The Background of Regional Lead Isotopic Compositions and Its Application in the Lower and Middle Reaches of the Yangtze River and Neighbouring Areas

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Abstract The paper systematically deals with the background of regional isotopic compositions in the lower and middle reaches of the Yangtze River and neighbouring areas. It is shown that the lead isotopic compositions of different geological formations and units are controlled by the primary mantle heterogeneity, dynamic process of crust–mantle interchange, abundances of uranium, thorium and lead of various layers of the earth and timing. Studies on the background of regional isotopic compositions may offer significant information for geochemical regionalization, tracing of sources of ore–forming materials, and regional prognosis of ore deposits.

Key words: background of regional lead isotopic compositions, tracing action, lower and middle reaches of the Yangtze River and neighbouring areas

1 Introduction

In recent years there is a growing interest in lead isotope geochemistry all over the world. Studies show that the characteristics and evolution of lead isotopic composition in the earth or regional lithosphere are controlled by the primary mantle heterogeneity, dynamic process of crust–mantle interchange, abundances of uranium, thorium and lead of various layers of the earth, and timing. Studies on the characteristics of lead isotopic compositions of different geological bodies and stratigraphic units on a regional scale may offer significant information for geochemical regionalization (lead isotopic mapping), tracing of sources of ore–forming materials and geochemical prognosis of ore deposits. Systematic studies have been carried out in the lower and middle reaches of the Yangtze River and neighbouring areas in accordance with most advanced thoughts and methods, in an attempt to discuss lead isotopic tracing either in the macro–field or in the micro–field. The feldspar lead and ore lead isotopic data of the great majority of magmatic rocks (139 lead isotopic data of feldspars and whole rocks and 104 ore lead isotopic data) used in the paper were published

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Table 1 Lead isotope ratios of pyrites (whole rocks) from different strata

Tectonic layer	Strata	Sampling location	Rock	Sample	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Second tectonic layer	Permian	Northern Jiangxi	Carbonaceous shale	Pyrite (1)	18.430 (0.18)	15.748 (0.16)	38.697 (0.38)
	Carboni–ferous	Tongling	Limestone, dolomite[1)]	Whole rock (5)	18.533	15.698	38.638
	Devonian	Northern Jiangxi	Sandstone[2)]	Pyrite (1)	18.625	15.695	38.590
		Tongling	Mudstone	Pyrite (1)	18.077 (0.10)	15.637 (0.08)	38.480 (0.21)
	Ordovician	Southern Hubei	Kontty limestone	Pyrite (1)	18.222 (0.06)	15.662 (0.05)	38.333 (0.12)
	Cambrian	Chuxian	Mud–banded dolomitic limestone	Pyrite (1)	21.584 (0.15)	16.045 (0.11)	38.720 (0.27)
		Northern Jiangxi	Limestone	Pyrite (1)	19.238 (0.16)	15.769 (0.13)	38.660 (0.315)
		Southern Anhui	Calcareous shale	Pyrite (1)	18.822 (0.05)	15.765 (0.05)	39.130 (0.11)
		Northern Jiangxi	Limestone	Pyrite (1)	18.556 (0.23)	15.815 (0.19)	38.754 (0.48)
		Southern Anhui	Marl	Pyrite (1)	18.481 (0.19)	15.957 (0.17)	38.944 (0.41)
		Southern Anhui	Mud–banded limestone	Pyrite (1)	18.396 (0.08)	15.760 (0.08)	38.680 (0.19)
		Northern Jiangxi	Siliceous shale	Pyrite (1)	31.270 (0.15)	15.527 (0.08)	38.180 (0.19)
		Southern Anhui	Carbonaceous shale	Pyrite (1)	19.091 (0.04)	15.708 (0.03)	38.560 (0.08)
	Sinian	Northern Jiangxi	Quartzose sandstone	Pyrite (1)	17.849 (0.14)	15.574 (0.13)	37.742 (0.31)
			Moraine breccia	Pyrite (1)	17.992 (0.12)	15.491 (0.11)	37.824 (0.26)
			Lenticular limestone	Pyrite (1)	17.976 (0.15)	15.598 (0.13)	38.059 (0.32)
			Carbonaceous–siliceous shale	Pyrite (1)	37.816 (0.07)	15.596 (0.06)	37.606 (0.14)
		Southern Jiangxi	Sandstone	Pyrite (1)	17.665 (0.09)	15.531 (0.08)	37.820 (0.19)
			Limestone	Pyrite (1)	17.966 (0.12)	15.647 (0.10)	38.342 (0.25)
First tectonic layer	Shuangjiao–shan Group	Northern Jiangxi	Greywacke	Pyrite (1)	17.982 (0.11)	15.600 (0.10)	37.960 (0.23)
			Silty slate	Pyrite (1)	18.073 (0.08)	15.714 (0.07)	38.196 (0.18)
	Shangxi Group	Southern Anhui	Black slate	Pyrite (1)	17.693 (0.15)	15.503 (0.13)	37.918 (0.31)
			Phyllitic fine sandstone	Pyrite (1)	17.973 (0.13)	15.728 (0.11)	38.388 (0.27)

