Feldspar Lead Isotopic Composition of Granitoids from the Eastern Qinling Orogenic Belt and Their Tectonic Significance

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Abstract This paper reports 48 feldspar lead isotope analyses from 27 granitic intrusions, which formed from the Late Proterozic to Mesozoic within the Eastern Qinling oregenic belt. It is found that the granitic rocks of South Qinling are characterized by a strong block–effect and depletion in U–Pb and Th–Pb, showing that these rocks came from the same lead isotope tectono–geochemical province, while those of North Qinling are characterized by higher U–Pb and Th–Pb for Late Proterozoic to Early Paleozoic ones and lower U–Pb and Th–Pb for Late–Palaeozoic and younger ones in their feldspar lead isotopic composition. In the North Qinling block, lead isotopic signatures reflect that the source of granitic magma had changed since the Late Palaeozoic. Comparison of feldspar lead isotopic composition between South Qinling and North Qinling shows that there is marked difference in lead isotopic composition for pre–Palaeozoic granitoids, indicating that the South Qinling and the North Qinling blocks belong to different tectonic units, but the similarities in lead isotopic composition are quite clear, which indicates that the South Qinling block had been welded with the North Qinling block and that the magma sources of both blocks were identical. The analysis provides direct evidence for underplating of the continental crust of South Qinling beneath the North Qinling block in the continent–continent interaction stage of the Eastern Qinling oregenic belt.

Key words: Eastern Qinling orogenic belt, granitic rock, feldspar Pb isotopic composition, tectonic significance

Feldspar lead isotopic ratios of granitoids can represent the initial ratios at the time of magma crystallization, and their significance in tracing geological features have been emphasized increasingly in recent years (Clayburn, 1988; Hampton and Taylor, 1983; Zhang Ligang, 1988; Zhang Ligang et al., 1993; Zhu, 1993). Large–scale feldspar lead isotopic mapping of Mesozoic granitoids in eastern China (Zhang Ligang et al., 1993) shows that the block–effect of lead isotopes in the Chinese continental lithosphere is very distinct. A similar idea has also been obtained through large–scale ore lead isotopic mapping (Zhu,

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1993). On the basis of the block–effect, the Chinese continental lithosphere is divided into several lead isotopic tectono–geochemical provinces. These results provide important constraints on the geological evolution of the Chinese continental lithosphere. But detailed lead isotopic mapping within an orogenic belt guided by the historical geochemistry theory is rare. The Qinling orogenic belt is a typical continental orogenic belt in China and one of the key regions for the study of formation and evolution of continental orogenic belts. In this orogenic belt, Late Proterozoic to Mesozoic granitic magmatism occurred widely. This paper will present the feldspar lead isotopic characteristics of granitoids of different ages in the East Qinling orogenic belt, and further discusses the continent–continent (block–block) interaction in the process of formation and development of the orogenic belt.

1 Geological Setting

It is widely accepted that the Late Proterozoic to Early Palaeozoic ocean–continent

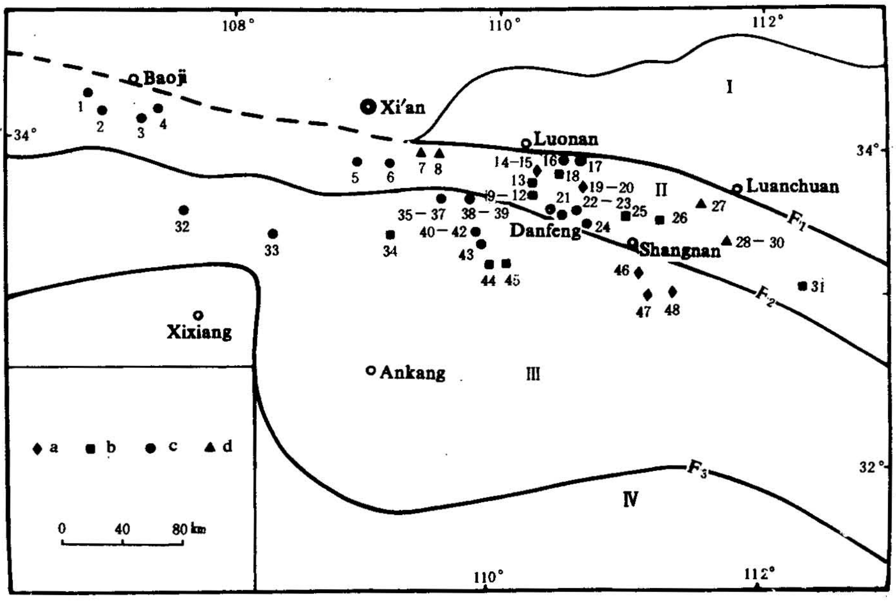

Fig. 1. Sketch map showing the tectonic units of the East Qinling orogenic belt and its adjacent areas and the localities of sampling.

