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Granitoid magmatism in the Qinling orogen, central China and its bearing on orogenic evolution

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The Qinling orogen is a typical composite orogen for understanding multi-stages of magmatism and orogenic processes. Many studies have been carried out on the magmatic rocks in the Qinling orogen but their petrogenesis is still controversial. This paper presents a review of all granitoid rocks based on previous and new studies of geochronology and geochemistry. Four distinct periods of granitoid magmatism, Neoproterozoic (979–711 Ma), Paleozoic (507–400 Ma), Early Mesozoic (250–185 Ma) and Late Mesozoic (160–100 Ma), have been recognized from the Qinling orogen according to zircon U-Pb ages, intrusion associations and deformation, as well as regional geology. The Neoproterozoic granitic rocks consist of three stages at 979–911, 894–815 and 759–711 Ma, respectively, corresponding to strongly deformed S-type, weakly deformed I-type and A-type granitoids. They can be interpreted as magmatic occurrences in syn-collisional, post-collisional and extensional settings, respectively, in response to old continental terranes of the Neoproterozoic tectonomagmatic events in the old continents of China, such as South China and Tarim cratons. Although this continental terrane would be involved in the Phanerozoic Qinling orogeny, the Neoproterozoic magmatic rocks are not the products of the Qinling orogenic processes. The Paleozoic magmatic rocks can be classified into three stages at 507–470, 460–422 and 415–400 Ma, respectively. The first-stage magmatism is temporally associated with ultra-high pressure metamorphism in the North Qinling terrane. These magmatic rocks are interpreted as magmatic occurrences in subductional, syn-collisional and post-collisional settings, respectively. The Early Mesozoic magmatic rocks occur in two stages at 252–185 and 225–200 Ma, respectively. The first-stage granitoids are mainly represented by I-type quartz diorites and granodiorites, and the second stage by granodiorites and monzogranites with the I- to A-type characteristics and some with rapakivi textures. Their emplacement ages and geochemical parameters such as A/CNK, K_2O/Na_2O ratios and $\varepsilon_{Nd}(t)$ values do not show any polarity change in perpendicular to subduction/collision zone. Therefore, all these Early Mesozoic granitoids are unlikely the product of continental subduction as some researchers suggested. Instead, they are plausibly related to the subduction of the Mianlue Ocean and the subsequent collision between the South China Craton and the South Qinling terrane. The Late Mesozoic granitoids were emplaced mainly at two stages of 160–130 and 120–100 Ma, and characterized by the evolution from I- to I-A- and A-type granitoids. These characteristics are consistent with the granitoid magmatic evolution from contractional to extensional settings during the Jurassic/Cretaceous in eastern China. Accordingly, the Late Mesozoic granitoid rocks in the Qinling orogen probably have a similar petrogenetic mechanism to those of the huge magmatic belt along the western Pacific margin, i.e., intra-continent magmatism related to a far-field effect of the subduction of Paleo-Pacific plate.

granitoid, zircon age, magmatism evolution, tectonics, Qinling orogen

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The Qinling orogen is characterized by multi-stage orogenic processes due to the long-term convergence between the North and South China cratons (NCC and SCC) (Mattauer et al., 1985; Kröner et al., 1993; Meng and Zhang 1999; Zhang et al., 2001; Dong et al., 2011a, 2015; Wu and Zheng, 2013), and had underwent four periods of tectonothermal magmatism in the Neoproterozoic, Paleozoic, Early and Late Mesozoic, respectively, corresponding to four periods of granitoid rocks. Consequently, this orogen is an ideal region for studying the relationship between granitoid magmatism and orogenic process. Previous studies of these magmatic rocks were mainly focused on individual plutons and magmatic zones of certain periods (e.g., Sun et al., 2002; Wang X X et al., 2008, 2011; Wang T et al., 2009; Zhang et al., 2008; 2013; Dong et al., 2011b; Li et al., 2015, references therein), and some comprehensive studies have been done on granitoids and their relationships to orogenic processes (e.g., Lu et al., 1991; Lu, 2000). In recent years, with the improvement and application of analytical techniques, an increased amount of geochronological and geochemical data have been obtained and reported for granitoids in the Qinling orogen. These data provide an opportunity to systematically summary the distribution, association and sources of the Qinling granitoids and a possibility to depict orogenic processes in the term of the magmatic evolution. Some studies have been made on the features of magmatism, particularly on Paleozoic and Early Mesozoic ones, and the relationship between them and the orogenic processes, proposing some new opinions (e.g., Zhang et al., 2008; Wang T et al., 2009; Chen, 2010; Wang et al., 2013; Wu and Zheng, 2013; Zhang et al., 2013; Li et al., 2015). However, there are still many controversies, such as the stages of Paleozoic magmatism and their interpretations, and the tectonic settings for the Early Mesozoic granitoid magmatism (subduction or subduction to collision). This paper, based on the previous studies, including the new zircon U-Pb ages and geochemical data, further discusses and summarizes the spatial and temporal distribution of granitoids in the Qinling orogen and their origin, sources and evolution as well as their constraints on the orogenic processes.

