyes and can be applied to a wide range of Late Quaternary deposits (Hall et al. 2005; Lowe 2011), while such studies in China are more inadequate. Cryptotephra identifications and correlations have been performed on the lacustrine sediments from Sihailongwan maar lake and peat bogs from Longgang volcanic field, and some glass shards from Changbaishan volcano have been detected (Guo et al. 2005; Zhao and Liu 2012; Sun et al. 2015; Zhao and Hall 2015). The cryptotephra layers from YYT also can be traced to Huguangyan maar lake (Guo et al. 2002). In addition, cryptotephra layers can be recorded in the loess and archeological sediments, for example, loess sediments from Shandong and Jiangsu province, and archeological sites from Jiangsu province record some of these glass shards, but, corresponding source volcanoes are not very clear (Eden et al. 1996; Zhou et al. 2000; Zheng et al. 2003; Fang et al. 2010). Chinese scholars also carried out some works on the archives (i.e. ice cores) from polar regions. For example, the marker role will be achieved through correlation between distal tephra in ice cores and proximal tephra, and then applications to glacial activities, volcanic sequence, constrain precise age of volcanic eruptions, evaluate climatic impacts of eruptions can be achieved (Qin et al. 1994; Zhang et al. 1996, 1997; Sun et al. 2014).

Progresses of Volcanoes Buried Underneath the Cretaceous Basin of NE China

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Paleo-volcano research concerns mainly of the volcanic petroleum reservoir, volcanostratigraphy and seismic volcanostratigraphy in Songliao Basin (SB).

1, Volcanic petroleum reservoir in Songliao Basin

Major reservoirs in the Songliao Basin are composed of volcanic rocks below 3,000 meters of buried depth. Gas accumulations are mostly found in the buried volcanic highs, which in general correspond to paleo-volcanic centers. Porosity in the volcanic rocks depends on both primary and secondary processes. The best porosity is preferentially developed in a proximal facies near the central part of each volcanic edifice. Lava and welded ignimbrite slowly lose porosity with burial depth. Porosity and permeability decrease with depth of burial for both volcanic and nonvolcanic sections, but their porosity-depth trends differ. Lava and welded ignimbrite slowly lose porosity with burial depth. Porosity and permeability of lava and ignimbrite exceed that of the other rocks, and thus they are the best reservoir rocks below burial depths of ca. 3,000 m in the SB. The paleo-volcanic domes are rich in both lava rocks and fractures of diverse origin and the topographic highs provide favorable locations for gas migration and accumulation.

2, Volcanostratigraphy and Seismic volcanostratigraphy in Songliao Basin

Volcanostratigraphy and Seismic volcanostratigraphy focus on the filling patterns including volcanic units and their stacking patterns confined by volcanostratigraphic boundaries, depict geological features and correlation of the successions, geologic history and their emplacement environment in SB. The volcanostratigraphic boundaries have been divided into 4 types according to the contact relation in SB. The primary and secondary pores are both distributed along the volcanic boundaries. The volcanic units are the relatively independent essential units of volcanic sequence. The volcanostratigraphy is built by the stacking of volcanic units, and the spatial and temporal distribution of the lithology, facies and reservoir is directly controlled by the shapes and stacking patterns of lava flow units. Different types of volcanic units are stacked, and constitute five filled patterns of basin for the (Seismic facies): aggradation, progradation, draping, mounding and cutting.