Note: Lead isotope analysis was made by the Isotope Laboratory of the Guilin Insititute of Geology and Mineral Resources; the data of isotopic ratios in the brackets are standard diviations. The figures in the brackets of samples analyzed are the number of samples; the same hereinafter.

1) Huang, 1991. 2) Northwestern Jiangxi Geological Team, 1990. Geology of Copper Deposits in Chengmenshan and Wushan.

from the eighties to the beginning of the nineties. This study puts emphasis on analysing the lead isotopic composition of sedmentary pyrites from basement to covers and the uranium and thorium contents in different rock types and granite batholiths. Based on these data, the background of regional lead isotopic compositions is summarized and discussed comprehensively in this paper.

Table 2 Uranium and thorium contents of various rock types from different strata

Tectonic layer	Strata		Rock type	U ($\times 10^{-6}$)	Th ($10 \times^{-6}$	Yh/U
Second tectonic layer	Permian	Upper Permian	Pelite (3)	8.37	15.20	1.82
			Chert (1)	12.50	2.40	0.19
		Lower Permian	Carbonate rock (7)	3.12	0.35	0.11
			Chert (3)	18.83	4.31	0.23
	Carboniferous		Coarse clastic rock (3)	2.29	9.08	3.97
			Clastic rocks (3)	3.53	13.45	3.78
			Pelite (1)	3.18	14.48	4.55
			Carbonate rock (1)	1.15	2.01	1.75
	Devonian		Clastic rock (6)	3.25	13.20	4.06
			Pelite	5.06	19.10	3.77
	Silurian		Clastic rock (6)	3.19	14.27	4.47
			Pelite (12)	2.95	15.85	5.37
	Ordovician		Clastic rock (2)	4.65	12.65	2.72
			Pelite (9)	3.54	16.10	4.55
			Carbonate rock (2)	2.05	5.30	2.59
			Carbonaceous shale (2)	12.20	11.70	0.96
	Cambrian		Pelite (15)	4.59	16.80	3.66
			Carbonate rock (18)	2.37	3.79	1.70
			Carbonaceous–siliceous shale (2)	23.70	8.20	0.35
	Sinian		Clastic rock (16)	1.51	8.42	5.58
			Pelite (10)	2.16	10.30	4.77
First tectonic layer	Proterozoic Shuangjiaoshan Group		Pelite (9)	2.35	11.55	4.91
			Clastic rock (6)	2.23	10.87	4.61
			Tuff (1)	2.20	11.10	5.05
			Spilitic basalt (1)	0.25	2.20	4.23

Note: Uranium and thorium were analyzed by INAA in the China Institute of Atomic Sciences. The average error of uranium is below 15% and the average error of thorium below 2%. Same hereinafter.

2 Lead Isotopic Compositions of Sedimentary Pyrites (Whole Rocks) from Different Strata

During the crustal evolution, tectonic movements in the lower and middle reaches of the Yangtze River experienced three stages which progressed from active to stable and again to active, thus forming three tectonic layers: the first tectonic layer is the middle Proterozoic basement, the second is Sinian to Early Triassic marine sedimentary covers, and the third tectonic layer is Mid–Late Triassic to Cenozoic continental volcaniclastic series. Table 1 shows lead isotope ratios of pyrites (whole rocks) from different strata or rock series in the first and second layers. Uranium and thorium contents of various rock types are shown in Table 2.

Lead isotopic ratios of pyrites from Middle Proterozoic argillo–arenaceous flysch formations in the first tectonic layer demonstrate the geological setting in the Yangtze block at that time. The ratio of thorium to uranium is constant at about 4.5 to 5.

As the Sinian is made up mainly of littoral clastic rocks and continental tillite or glaciofluvial deposits, the lead isotopic composition and ratio of thorium to uranium illustrate that primary covers inherited materials from the basement.

