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Geochemistry of Cenozoic Basaltic Rocks around Liuhe National Geopark, Jiangsu Province, Eastern China: Petrogenesis and Mantle Source

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Yen-Tsui Hu and Chih-Cheng Chen

Abstract**—**Cenozoic basalts found in Jiangsu province of eastern China include tholeiites and alkali basalts. The present paper analyzed the major, trace elements, rare earth elements of these Cenozoic basalts and combined with Sr-Nd isotopic compositions proposed by Chen et al. (1990)[1] in the literatures to discuss the petrogenesis of these basalts and the geochemical characteristics of the source mantle. Based on major, trace elements and fractional crystallization model established by Brooks and Nielsen (1982)[2] we suggest that the basaltic magma has experienced olivine + clinopyroxene fractionation during its evolution. The chemical compositions of basaltic rocks from Jiangsu province indicate that these basalts may belong to the same magmatic system. Spidergrams reveal that Cenozoic basalts from Jiangsu province have geochemical characteristics similar to those of ocean island basalts(OIB). The slight positive Nb and Ti anomalies found in basaltic rocks of this study suggest the presence of Ti-bearing minerals in the mantle source and these Ti-bearing minerals had contributed to basaltic magma during partial melting, indicating a metasomatic event might have occurred before the partial melting. Based on the Sr vs. Nd isotopic ratio plots, we suggest that Jiangsu basalts may be derived from partial melting of mantle source which may represent two-end members mixing of DMM and EM-I. Some Jiangsu basaltic magma may be derived from partial melting of EM-I heated by the upwelling asthenospheric mantle or asthenospheric diapirism.

Keywords**—**Geochemistry, Jiangsu Province, Cenozoic basalts, Fractional crystallization.

I. INTRODUCTION

THE basalts of Jiangsu province are situated in the boundary of Yangtze Craton and southeastern edge of Sino-Korean Craton, one of the oldest Archean continental nuclei in the world [3]-[6]. The Sino-Korean Craton represents preserved crustal remnants as old as 3800 Ma [6], and the largest cratonic block in China, covering an area of more than 1500000 Km^2. The Sulu ultrahigh pressure metamorphic belt formed by the collision between the Sino-Korean Craton and the Yangtze Craton in Triassic time was extrapolated as the suture of the Sino-Korean Craton and the Yangtze Craton to the east of Tanlu fault zone [7]-[8]. Previous studies [3][9]-[10] suggested a crustal-detachment model for the suturing of the Sino-Korean Craton (SKC) and the Yangtze Craton.

Along the eastern Asian continental margin, Cenozoic extensional basins and associated volcanic eruptions are developed, extending over 4000 km from Siberia to east China. Cenozoic basalts are widely distributed along the eastern China from north of Heilongjiang province to south of Hainan island, and South China Sea [12]. The Cenozoic volcanic rocks from Anhui-Jiangsu provinces are spread over an area of more than 2,000 km^2 in eastern Anhui and western Jiangsu. The spatial distribution of volcanic rocks in this region is controlled by the NNE-trending Tan-Lu fault and its adjacent NW-trending basins and faults which can be divided into three periods [13]-[14]: (A) volcanic rocks of 1st period- non-marine fissure eruption of Paleogene located in the central and eastern parts of the Subei basin are mainly tholeiites, olivine tholeiites and alkali basalts [15] intercalated with Paleocene, Eocene and Oligocene sedimentary sequences. (B)volcanic rocks of 2nd period- mainly lava flows and pyroclastic rocks of Pliocene lie on the top of fossiliferous sediments of Miocene and early Pliocene age. The Pliocene volcanic rocks located in the southwestern part of the Subei basin include alkali olivine basalts and related rocks, covering an area of about 1500km^2. (C) volcanic rocks of 3rd period- the eruption process of this period occurred in Pleistocene and produced basanites and olivine nephelinites with abundant peridotite xenoliths and megacrysts.

The purpose of this paper is to analyze the major and trace elements (including rare-earth elements) of these basalts combined with Sr and Nd isotopic ratios proposed by Chen et al. (1990)[1] in order to deduce the petrogenesis and magmatic evolution of these rocks and confer the process of differentiation controlled the variation of chemistry of these basaltic rocks as well as to identify the geochemical characteristics of the upper mantle beneath Jiangsu province.