Age: a. Late Proterozoic; b. Early Palaeozoic; c. Late Palaeozoic; d. Mesozoic. Major faults: F_1– Luonan–Luanchuan fault; F_2– Shangdan fault; F_3– Dabashan arcuate fault. Tectonic units: I –North China craton; II –North Qinling orogenic belt; III –South Qinling orogenic belt; IV –Yangtze craton. Samples: 1–4. Baoji monzogranite; 5–6. Cuihuanshan biotite granite; 7–8. Muhuguan monzogranite; 9–12. Zaoyuan biotite granite; 13. Qiushuping biotite granite; 14–15. Cai'ao granodirite; 16–17. Mangling monzogranite; 18. Shimen biotite granite; 19–20. Huangbaiyu granodiorite; 21. Tieyupu biotite granite; 22–23. Kuanping biotite granite; 24. Wuguan biotite granite; 25. Huichizi biotite granite; 26. Piaochi biotite granite; 27. Laojunshan biotite granite; 28–30. Erlangping biotite granite; 31. Wuduoshan monzogranite; 32. Wulong biotite granite; 33. Laocheng granodiorite; 34. Mihunzhen quartz diorite; 35–37. Caoping monzogranite; 38, 39. Shahewan monzogranite; 40–42. Xiaohekou granodioritic porphyry; 43. Yuanzijie quartz dioritic porphyry; 44, 45. Banbanshan monzogranite; 46. Sanpinggou quartz diorite; 47. Fengzishan granodiorite; 48. Gangou granodiorite.

interaction stage in the East Qinling orogenic belt passed to the continent–continent interaction stage in the Late Palaeozoic. The Shangdan fault within the orogenic belt is a major suture zone between the North China and Yangtze (South China) plates. The north side of the fault is called the North Qinling orogenic belt (simply called North Qinling), and the south side of the fault is called the South Qinling orogenic belt (simply called South Qinling) (Fig. 1). Late Proterozoic to Mesozoic granitic intrusions are not only distributed in North Qinling but also in South Qinling. In North Qinling, most intrusions occur in the Qinling Group, and a few in the Kuanping Group, Danfeng Group and Erlangping Group. In South Qinling, most intrusoins are distributed in the Devonian and Douling Group, and a few in other groups. The main geological and geochemical characteristics and chronological data of these granitic intrusions have been described in detail in relevant monographs (Yan, 1985; Shang and Yan, 1988; Zhang Benren et al., 1994), and their rock types and formation ages are also summarized in Fig. 1.

2 Sample Description and Results

Twenty–eight granitic intrusions exposed on both sides of the Shangdan fault are concerned in this study, of which 17 granitic intrusions are located in North Qinling and 11 in South Qinling. Feldspar lead isotopic samples (17 samples from South Qinling and 31 from North Qinling) were picked out by hand under the binocular microscope with a purity of more than 98%. K–feldspar samples were selected from biotite granites, monzogranites, granodirites and granodiritic porphyry, while plagioclase samples from quartz diorites or quartz dioritic porphyry. Fig. 1 shows their localities. Measurements of lead isotopic ratios were performed at the Institute of Geology, Chinese Academy of Sciences. The data were normalized to the NBS981, an international isotope standard. The results indicate that the uncertainties at 95% confidence level are superior to 0.1% for $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$. The lead isotopic data of the South Qinling and North Qinling granitoids are listed in Table 1 and Table 2, respectively.

3 Discussions

3.1 South Qinling

From Table 1, it may be found that the lead isotopic ratios of felspars from the South Qinling granitoids of different ages show a narrow variation. The $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios for most samples are lower than 17.8 and 37.9, respectively. Therefore, the South Qinling granitic rocks are generally characterized by low radiogenic lead ratios. Also from Table 1, the feldspar lead isotopic ratios of the South Qinling granitoids are similar to those of the South Qinling basement rocks such as the Wudan Group and Yaolinghe Group amphibolites and the Fuping Group biotite–plagioclase gneiss, which indicates that the South Qinling granitoids might be formed by recycling of the South Qinling basement rocks.