In the Early Cambrian, the depositional environment setting changed to an epicontinental rift sea basin, which was characterized by deep waters, lower oxygen and abundant UO^{2+} that was derived by the continental chemical erosion and deposition. Abundant uranium was deposited and absorbed by carbonaceous–argillaceous materials, resulting in the ubiquitous presence of high uranium contents and a marked increase of the ratio of uranium to lead in the Cambrian (siliceous and carbonaceous rocks in particular). On the other hand, the thorium content varies little because the element is still in a four valence state and has lower solubility during its weathering (Table 2). So the Cambrian is the first abnormal uranium–lead isotopic layer in the covers.

Table 3 Lead isotope ratios of feldspars from intrusive rocks and volcanic rocks (whole rocks)

Era	Continental block	Intrusive rocks and volcanic rocks	Sample	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Data sources
Cenozoic	Yangtze	Jurong–Jiangning alkali basalt	Whole rock (3)	18.186	15.529	38.299	Zhi and Chen, 1992
		Liuhe alkali basalt	Whole rock (3)	17.865	15.514	37.985	
		Liuhe ultramafic periodotite xenolith	Whole rock (2)	17.700	15.492	37.552	
	North China	Jiashan–Nushan alkali basalt	Whole rock (5)	17.157	15.395	37.630	Zhi and Chen, 1992
Mesozoic	Yangtze	Copper– and iron–bearing intermediate–acid small intrusion along Yangtze River	Feldspar (22)	17.961	15.540	38.162	Synthetic data
		"A" type granite along Yangtze River	Feldspar (10)	18.152	15.483	38.205	Zhang Bangtond, 1988
		Jiangnan granite batholith	Feldspar (10)	18.291	15.613	38.503	Zhang Ligang and Xing, 1993
	Dabie	Dabie granite batholith	Feldspar (3)	16.547	15.373	37.421	This paper, 1994
Proterozoic	Yangtze	Granodiorite	Feldspar (2)	17.851	15.520	37.979	Zhang Ligang and Xing, 1993
		Spilitic basalt and quartz–keratophyre	Whole rock (4)	18.043	15.661	38.287	①

① Zhu Xianjia et. al, 1986. Studies on Palaeovolcanic Rock and Its Metallogeny in North Jiangxi.

The normal sedmentary environment occurred after the Ordovician. Due to the differentiation of continental crustal materials and normal radioactive decay, the lead isotopic content increased gradually. But the lead isotopic composition shows relatively strong anomaly in carbonate and pyrites in the Devonian, Carboniferous and Permian. This feature coincides with a relatively high uranium content in local places in these strata (Table 2). These strata form the second abnomal uranium–lead isotopic layer in the covers, but they are distributed unevenly in a small areal extent.

3 Lead Isotopic Compositions of Feldspars (Whole rocks) from Regional Magmatic Rocks

Table 3 shows clearly that lead isotope ratios of intrusive rocks and volcanic rocks of different ages and origins in the same block (e.g. Yangtze block) are similar. The maximum differences of $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ are 0.59%, 0.18% and 0.88% respectively. But in different blocks, they are quite different though these rocks are of the same origin. It can be explained by their subordinations. The Yangtze block, Dabie block and North China block differ evidently in contents of uranium and thorium in the basement: higher uranium and lower thorium in the Yangtze black, and lower uranium and higher thorium in the Dabie block. Consequently, there is marked difference in ratio of thorium to uranium between the two blocks (Table 4).

Table 4 Uranium and thorium contents of basement rocks and granitic rocks from different blocks

Block	Batholith and basement		Intrusion or strata	Rock type	U ($\times 10^{-6}$)	Th ($\times 10^{-6}$)	Th/U
Yangtze	Granite batholith	Mesozoic	Taiping	monzonitic granite	5.52	17.2	3.12
			Qingyang	granodiorite	5.59	17.1	3.06
			Jiuhua	K–feldspar granite	6.30	24.8	3.94
			Zongpu	porphyritic diorite	1.51	4.9	3.25
		Proterozoic	Jiuling	plagioclase granite	2.28	9.4	4.12
			Xiuning	granodiorite	1.43	6.7	4.69
	Pre–Sinian basement		Shuangjiaoshan Group		2.31	11.1	4.81
			Xingzi Group		1.72	7.6	4.42
			Dongling Group		1.63	6.6	4.05
Dabie	Granite batholith	Mesozoic	Zhubo	Granite	3.46	28.4	8.21
			Wanshan	monzonitic granite	2.43	14.9	6.13
			Baimajian	monzonitic granite	1.79	22.3	12.46
				monzonitic granite	2.08	25.8	12.40
			Sikongshan	granodiorite	1.25	7.7	6.16
			Gongping	monzonitic granite	1.46	19.3	13.22
	Pre–Sinian basement		Dabie Group		1.25	10.2	8.18