1 Outline of the Qinling orogen and granitoids

The Qinling orogen is an important element of the China Central Orogenic Systems (CCOS, e.g., Zhang et al., 2001). Several subdivisions of tectonic units within this orogen have been proposed in terms of plate tectonics system (e.g., Matture et al., 1985; Xu et al., 1988; Zhang et al., 1988, 1996, 2001; Meng and Zhang, 1999, 2000; Dong et al., 2011a; Wu and Zheng, 2013) and tectonic facies (e.g., Wang Z Q et al., 2009). Most researchers agree with that this orogen contains two sutures (Shangdan and Mianlue) and three blocks, North Qinling Belt (NQB), including the southern margin of the NCC, South Qinling Belt (SQB) and northern margin of the SCC (Figure 1). The NQB is predominately composed of Proterozoic to Paleozoic medium- to high-grade metasedimentary and metavolcanic rocks, including the Qinling Complex or Qinling Group, and the Kuanping, Erlangping and Danfeng groups. The Proterozoic Qinling Complex consists of gneisses metamorphosed to amphibolite facies and deformed plutons (You and Suo, 1991; Wang et al., 1997). The Paleozoic ultra-high pressure (UHP) eclogite occurred along the northern margin in the eastern NQB (Hu et al., 1994; Yang et al., 2003) and Paleozoic high pressure (HP) granulite and retrograde metamorphosed eclogite outcropped in the southern NQB (Liu L et al., 1996, 2010, 2013; Chen et al., 2004; Chen and Liu, 2011, references therein). The Erlangping Group, located to the north of the Qinling Complex, constitutes ophiolite and volcanic sedimentary rocks (Sun et al., 1996). The Kuanping Group is chiefly composed of greenschist, amphibolite and metaclastics. The SQB mainly consists of the

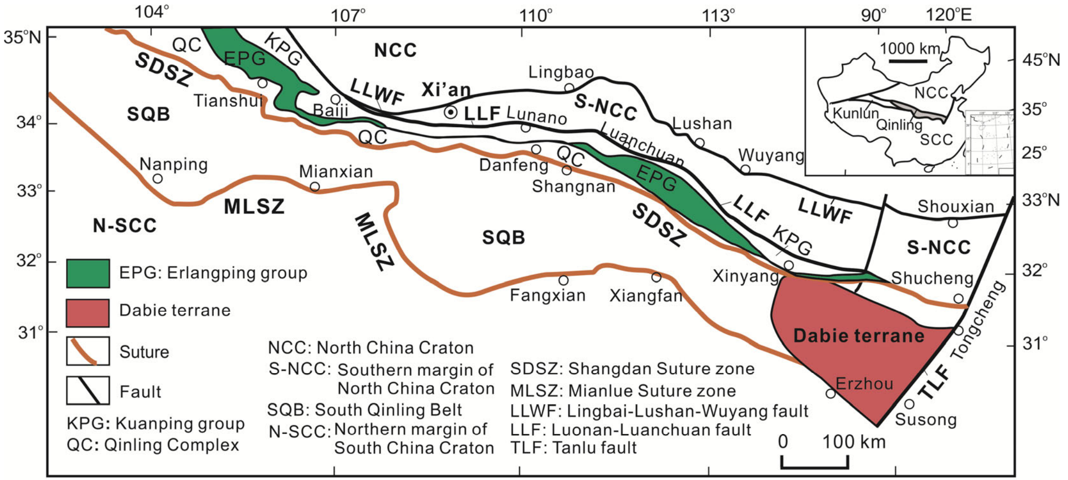


Figure 1 A tectonic sketch map of the Qinling orogen. After Dong et al. (2011a).