Comparison of granitoids of the same age indicates that their feldspar lead isotopic ratios are very close and are not related to their rock types but show an evolution trend of gradual increase from the Late Proterozoic to Late Palaeozoic and Early Mesozoic granitic rocks. This trend is in agreement with the normal evolution of lead isotopic ratios under a unifying tectonic setting, suggesting that the sources of the South Qinling granitic magma

Table 1 Feldspar Pb isotopic ratios of granitoids and other associated rocks from South Qinling

Age	Intrusion	Sample No.	Rock type	Analyzed material	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Late Proterozoic	Sanpingou	SPG-1	quartz diorite	K-feldspar	17.416	15.528	37.535
	Fengzishan	FZS-1	granodiorite	K-feldspar	17.298	15.421	37.506
	Gangou	GG-1	granodiorite	K-feldspar	17.275	15.400	37.298
	Average				17.330	15.450	37.466
Early Palaeozoic	Banbanshan	BBS-4	monzogranite	K-feldspar	17.338	15.435	37.399
		BBS-6	monzogranite	K-feldspar	17.447	15.423	37.411
	Mihunzhen	MHZ-3	quartz diorite	plagioclase	17.652	15.466	37.413
	Average				17.479	15.441	37.408
Late Palaeozoic	Caoping	CP-2	monzogranite	K-feldspar	17.554	15.436	37.540
		CP-8	monzogranite	K-feldspar	17.528	15.435	37.516
		CP-10	monzogranite	K-feldspar	17.659	15.564	37.860
	Shahewan	SH-1	monzogranite	K-feldspar	17.508	15.446	37.526
		SH-2	monzogranite	K-feldspar	17.655	15.576	37.815
	Laocheng	LC-2	granodiorite	K-feldspar	17.613	15.442	37.527
	Wulong	WL-5	monzogranite	K-feldspar	17.834	15.401	37.577
	Average				17.586	15.483	37.622
Mesozoic	Xiaohekou	XHK-1	granodiritic porphyry	K-feldspar	17.860	15.506	38.326
		XHK-2	granodiritic porphyry	K-feldspar	17.551	15.462	37.581
		YHK-3	granodiritic porphyry	K-feldspar	17.415	15.405	37.389
	Yuanzijie	YZJ-1	quartz dioritic porphyry	K-feldspar	18.019	15.601	38.129
	Average				17.771	15.519	37.885
Average of feldspar Pb from granitoids in South Qinling					17.549	15.472	37.607
Fuping Group biotite plagioclase gneiss①				whole-rock (1)	17.645	15.418	37.671
Wudan Group basic rock①				whole-rock (2)	17.717	15.490	37.888
Yaolinghe Group basic rock②				whole-rock(10)	17.634	15.472	38.320

Isotopic data of ① and ② are from Xu Jifeng (1995) and Wang Souqiong (1994), respectively. Figures in parentheses indicate the number of samples.

have similar μ-values ($^{238}U/^{204}Pb$). On the other hand, if the feldspar lead isotopic ratios of the pre-Mesozoic granitoids of South Qinling are separately corrected on the basis of their U-Th-Pb systems and converted to those of Mesozoic granitoids, their lead isotopic ratios will apparently increase, i.e. the corrected feldspar lead isotopic ratios for the pre-Mesozoic granitoids will be very close to those of Mesozoic granitoids of South Qinling. Thus, the lead isotopic block-effect of the South Qinling granitoids is rather pronounced though the granitic bodies of South Qinling were formed in different positions and periods of time, showing that they were formed in the same tectonic unit or lead isotopic tectono-geochemical province. In terms of the feldspar lead isotopic ratios of the Mesozoic granitoids of South Qinling, the average values of $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ are 17.771, 15.519 and 37.885, respectively, which are similar to the lead isotopic ratios (17.840,15.538 and 38.055) of B2-2 province (Northern Yangtze) and different from the lead isotopic ratios (17.460, 15.481 and 37.965) of A3-2 province (North China). The two aforesaid provinces are adjacent and were both defined by Zhang Ligang (Zhang Ligang et al., 1993) when he carried out large-scale lead isotopic mapping of Mesozoic granitoids in eastern China. Thus, the South Qinling block should belong to the