Lead isotopic ratios of granites of different provenances are slightly different in the same block. In the Yangtze block, the lead isotopic ratios of the Mesozoic crust–anatexis Jiangnan granite batholith are a bit higher than those of crust–mantle syntexis, ore–bearing, intemediate–acid small intrusions along the Yangtze River. This is due to the difference in source between the two types of granite. The Jiangnan granite batholith originated from the middle and upper crust a bit richer in uranium and thorium, while ore–bearing small intrusions were derived by fusion of the deep crust and mantle poor in uranium and thorium. In the same provenance copper– and iron–bearing intermediate–acid small intrusions along the Yangtze River have astonishing similarity in lead isotopic composition (Table 5).

Table 5 Lead isotope ratios of feldspars from copper– and iron–bearing intermediate and intermediate–acid small intrusions along the Yangtze River

Intrusion	Rock type	Sample analyzed	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Ore	Data sources
Tieshan	quartz diorite	Feldspar (1)	17.920	15.500	38.400	Fe, Cu	Shu et al., 1992
Jinshandian	quartz diorite	whole rock (1)	17.933	15.442	38.141	Fe, Cu	
Fengshandong	granodiorite	feldspar (1)	18.080	15.570	38.470	Cu, Mo	
Wushan	granodiorite porphyry	Feldspar (2)	17.877	15.546	37.937	Cu	①
Chengmenshan	granodiorite porphyry	Feldspar (1)	18.042	15.572	37.733	Cu, Mo	
Jinkouling	quartz diorite	Feldspar (3)	17.882	15.520	38.070	Cu	Huang, 1991
Mashan	quartz diorite	Feldspar (2)	17.969	15.588	38.315	Cu	
Tongguanshan	quartz diorite	Feldspar (3)	17.834	15.540	38.108	Cu	

① Northwestern Jiangxi Geological Team, 1990. Geology of Copper Deposits in Chengmenshan and Wushan.

As is the case with granites, alkali basalts, the representive of mantle materials, may have different lead isotopic compositions as they occur in different blocks. For example, the difference in $^{206}Pb/^{207}Pb$ between the Jiashan–Nushan alkali basalt and the Jurong–Jiangning alkali basalt reaches 1%, the former belonging to the North China block and the latter to the Yangtze block. It indicates the heterogeneity of their provenance—upper mantle.

4 Lead Isotopic Composition of Ores from Different Deposits

Three metallogenic belts are distributed in the middle and lower reaches of the Yangtze River and neighbouring areas. They are the copper–iron metollogenic belt along the Yangtze River, the tungsten–tin metallogenic belt in the transition area between the Jiangnan platform uplift and depressions along the Yangtze River, and the gold metallogenic belt in the Middle Proterozoc gold–bearing formation in the Jiangnan platform uplift. Their difference in ore lead isotopic composition is attributed to their different sources of ore–forming materials (Table 6).

Ore lead isotopic compositions of skarn and prophyry ore deposits in the copper–iron metallogenic belt along the Yangtze River are similar to feldspar lead isotopic compositions of intermediate acid small intrusions in the same belt, but quite different from ore lead isotopic compositions of massive pyrite polymetallic deposits.

In the tungsten–tin metallogenic belt, the ore lead isotopic composition of the Zengjialong skarn deposit and the feldspar lead isotopic composition of their parent rocks (two–mica alkali–feldspar granite) are both characterized by abnomal uranium and thorium. Crust–anatexis acid–ultra–acid granites occur in transitional areas between the