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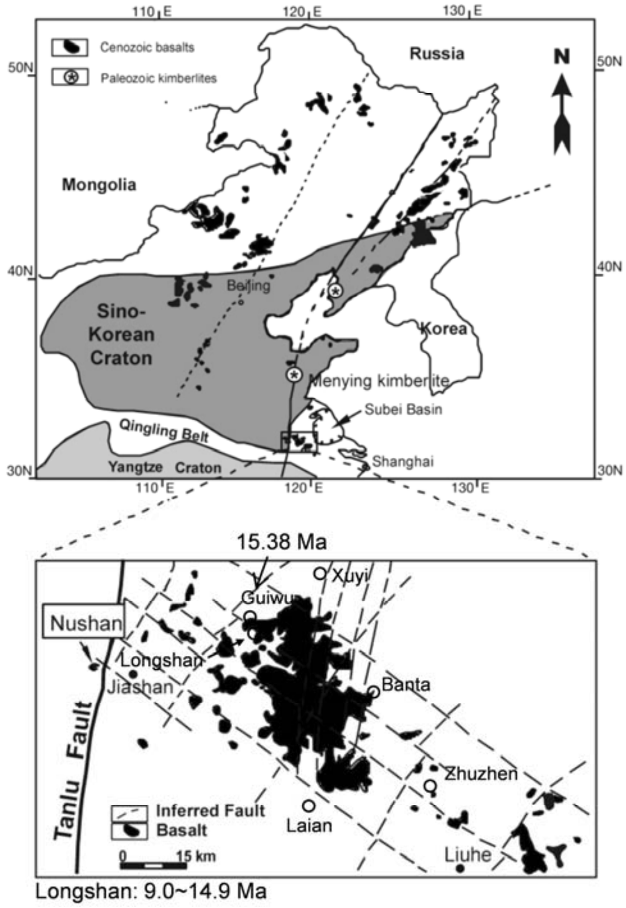

Fig.1 A sketch map showing the simplified tectonic framework of eastern China and the location of the studied area (modified after Xu and Bodinier, 2004).[16]

II. ANALYTICAL METHODS

Twenty Cenozoic basalts sampled from Jiangsu province (Fig. 1) were selected for bulk chemical analyses. The chemical analyses of the basalts in the present study have been carried out by colorimetry (Si, Al, Ti, P), atomic absorption (Fe, Mg, Ca, Na, K, Mn), inductively coupled plasma mass spectrometry (Ba, Co, Cr, Cs, Cu, Ga, Hf, Li, Nb, Ni, Pb, Rb, Sc, Sr, Ta, Th, U, V, Y, Zn, Zr and REEs) at the National Taiwan and Tsing-Hua Universities.

The calibration curves were constructed using USGS standard rocks BHVO-1, AGV-1, BCR-1, W-2, G2 and NBS standard rock basalt. The precision of the analyses in the present study is estimated to be around ±2% for colorimetric and atomic absorption methods and better than ±5% for all ICP-MS analyses.

III. RESULTS AND DISCUSSIONS

Based on plots of SiO_2 vs. Na_2O+K_2O proposed by Irvine and Baragar (1971)[17], the basaltic rocks in the present study can be divided into two types: (A)alkali basalt; (B)tholeiite. CIPW normative data suggest that alkali basalt is the major rock type in Jiangsu province.

The average chemical compositions of the alkali basalts and tholeiite from Jiangsu province are listed in Table 1. The SiO_2 contents of the alkali basalts are lower than those of tholeiite, rangeing from 44.87% to 52.90% ,and from 51.61% to 52.60% , respectively. The SiO_2 contents show negative correlation with MgO, ΣFeO, CaO, MnO which indicate the possibility of fractional crystallization of ferromagnesian minerals such as olivine and clinopyroxene in magmatac evolution. The Sr contents are positively correlated with SiO_2 contents and the fractional crystallization model proposed by Brooks and Nielsen (1982)[2](Fig.2), suggesting fractional crystallization of olivine and clinopyroxene may have occurred during magmatac evolution. The variations of Ni in the basaltic rocks of this study is 84~361 ppm. In some alkali basalts of this study the Ni and Cr contents are close to the primitive basalts suggested by Frey and Prinz (1978)[18] and Wilkinson and LeMaitre (1987)[19].