Table 2 Feldspar Pb isotopic ratios of granitoids and other associated rocks from North Qinling

Age	Intrusion	Sample No.	Rock type	Analyzed Material	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Late Proterozoic	Huangbaiyu	HBY−1	granodiorite	K−feldspar	18.191	15.619	38.141
		HBY−2	granodiorite	K−feldspar	18.251	15.611	38.477
	Cai' ao	CO−1	granodiorite	K−feldspar	18.476	15.670	38.340
		CO−2	granodiorite	K−feldspar	18.224	15.531	38.350
Early Palaeozoic	Piaochi	PC−1	monzogranite	K−feldspar	18.232	15.475	37.858
	Huichizi	HCZ−1	biotite granite	K−feldspar	18.197	15.626	38.493
	Wuduoshan	ZM−1	monzogranite	K−feldspar	18.105	15.549	38.073
	Zaoyuan	ZY−1	biotite granite	K−feldspar	18.140	15.546	38.151
		ZY−2	biotite granite	K−feldspar	17.855	15.362	37.409
		ZY−3	biotite granite	K−feldspar	18.289	15.630	38.296
		ZY−4	biotite granite	K−feldspar	17.801	15.177	37.562
	Shimen	SM−1	biotite granite	K−feldspar	18.575	15.472	37.735
	Qiushuping	QSP−1	biotite granite	K−feldspar	18.277	15.557	38.005
Late Palaeozoic	Cuihuashan	CH−1	biotite granite	K−feldspar	17.413	15.382	37.379
		CH−2	biotite granite	K−feldspar	17.496	15.410	37.654
	Mangling	ML−2	monzogranite	K−feldspar	17.682	15.473	37.890
		ML−4	monzogranite	K−feldspar	17.508	15.430	37.553
	Baoji	BJ−1	monzogranite	K−feldspar	17.731	15.471	37.593
		BJ−2	monzogranite	K−feldspar	17.695	15.433	37.711
		BJ−3	monzogranite	K−feldspar	17.734	15.484	37.776
		BJ−4	monzogranite	K−feldspar	17.677	15.456	37.708
	Tieyupu	TYP−1	biotite granite	K−feldspar	18.005	15.362	37.553
	Kuanping	KP−1	biotite granite	K−feldspar	18.492	15.637	38.426
		KP−2	biotite granite	K−feldspar	18.097	15.382	37.607
	Wuguan	WG−1	biotite granite	K−feldspar	18.505	15.930	38.025
Mesozoic	Muhuguan	MH−1	monzogranite	K−feldspar	17.768	15.553	38.028
		MH−2	monzogranite	K−feldspar	17.860	15.544	38.160
	Erlangping	ELP−1	biotite granite	K−feldspar	17.840	15.502	37.991
		ELP−2	biotite granite	K−feldspar	17.865	15.520	38.006
		ELP−3	biotite granite	K−feldspar	17.581	15.345	37.506
	Laojunshan	LJ−1	biotite granite	K−feldspar	17.833	15.430	37.731
Qinling Group biotite−plagioclase gneisses①				whole−rock(9)	18.114	15.601	38.343
Qinling Group meta−basic rocks②				whole−rock(4)	18.483	15.624	38.359
Kuanping Group meta−basic rocks③				whole−rock(2)	18.774	15.774	39.105
Songshugou ophiolite③				whole−rock(4)	18.429	15.676	38.486
Danfeng Group meta−basic rocks④				whole−rock(10)	18.366	15.536	38.168

Isotopic data of ①, ②, ③ and ④ are from You Zhendong (1988), Hu Yunping (1990), Xu Jifeng (1995) and Zhang Qi (1995). The number in parentheses is sample number.

North Yangtze tectono−geochemical province.

The above study indicates that from the Late Proterozoic to Mesozoic (at least from the Late Palaeozoic to Early Mesozoic), the crustal system of South Qinling was in a relatively stable state, which coincides with the development history of South Qinling as a passive continental margin of the Yangtze block from the Sinian till Late Palaeozoic (Zhang Benren et al., 1994).