Table 6 Lead isotope ratios of ores from different deposits

Belt	Type	Deposit	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Data sources
Copper–iron metallegenic belt along the Yangtze River	Skarn copper deposit	Wushan (6)	17.826	15.561	37.905	①
		Chengmenshan (3)	17.885	15.530	37.876	
		Jinkouling (5)	18.096	15.547	38.227	Huang, 1991
	Skarn tungsten–tin deposit	Ruanyiwan (1)	17.804	15.526	37.940	Shu et al., 1992
	Porphyry copper–molybdenum deposit	Chengmenshan(3)	18.000	15.510	37.901	①
	Massive pyrite polymetallic deposit	Chengmenshan (7)	18.504	15.788	39.155	①
		Mashan (10)	18.397	15.624	38.489	Huang, 1991
		Xinqiao (8)	18.558	15.646	38.591	Liu Yuqing and Liu, 1991
		Others (9)	18.318	15.647	38.490	
	Stratified and stratoid lead–zinc deposit	Qixiashan (8)	17.494	15.474	37.768	②
Tungsten–tin metallogenic belt	Skarn tin deposit and tin–bearing alkali granite	Zengjialong (1)	21.046	16.808	38.306	③
		Changshi (2)	25.287	18.690	39.347	
Gold metallogenic belt on Jiangnan platform uplift	Gold deposit in Middle Proterozoic gold–bearing formation	Wangu (2)	18.022	15.600	38.341	This paper, 1994
		Gaotian (5)	18.085	15.614	38.166	Liu Yingjun et al., 1992
		Huangjindong (13)	17.852	15.533	38.106	④
		Dabeiwu (3)	17.704	15.623	37.900	⑤
		Jinshan (7)	17.471	15.515	37.495	Zhu Kaijun and Fan, 1991
		Xiaoliankou Tianjingshan (3)	18.068	15.600	38.285	⑥

① Northwestern Jiangxi Geological Team, 1990. Geology of Copper Deposits in Chengmenshan and Wushan. ② East China Bureau of Geological Exploration, CNNC, 1990. ③ No. 916 Geological Team, 1985. Tin Deposit in Dean, Jiangxi. ④ Sang Zunan, 1994. Gold Metallogenic Series and Regional Prognosis of Ore Deposits of Low–grade Metamorphic Rock in Jiangnan Anteclise. Thesis for M.S. Degree, China University of Geosciences. ⑤ Shen Tingyuan, 1993. Personal communication. ⑥ Ma Rongsheng, 1993. Personal Communication.

Jiangnan platform uplift and depressions along the Yangtze River. They are alumina–oversaturated and rich in lithophile elements including tungsten, tin uranium and thorium. So the Zengjialong two–mica alkali granite and its related tin ore are rich in thorium and lead.

The ore lead isotopic composition of gold deposits and pyrite lead isotopic composition of Proterozoic argillo–arenaceous flysch gold–bearing formation in the Jiangnan platform uplift (Table 1) are almost the same, indicating that they were derived from the same provenance. All the above analyses of the background features of regional lead isotopic

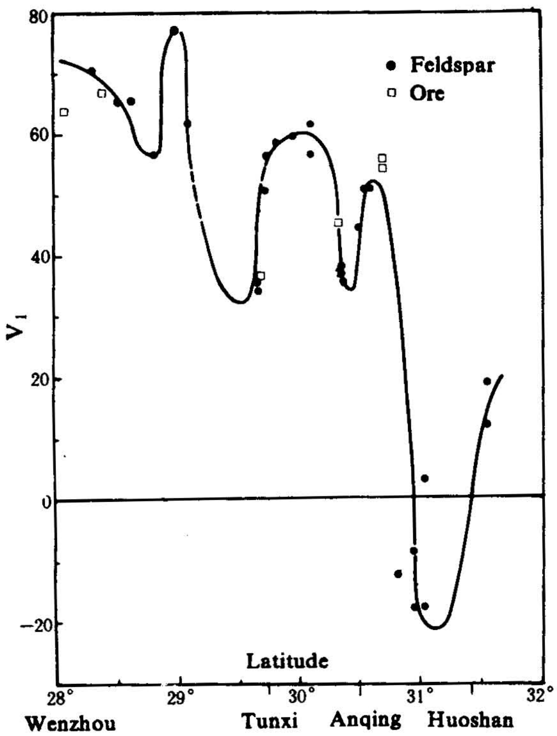

Fig. 1. Latitudinal projection of the lead isotope V_1 value of feldspars of Mesozoic magmatic rocks from Wenzhou–Tunxi–Huoshan.

compositions of various geological bodies show that their major applications may be: (1) in conducting geochemical regionalization on the basis of the difference in lead isotopic compostition between different blocks; (2) tracing evolution mechanism between various layers and magma sources on the basis of the synchronous effect of the same block and changes between different layers of the earth; and (3) tracing sources of ore–forming materials and providing significant information for regional prognosis of ore deposits by means of the study of the regional lead isotope setting.