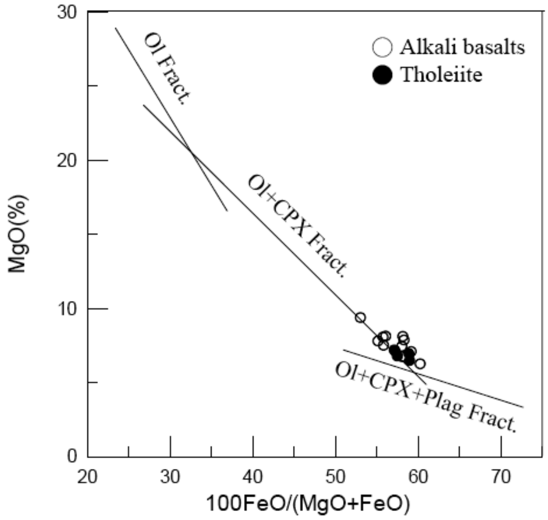

Fig. 2 The MgO vs. 100FeO/(MgO+FeO) plots for basaltic rocks from Jiangsu province. Fractionation model modified from Brooks and Nielsen(1982)[2].

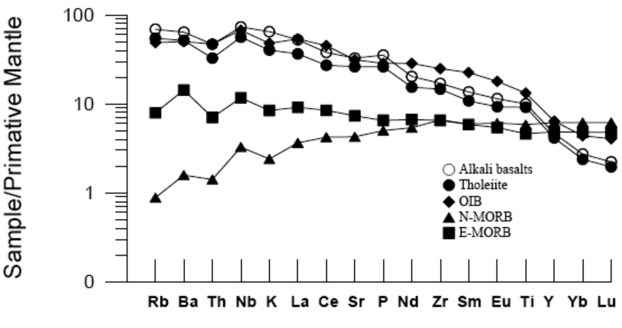

Fig. 3 Primitive mantle normalized incompatible element patterns for average basaltic rocks from Jiangsu province. OIB,N-MORB, E-MORB and primitive mantle data are from Sun and McDonough (1989)[20].

The Primitive mantle-normalized incomepatible element diagrams of basalts from Jiangsu province and OIB, E-MORB as well as N-MORB are shown in Fig.3. The spidergrams of Jiangsu basalts are similar to that of OIB (oceanic island basalt; [20]), indicating an enriched mantle source beneath the study area. The spidergrams do not have obvious depletions in Nb, indicating crustal contamination can be excluded during magma generation [9][21]-[25]. The patterns generally dip from left to right with decreasing element incompatibility except for Rb. The slight negative Rb anomaly may be due to the occurrence of residual Rb-bearing minerals or lower contents of K-bearing minerals in the mantle source. The slight Nb and Ti positive anomaly observed in the basalts support the suggestion that the basaltic magma may have derived from a rutile-bearing mantle source and rutile has involved in the partial melting process [26]-[28].

On the Ce contents vs. Ce/Nb ratio plots (Fig.4), the basaltic rocks found in Jiangsu province fall in OIB field defined by Hofmann et al. (1986)[29], indicating a OIB-like mantle source.

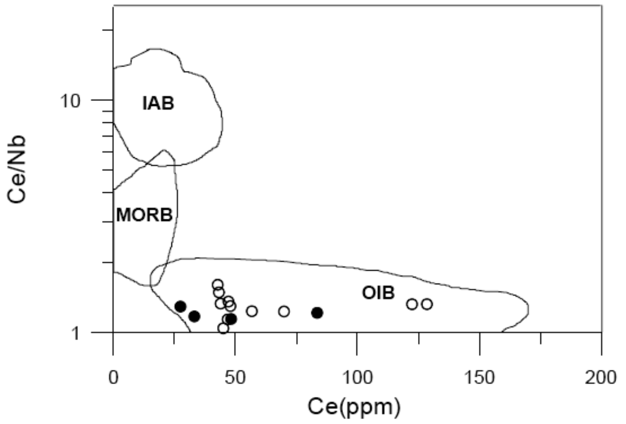

Fig. 4 The Ce contents vs. Ce/Nb ratio plots for basaltic rocks from Jiangsu province. Variation fields after Hofmann et al. (1986)[29]. Symbols same as Fig. 2.