Neoproterozoic and Devonian sedimentary sequence (Zhang et al., 2001).

Neoproterozoic, Palaeozoic and Mesozoic magmatism occurred widely in the Qinling orogen (Figure 2), establishing the main tectonothermal framework of this orogen. The Neoproterozoic deformation and magmatic event are generally considered as corresponding to the continental assembly and breakup during Neoproterozoic (e.g., Kröer et al., 1993; Xue et al., 1996b; Wang et al., 1999, 2005, 2013; Lu et al., 2004). The Palaeozoic magmatism was related to the subduction, accretion and collision of the NQB along both Shangdan and Erlangping zones during Palaeozoic (e.g., Ratschbacher et al., 2003; Wang et al., 2005, 2009, 2013; Zhang et al., 2013; Dong et al., 2015). The Early Mesozoic (Triassic) magmatism was widespread in the whole Qinling orogen (e.g., Sun et al., 2002; Zhang et al., 2008; Wang et al., 2013), while the Late Mesozoic ones mainly occurred only in the East Qinling (Lu et al., 1991; Lu, 2000; Wang X X et al., 2013, 2015) and formed voluminous granitoid plutons (Figure 2).

2 Neoproterozoic granitoid magmatism-constraint on collision

2.1 Age, deformation and origin of the Neoproterozoic three-stage granitoids

Based on the zircon U-Pb dating and the deformation of the granitoid plutons (Wang et al., 2013), the Neoproterozoic granitic rocks can be subdivided into three stages of 979–911, 894–815 and 759–711 Ma (Figure 3).

The first stage granitoids are predominately composed of S-type biotite-muscovite monzogranites with strong deformation. Their ^{87}Sr/^{86}Sr(t) ratios (0.706–0.7227) and $\varepsilon_{\rm Nd}(t)$ values (−4.93 to −4.2) are low and Nd mantle model ages ($T_{\rm DM2}$) from 2.21 to 1.99 Ga, similar to some ages of the Qinling Complex. These suggest that the sources of the granitoids are most probably affinity with the gneisses of the Qinling Complex. The representative pluton is the Niujiaoshan pluton (959 Ma, see Wang et al., 1998, 2005).

The second stage granitoids, occurring in the Qinling Complex and SQB, consist of granodiorites and monzogranites, as well as some late A-type syenogranites. They show large variations of $\varepsilon_{\rm Nd}(t)$ values (−5 to 10). Some values are overlapped with that of Paloe- to Meso-proterozoic crustal components and others with depleted mantle. The Caiwa and Dehe plutons are the representative plutons of this stage (Zhang et al., 2004; Chen et al., 2006).

The third stage granitoids, located only in the SQB, are composed of quartz diorites, granodiorites and alkali granite, characterized by I- and A-type granites. The $\varepsilon_{\rm Nd}(t)$ values (−5 to 5) of some granitoids are between the Paloe- to Meso-proterozoic crust and chondrite while others between chondrite and depleted mantle. The representative A-type pluton is the Tuwushan pluton (Lu et al., 1999).

2.2 Tectonic settings of the three-stage granitoids—Syn-collision to post-collision?

The following several lines of evidence suggest that the Neoproterozoic granitoids in the NQB formed in a syn-collisional to post-collisional setting (Zhang et al., 2004; Wang et al., 2013).

(1) Rock types. Most of the first stage granitoids (979–911 Ma) are monzogranites with high aluminous primary phases such as muscovite and garnet, and are of high-K calc-alkaline and strongly peraluminous features, so they are typical S-type granites. The second stage granitoids (894–815 Ma) are mainly granodiorites and monzogranites. Most of them are I-type granites, showing calc-alkaline, metaluminous features, and some are S-type granites with calc-alkaline and peraluminous affinities. The third stage granitoids (759–711 Ma) are I- and A-type granitoids and the A-type granitoids contain alkaline mafic minerals.