5 Applications

Since R. E. Zartman (1974) studied Mesozoic granite batholiths and related ore deposits in the Cordillera in the western United States based on 240 lead isotopic data in 1974, many scientists have been increasingly interested in the study of the application of the lead isotopic composition in geology and ore deposit prognosis (Zhang Bangtong et al., 1988; Doe and Zertman, 1979; Ma, 1986; Zhu Bingquan, 1993; Zhu Bingquan et al., 1993; Zhang Ligang et al., 1993). They have gained a series of fuitful results.

5.1 Mapping of the feldspar lead isotopic composition of Mesozoic granite

The isotopic composition of feldspar lead from granites is controlled by the ratio of uranium to lead and the ratio of thorium to lead of the uranium, thorium and lead reservoir in the continental crust. In order to eliminate the effect of timing on the composition, the method of relative deviation of feldspar lead composition between contemporaneous (T = 130 Ma) Mesozoic granites and the mantle was adopted. At the same time, vectors (V_1 and V_2) of three–dimensional spatial topology of lead isotopes were used to highlight the controlling effects of different blocks on the lead isotopic composition (Zhu Bingquan, 1993). The Wenzhou–Tunxi–Huoshan profile was chosen for mapping, which extends from the Huaxia block through northeastern Jiangxi, southern Anhui and the Yangtze block to the Dabie block and North Huaiyang. The V_1 value of lead isotopic compositions of feldspars from various Mesozoic granites on the profile are plotted on the latitude line (Fig. 1, Table 7). Several applications are summarized as follows.

Determining the boundary between two continental blocks The boundary between the South China and Yangtze blocks is defined at $V_1 = 58$ ($^{207}Pb > 15.6$, $^{208}P / ^{204}Pb > 38.6$). It coincides with the Jiangshao fault zone and is also consistent with the boundary determined

Table 7 Lead isotope ratios of feldspars and V_1, V_2 values from Mesozoic magmatic rocks in Wenzhou–Tunxi–Huoshan

Region	Intrusion	Rock type	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$\varepsilon_{\Delta rp}$	V_1	V_2	Data sources
Wenzhou–Tunxi	Jinyun Chunqian	Granite	18.428	15.677	38.847	0.38	69.7	50.7	Zhang Ligang et al., 1994
	Wuyi	Dacite–liparite porphyry	18.209	15.693	38.907	1.62	65.5	39.7	
	Sucun,Suichang	Plagioclase granite	18.263	15.612	38.860	0.69	65.7	41.0	
	Matou	Monzonitic granite	18.129	15.603	38.617	0.83	56.4	36.9	
	Beijie, Longyou	Monzonitic granite	18.306	15.655	39.276	1.22	76.9	39.5	
	Honggong, Jiangshan	Granite	18.133	15.619	38.848	1.10	62.1	34.9	
North–eastern Jiangxi	Yinshan	Quartz porphyry	17.957	15.492	37.883	−0.19	34.4	34.2	Shen et al., 1991
		Dacite porphyry	18.023	15.467	37.900	−0.06	36.5	36.6	
Southern Anhui	Fuling, Jixi	Granite	18.255	15.580	38.455	0.16	55.8	44.4	Zhang and Xing, 1993
	Tongkeng	Granite	18.298	15.623	38.196	0.28	50.6	50.3	
		Granite	18.279	15.586	38.475	0.16	56.9	45.5	
	Changhai, Shexian	Granite	18.254	15.545	38.577	−0.09	58.7	42.2	
	Yixian	Biotite granite	18.242	15.659	38.622	1.04	59.5	43.7	
	Dali, Qimei	Granite	18.234	15.642	38.508	0.83	56.5	44.2	
		Granite	18.321	15.613	38.611	0.38	61.2	46.6	
	Taiping	Granodiorite	18.295	15.636	38.576	0.64	59.7	46.3	
	Wushilong, Taiping	Granite	18.337	15.599	38.385	0.06	56.2	49.6	
Tongling	Mashan	quartz diorite	17.969	15.588	38.315	0.94	45.1	32.1	Huang, 1991
	Jinkouling	Quartz diorite (3)	17.882	15.520	38.070	0.40	36.9	29.1	
	Tongguanshan	Quartz diorite (3)	17.834	15.540	38.108	0.74	36.6	26.7	
Zonghuai	Maowangmiao	Monzonite porphyry	18.091	15.604	38.342	0.83	51.0	37.2	Ren et al., 1991
	Chengshan	Alkali granite	18.120	15.510	38.370	−0.17	50.3	37.2	Zhang Banglong et al., 1988
	Dalongshan	Granite (2)	18.064	15.472	38.218	−0.47	45.2	35.2	
	Hongzhen	Granite	16.990	15.370	36.950	0.79	−12.9	−5.5	①
Dabie	Shucheng Hepeng	Quartz diorite	16.990	15.452	37.623	1.98	3.5	−11.3	Zhang and Xing, 1993
		Quartz diorite	16.539	15.454	37.220	3.00	−18.0	−28.7	Chen Jiangfeng, 1991
	Shucheng Longmianzhai	Quartz syenite	16.539	15.350	37.215	2.03	−18.1	−31.0	
		Quartz syenite	16.968	15.350	37.192	0.82	−7.1	−9.8	
North Huaiyang	Jinzhai Xianghongdian	Nepheline syenite	17.242	15.423	37.715	1.06	12.0	−0.5	Zhou et al., 1992
		Nepheline–bearing syenite	17.202	15.494	38.064	2.05	19.0	−4.7	