3.2 North Qinling

Table 2 shows that the lead isotopic ratios of feldspars from North Qinling granitoids of different ages display a wide variation. The samples from Late Proterozoic to Early Palaeozoic granitic rocks are rich in U–Pb and Th–Pb. The $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios for most samples are 18 and >38, respectively, and are similar to those of North Qinling basement rocks (Table 2), showing that the North Qinling block was characterized by high radiogenic lead in the early stage of its evolution. The feldspars of Late Palaeozoic granitoids have more complex lead isotopic compositions. Smaller magmatic bodies occurring in the Danfeng Group, such as the Kuanping, Tieyupu and Wuguang rock bodies, have a lead isotopic composition similar to those of Late Proterozoic to Early Palaeozoic granitoids. Because they are geological autochthonous or subautochthonous granitic bodies and their rock–forming materials were mainly derived from reworking of the Danfeng Group volcanic–sedimentary rocks (Zhang Benren et al., 1994), so the isotopic compositional features of these smaller rock bodies must have inherited those of the Danfeng Group rocks with higher radiogenic lead. But, the lead isotopic composition of feldspar from the Late Palaeozoic granitic batholiths, such as the Cuihuashan, Mangling and Baoji batholiths in the Qinling Group, are obviously different from those of the above–mentioned intrusions. They are characterized by lower radiogenic lead, with a $^{206}Pb/^{204}Pb$ ratio lower than 17.8 and a $^{208}Pb/^{204}Pb$ ratio lower than 37.9. The feldspar lead isotopic ratios of Mesozoic granites are similar to those of the Late Palaeozoic granitic batholiths, only the former being slightly higher than the latter.

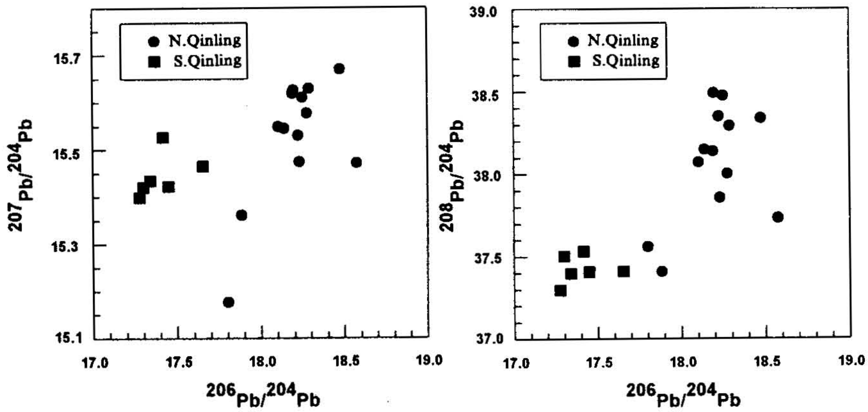

Fig. 2. Feldspar lead isotope covariant plots of pre–Late Palaeozoic granitoids from South Qinling and North Qinling.

The above data indicate that the lead isotopic block–effect is not conspicuous in the North Qinling block. According to the evolutionary trend of lead isotopic composition in a similar μ–value source, the lead isotopic ratios should increase with time, but it can not explain the change of the lead isotopic composition of North Qinling granitic rocks, which evolved towards low radiogenic lead from the Late Proterozoic to Mesozoic. Therefore the granitic rocks of North Qinling were derived from different magma sources in different tectonic settings. The Late Proterozoic to Early Paleozoic granitic magma came from a higher μ–value source, while the Late Palaeozoic granitic batholiths and Mesozoic granites came from lower μ–value sources. This indicates that in the Late Palaeozoic the interaction between the North Qinling block and another block, both of which have distinct μ–values, had happened and that the nature of the structure inducing the formation of granitic magma had changed in North Qinling in the Late Palaeozoic and later.