(2) Structural deformation. The first stage granitoid plutons were strongly deformed and characterized by the

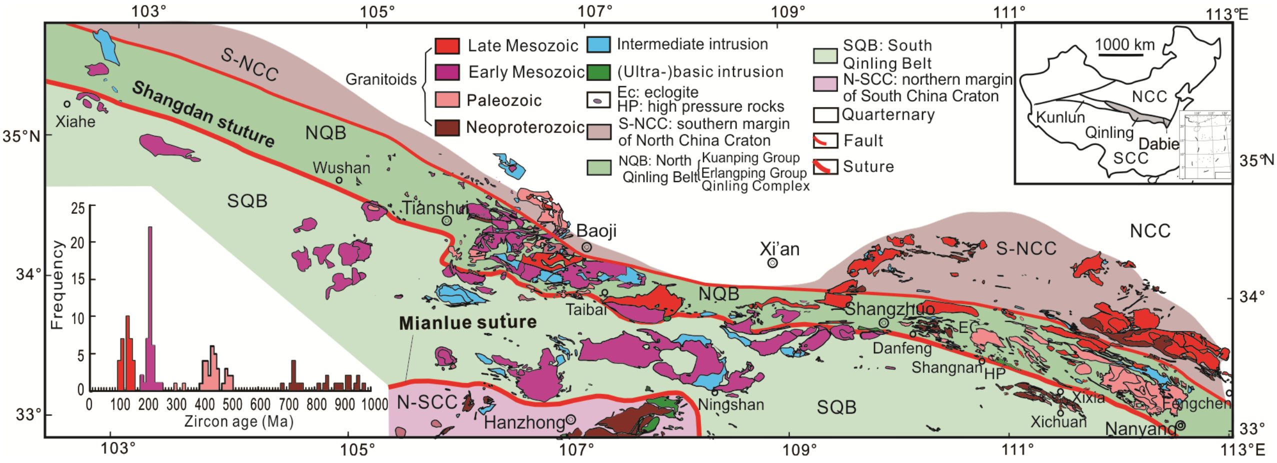
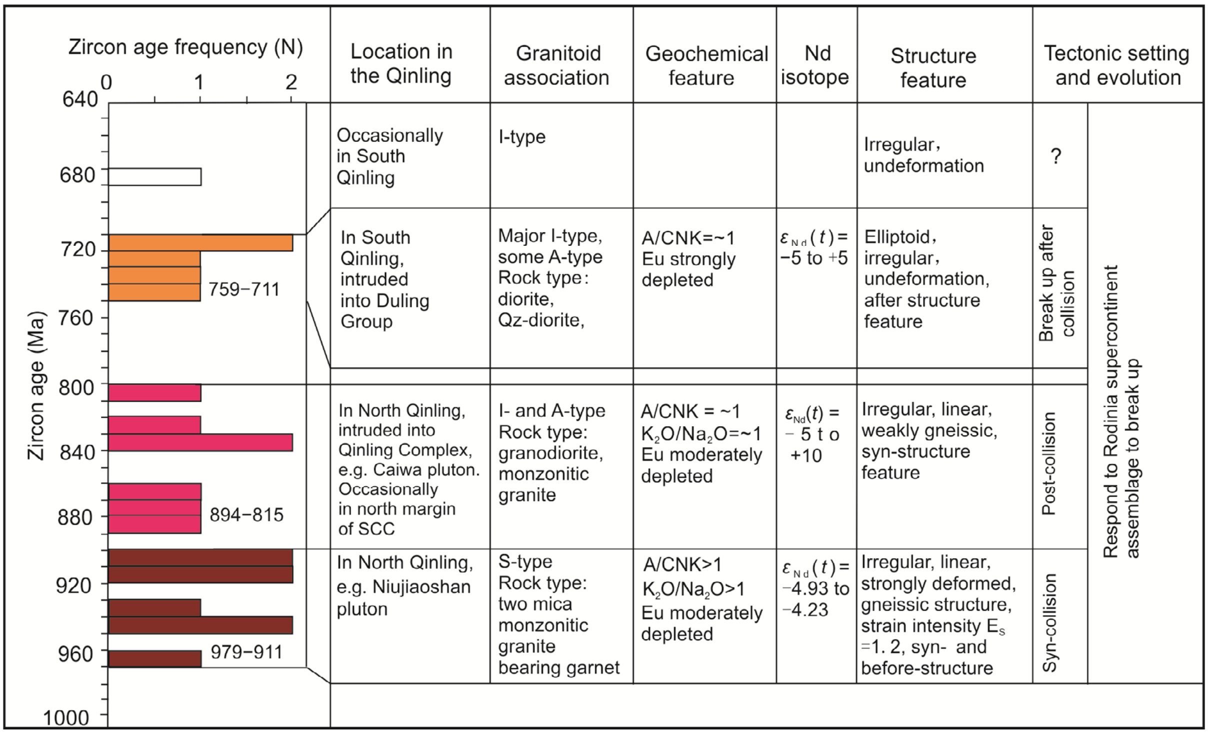