Fig. 5 shows the chondrite-normalized REE patterns of basaltic rocks in the present study as compared with the patterns of the OIB, E-MORB and N-MORB. The basaltic rocks of this study show distinct features as follows: (A) the patterns generally dip from left to right; (B) the contents of REE in alkali basalts are higher than those in tholeiite; (C) with negative heavy REE (Yb and Lu) anomalies; (D) the patterns are similar to those of OIB. The negative heavy REE (Yb and Lu) anomalies in the basaltic rocks studied may be attributed to the presence of garnet peridotite in the upper mantle which can hold back HREE (Yb and Lu). The patterns are steeply sloping from La to Lu with the $(La/Yb)_N$ ratios ratios varying from 8.00 to 51.17 and similar to those of OIB , suggesting the enrichment of LREE and a OIB-like mantle source beneath the study area.

Cenozoic basalts from North China (Sino-Korean Craton) reflect mixing between an asthenospheric mantle and EM-I, and South China (Yangtze Craton and Cathysia block) basalts were produced by mixing between an asthenospheric mantle and EM-II. It should be noted that Chen et al. (2007)[30] suggested that the petrogenesis of basaltic rocks from northeast China can not be fully explained by a mixing of depleted mantle with EM1 component. Sr-Nd-Pb isotopic data of potassic basalts from NE China were interpreted to result from mixing between a FOZO end-member and a LoMμ end-member.

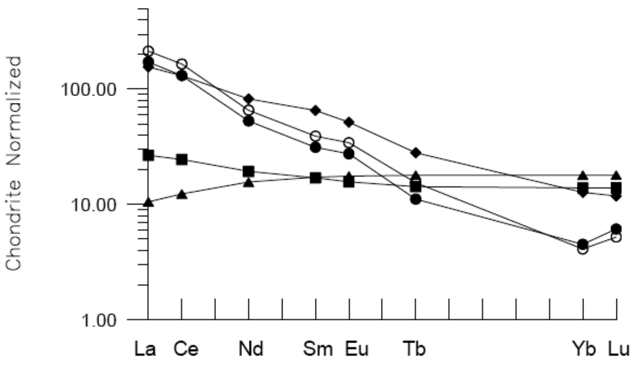

Fig. 5 Average REE composition of basaltic rocks from Jiangsu province as compared with OIB, N-MORB and E-MORB (Sun and McDonough,1989).[20] Symbols same as Fig. 3.

On the $^{143}Nd/^{144}Nd$ vs. $^{87}Sr/^{86}Sr$ diagram (Fig. 6), all basaltic rocks fall between MORB and EM-I defined by Zindler and Hart (1986)[31], and most of samples are closely related to the mantle array, indicating a mixed mantle source before partial melting. On the Th contents vs. incompatible element ratios (Ba/Nb, Ba/Th, Th/Nb) plots for basaltic rocks of this study (Fig. 7), most of the basaltic rocks approach to EM-I component which indicates that basalts of this study can be porduced by MORB and EM-I [31] components mixing and small degree of partial melting may be the major controlling factor during generation of basaltic magma. The volcanic activities in this region may be closely related to deep continental rifting process[32]. The basalts fall within the WPB field in the discriminant plot of 2Nb-Zr/4-Y (Fig. 8).

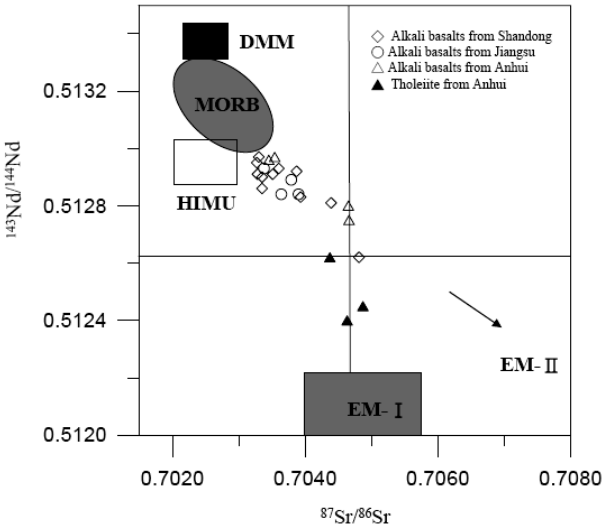

Fig. 6 $^{87}Sr/^{86}Sr$ vs. $^{143}Nd/^{144}Nd$ plots for basaltic rocks from Shandong, Anhui and Jiangsu provinces. Data from Chen et al.(1990)[1]. DMM, HIMU, EM-I, EM-II and MORB are from Hart (1988)[33].