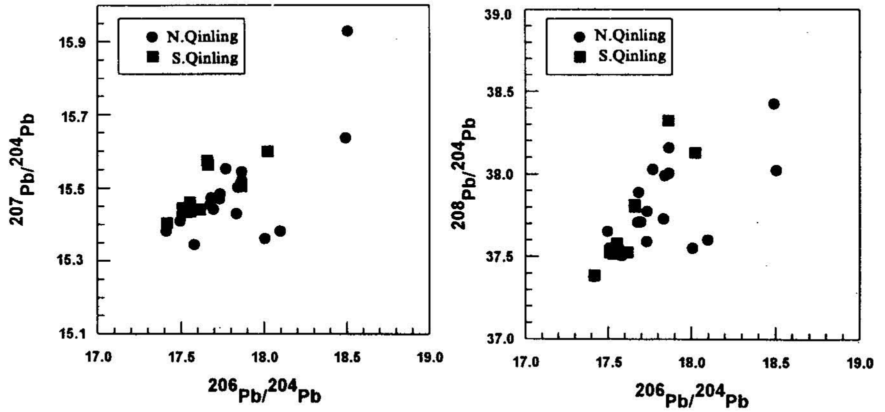

Fig. 3. Feldspar lead isotope covariant plots of Late Palaeozoic and younger granitoids from South Qinling and North Qinling.

3.3 Amalgamation between South Qinling and North Qinling

To avoid possible time–effect of lead isotopes, a comparison in feldspar lead isotopic composition between South Qinling and North Qinling granitoids, which are similar in age, has been made (Figs. 2 and 3). It is found that there is marked difference in feldspar lead isotopic composition between North Qinling and South Qinling granitoids before the Late Palaeozoic (Fig. 2), that is, the South Qinling granitic rocks are depleted in radiogenic lead, while the North Qinling granitic rocks are rich in radiogenic lead, suggesting that the μ–value of the granitic magma source of South Qinling is notably different from that of North Qinling. This indicates that before the Late Palaeozoic the South Qinling block and North Qinling block were independent of each other, belonging to different tectonic units. Since the Late Palaeozoic, however, feldspar lead isotopic compositions of the South Qinling and North Qinling granitoids have become similar, and the μ–values of their granitic magma sources are alike except for autochthonous–subautochthonous granites occurring in the Danfeng Group (Fig. 3). Therefore, it can be concluded that the North Qinling block had been welded together with the South Qinling block and that the Qinling orogenic belt had developed into the continent–continent interaction stage after the Late Palaeozoic, which is in agreement with the conclusion drawn according to the simultaneous emplacement of collision–type granites on both sides of the Shangdan fault in the Late Palaeozoic, an analysis of the source of arenaceous–pelitic rocks and the sedimentary water mass nature reflected by pure carbonate rocks (Zhang Benren et al., 1994). Owing to the continent–continent interaction or intracontinental subduction, the magma source of the Late Palaeozoic and younger granitic batholiths of North Qinling was not mainly derived from the North Qinling block itself with a high μ–value, but rather came from the South Qinling middle–lower crust with a lower μ–value, which has been also confirmed by Nd and Sr isotopic studies of these granitic rocks (H.F. Zhang et al., in press). This result provides direct evidence for the decoupling and subduction of the South Qinling middle–lower crust beneath the North Qinling block. This idea was only conjectured in light of the surface geology and geophysical sounding of QB–1 geological cross section in the past (Cao et al., 1994; Zhang Guowei, 1988).

4 Conclusions

(1) The study of lead isotopic compositions of feldspars from granitoids of varying ages within orogenic belts from the view–point of historical geochemistry has important significance to the development and evolution of the orogenic belt.

(2) Although the South Qinling granitoids were formed in different times, their lead isotopic block–effect is still clearly observed, showing that the South Qinling granitic magmas came from a relatively homogeneous μ–value source and that the South Qinling crust system was in a relatively stable state. In the lead isotopic tectono–geochemical divisions, the South Qinling block should belong to the Northern Yangtze province.

(3) In North Qinling, the lead isotopic compositions of the Late Palaeozoic to Mesozoic granitic magma source are obviously different from those of the Late Proterozoic to Early Palaeozoic granitic magma source. Such difference can not be explained by the time evolution of lead isotopes. It indicates that in the Palaeozoic the interaction between the North Qinling block and another block (South block) had happened and that the tectonic nature inducing the granitic magma formation had been changed, and it also reveals that owing to the block–block interaction the lead isotopic block–effect did not occur in the North Qinling block. Thus, the lead isotopic block–effect is only present in a relatively stable block.

(4) Before the Late Palaeozoic, the South Qinling block and the North Qinling block were independent of each other, but after the Late Palaeozoic, the South Qinling block was amalgamated with the North Qinling block and the granitic magma of the North Qinling block was derived from the middle and lower crust of the South Qinling block, which provides direct evidence for the decoupling and subduction of the South Qinling crust beneath the North Qinling crust.

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