Figure 2 Distribution of the granitoids in the Qinling orogeny. After Wang et al. (2013).



Location in the Qinling	Granitoid association	Geochemical feature	Nd isotope	Structure feature	Tectonic setting and evolution	
Occasionally in South Qinling	I-type			Irregular, undeformation	?	Respond to Rodinia supercontinent assemblage to break up
In South Qinling, intruded into Duling Group	Major I-type, some A-type Rock type: diorite, Qz-diorite,	A/CNK=~1 Eu strongly depleted	$\varepsilon_{Nd}(t)$= −5 to +5	Elliptoid, irregular, undeformation, after structure feature	Break up after collision	
In North Qinling, intruded into Qinling Complex, e.g. Caiwa pluton. Occasionally in north margin of SCC	I- and A-type Rock type: granodiorite, monzonitic granite	A/CNK = ~1 K_2O/Na_2O=~1 Eu moderately depleted	$\varepsilon_{Nd}(t)$ = −5 to +10	Irregular, linear, weakly gneissic, syn-structure feature	Post-collision	
In North Qinling, e.g. Niujiaoshan pluton	S-type Rock type: two mica monzonitic granite bearing garnet	A/CNK>1 K_2O/Na_2O>1 Eu moderately depleted	$\varepsilon_{Nd}(t)$= −4.93 to −4.23	Irregular, linear, strongly deformed, gneissic structure, strain intensity E_s =1. 2, syn- and before-structure	Syn-collision	

Figure 3 Evolution of the Neoproterozoic granitoids in the Qinling orogeny. Age data after Wang et al. (2013), original age data see the references in Wang et al. (2013).

gneissic granitoids or granitic gneisses. Their deformation occurred at 955–929 Ma (Wang et al., 2005). The key evidence is that weakly deformed 929 Ma granitic dikes intrude into the strongly deformed 959 Ma granitic gneisses (Wang et al., 2005), indicating strongly regional deformation occurred during 955–930 Ma and caused the granitoid plutons to granitic gneiss plutons. Besides, continuous transition of the rock fabrics from magmatic flow to high-temperature solid flow is a typical characteristics of syn-tectonic or syn-emplacement deformation plutons (Wang et al., 1998). All these suggest that the granitoids of this stage underwent a strongly deformation process, suggesting a syn-collisional setting. The second stage granitoids show weakly deformation, consequently it suggests no or weak regional deformation further continued during 959–900 Ma.

(3) Evolution on the genetic types of granitoids. The Neoproterozoic granitoids in the Qinling orogen probably change from strongly deformed S-type to weakly deformed I-type then to undeformed A-type from early to late. In the NQB, the granitoids evolved from S-I-S-type then to A-type from 979 to 815 Ma and in the SQB they are of I-A-type granitoids from 759 to 711 Ma. This evolutionary trend is much similar to those of magmatism evolution from a syn- to post- and after-collision.

(4) Other evidence. 1000–973 Ma mafic intrusions have been found in the NQB and are interpreted as the result of subduction (Zhang Z Q et al., 2006).