① Xing Fengming, 1993. Granite and Geochemical Field—A case study of Anhui.

by Zhu Bingquan (et al., 1993) based on the V_1 value of Cenozoic tholeiite. The boundary between the Yangtze block and Dabie uplift lies in the V_1 gradient abruptly changing zone, where the V_1 value decreases sharply from +3—+45 to −7—−18. The boundary is on the south side of the line of Chuxian–Hongzhen between latitudes 30.8° and 30.9°

Revising the natures of unknown blocks Tracing of the V_1 value of lead isotopic composition of the Hongzhen (Chuxian, Guandian) indicates the following: (1) the natures of the provenances of the three intrusions are similar to that of the Dabie–North China continental crust rather than the Yangtze crust; (2) the deep structure of the Chuxian depression is close to that of the North China block but quite different from that along the Yangtze River, which verifies the geophysical data (Lu and Chen, 1993); (3) the "crossing" of lead isotopic compositions of the three batholiths between the Dabie and Yangtze crusts should shift southeastwards to the line of Chuxian–Hongzhen.

Table 8 Lead isotope ratios and V_1 and V_2 values from Cenozoic alkali basalts from Shengxian–Nushan

Area	Intrusion	Location	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$\varepsilon_{\Delta rp}$	V_1	V_2	Data sources
Shengxian–Xinchang	N–AL	Chenghuangshan, Shengxian	18.362	15.584	38.478	0.18	49.7	43.7	Zhu Bingquan, et al., 1993
	N–AL	Shangzizhou, Xinchang	18.276	15.444	38.171	–1.10	40.2	39.2	
Jiangning–Jurong	ADFF	Fushan, Dangtu	18.150	15.574	38.469	0.66	44.1	33.0	Zhi and Chen, 1992
	JJNF	Fangshan, Jiangning	18.252	15.547	38.369	0.07	44.3	38.4	
	JJT	Chishan, Jurong	18.103	15.467	38.058	–0.46	33.1	32.8	
Liuhe–Yizheng	JLHT	Liuhe	17.962	15.489	37.911	0.04	26.0	28.1	
	JLHF–1	Fangshan, Liuhe	17.844	15.517	38.046	0.72	26.2	21.5	
	JLHF–5	Fangshan, Liuhe	17.789	15.536	37.999	1.02	23.7	19.8	
	PSS2	Panshishan, Liuhe (lherzolite xenoliths)	17.882	15.473	37.774	0.03	20.7	25.4	Lu and Chen, 1993
	PSS6		17.784	15.534	37.822	0.90	19.9	21.5	
	PSS12		17.435	15.468	37.060	0.78	–7.8	11.5	
Jiashan–Nushan	AJSM–3	Mingguang	17.147	15.370	37.624	1.01	–1.6	–11.0	Zhi and Chen, 1992
	AJSD–2	Dahengshan, Jiashan	16.594	15.317	37.352	1.88	–22.2	–36.0	
	AJSL–2	Laohushan	17.266	15.414	37.684	1.13	2.8	–4.9	
	AJSQ–2	Jiashan	17.009	15.437	37.782	2.12	–1.3	–17.9	
	AJSN–1	Nushan	17.771	15.437	37.707	–0.04	16.2	19.9	

Tracing the sources of rocks in the same block The V_1 value of the Mesozoic granite lead isotopic composition in the Yangtze block shows an "Ω" pattern. It is a distinct manifestation of lead isotopic compositions of different provenances in the same block. The V_1 value of the crust–anatexis granite batholiths in the Jiangnan platform uplift is 50–60,