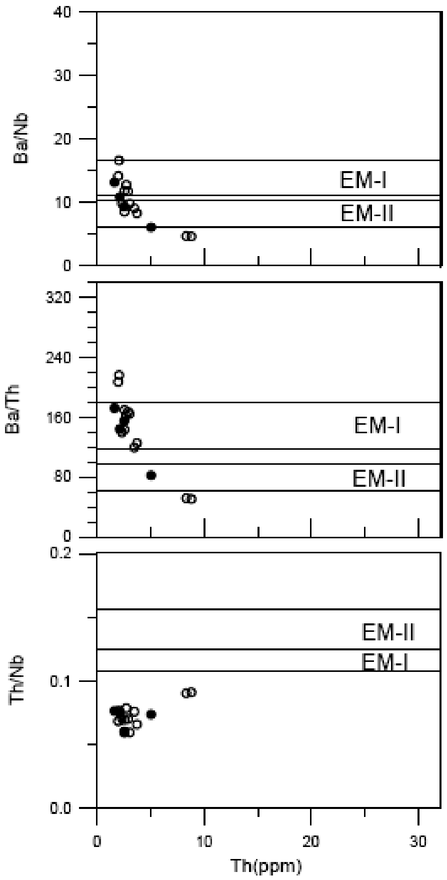

Fig. 7 Incompatible element ratios vs. Th plots for basaltic rocks from Jiangsu province. EM-I and EM-II fields are after Weaver (1991)[34]. Symbols same as Fig. 2.

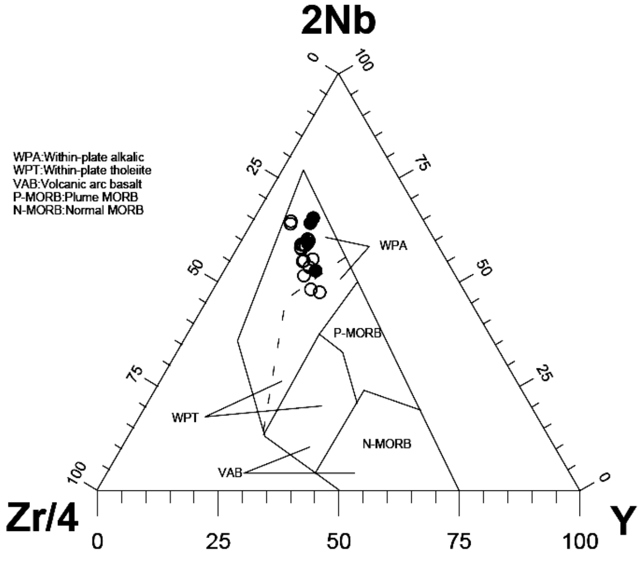

Fig. 8 2Nb-Zr/4-Y tectonomagmatic discrimination diagram for basaltic rocks from Jiangsu province. Variation field after Meschede(1986)[35]. Symbols same as Fig. 2.

IV. CONCLUSIONS

The basaltic rocks in the present study can be divided into alkali basalt; and tholeiite. CIPW normative data suggest that alkali basalt is the major rock type in Jiangsu province. Based on major, trace elements and fractional crystallization model established by Brooks and Nielsen (1982) we suggest that the basaltic magma has experienced olivine + clinopyroxene fractionation during its evolution. Spidergrams, REE patterns and the Ce contents vs. Ce/Nb ratio plots reveal that Cenozoic basalts from Jiangsu province have geochemical characteristics similar to those of ocean island basalts(OIB) suggesting a derivation related to OIB-like mantle source. The ^{143}Nd/^{144}Nd vs. ^{87}Sr/^{86}Sr diagram and the Th contents vs. incompatible element ratios (Ba/Nb, Ba/Th, Th/Nb) plots for basaltic rocks of this study indicate that basaltic rocks from Jiangsu province can be produced by an depleted asthenospheric mantle source (MORB) and an EM-I components mixing. We suggest that the enrichment of the lithospheric mantle beneath the study area may be related to ancient subduction processes. Some Jiangsu basaltic magma may be derived from partial melting of EM-heated by the upwelling asthenospheric mantle or asthenospheric diapirism.

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