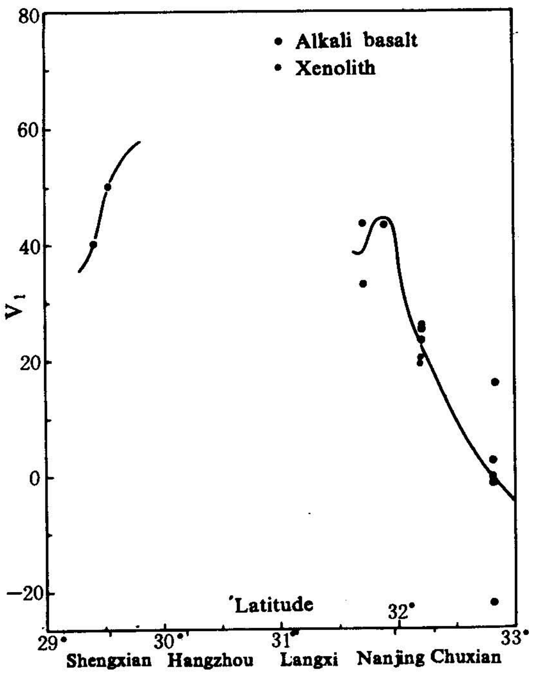

Fig. 2. Latitudinal projection of lead isotope V_1 value of Cenozoic alkali basalts from Shengxian–Nushan.

which indicates the characteristics of lead isotopic compositions of the middle and upper crust; while the V_1 value of intermediate–acid small mineralized intrusions in the depressions on both sides of the uplift is 30–45, which reflects the lead isotopic composition of the mixed source of the lower crust and upper mantle.

Indicating the location of metallogenic belts Large and super–large ore deposits in the Yangtze block all occur near the V_1 gradient abruptly changing zone. The Dexing porphyry copper deposit, Yinshan copper–, lead–, zinc–sliver deposit and Lengshuikeng copper–gold–silver deposit are all in the abruptly changing zone between the South China and Yangtze blocks; while the copper–iron metallogenic belt along the Yangtze River is located in that between the Yangtze and North China (Dabie) blocks.

5.2 Mapping of lead isotopic compositions of Cenozoic alkali basalts

Cenozoic alkali basalts are taken as the representative of the mantle composition. Two Cenozoic basalt groups are distributed in the study region: the Jiashan–Liuhe basalts on the southeast side of the Tanlu fault and the Shengxian–Xinchang basalts on the southeast side of the Jiangshao fault. Their characteristics are shown in Table 8 and Fig. 2.

Alkali basalts in the Shengxian–Xinchang area and the Dangtu–Jiangning area are similar in lead isotopic composition. The V_1 value ranges from 40 to 50. But the V_1 value range (+16 to −22) of alkali basalts in Jashan–Nushan, Anhui, shows the characteristics of the mantle in North China. Cenozoic tholeiite and alkali basalt in Hannuoba and Datong have the following lead isotope ratios: $^{206}Pb/^{204}Pb$: 17.175–17.947, $^{207}Pb/^{204}Pb$: 15.322–15.439, and $^{208}Pb/^{204}Pb = 37.112–37.935$ (Xie et al., 1989).

The V_1 value range (23 33) of alkali basalts in Chishan of Jurong and Fangshan of Liuhe, Jiangsu, is consistent with the features of lead isotopic compositions of ores and feldspars from Mesozoic deep–seated magmatic rocks in the Ningzhen area. Lead isotopic compositions in this area is obviously lower than that in the other parts of the eastern Yangtze block, which may be interpreted by mutual superimposition, wedging and exchange between various layers of the Yangtze and North China blocks.

As shown in Fig. 2, the V_1 gradient variation of lead isotopic composition in alkali basalts between Yangtze and North China is transitional and less abrupt than that of continental crust (Fig. 1). This kind of transition might be due to the subduction of the Yangtze mantle towards the North China block, which occurred together with the obduction ("crossing") of the North China (Dabie) continental crust. Is it the tracing action of lead isotopes on the dynamic mechanism of interaction of blocks?

The lead isotope ratios of xenoliths of mantle–derived ultramafic peridotite is slightly lower than its host rock (alkali basalts). For this, two causes may be inferred: (1) xenoliths and alkali basalts represent the vertical compositional variation of the mantle, and (2) alkali basaltic magma was contaminated by the crust during its intrusion.

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