All these characteristics of the granitoids, particularly their genetic type and deformation evolution as well as the regional geology indicate that the Neoproterozoic magmatic processes can be interpreted as syn-collision (979–911 Ma), post-collision and breakup after collision (759–711 Ma). Strongly deformed Neoproterozoic plutons (920–900 Ma) were also reported in the West Qinling and are considered to be formed in a syn-collisional setting (Pei et al., 2007). The granitoids with ages of 780–680 Ma in the Dabie-Sulu orogen were produced in a breakup setting (e.g., Wu et al., 2004; Zheng et al., 2004, 2005, 2009; Xu et al., 2006; Tang et al., 2008). Therefore, the Neoproterozoic granitoids are widespread not only in the Qinling orogen but also in the whole CCOS. It should be noted that these Neoproterozoic intrusions are recognized as the remnants of early magmatic events identified from the Paleozoic to Mesozoic orogen. Considering the evolutional features of the Neoproterozoic magmatism being similar to that from syn- to post-collisional settings and other evidence from previous studies (e.g., Lu et al., 2003), it is concluded that the Neoproterozoic magmatism in the Qinling orogen suggest a tectonic setting evolved from syn- to post-collision. As to the collision blocks, it is difficult to know and just to be inferred.

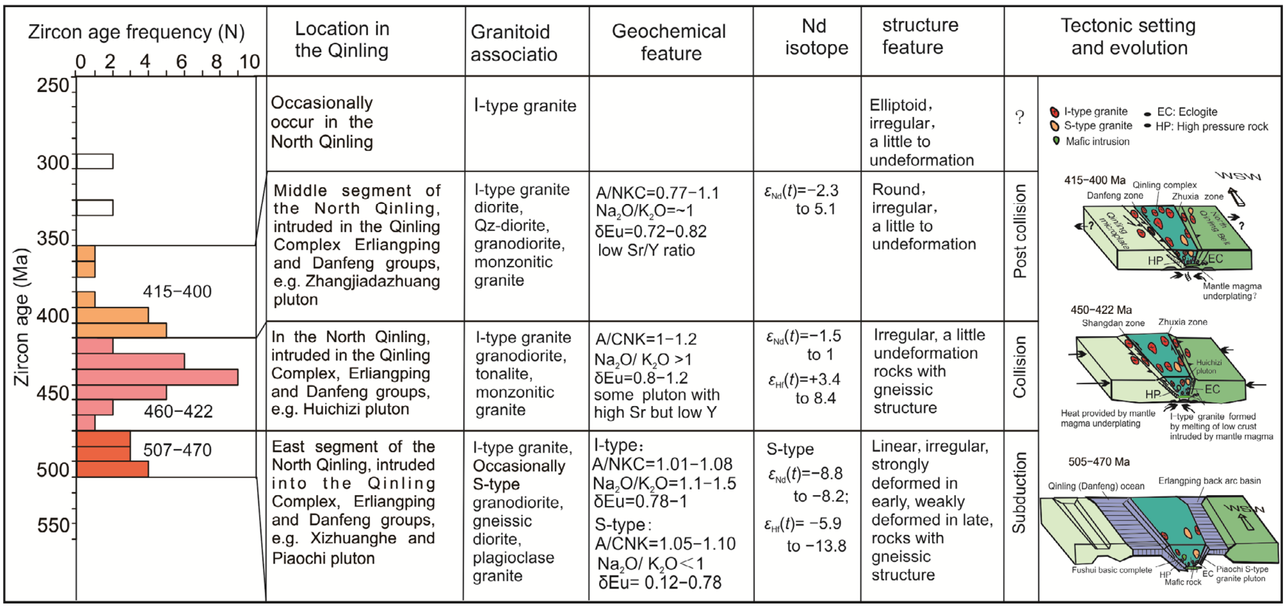
Actually, Neoproterozoic tectonomagmatic events have been widely recognized in the old continents of China, especially in the South China and Tarim cratons and adjacent regions as well as in the Alxa Block (e.g., Geng and Zhou, 2010; Hu et al., 2010; Lu et al., 2003; Zhang and Zheng, 2013; Zheng et al., 2013), and they are regarded as the result of continent assembly and breakup (e.g., Wang T et al., 2003; Lu et al., 2003, 2004; Zhang et al., 2012). Undeformed A-type granitoid plutons (759–711 Ma) and mafic rocks occurred in the SCC and in the Jiangnan ancient continent, and they are interpreted as the response to the breakup of the Rodinia supercontinent (e.g., Li et al., 2008; Wang et al., 2010) or post-collisional extension (e.g., Zheng et al., 2008). Therefore, the Neoproterozoic granitoids and their syn-collisional to post-collisional or breakup settings are closely related to assembly and breakup of South China continent. In the view of these points, some researchers considered that the Qinling Complex (North Qinling unit) were derived from the breakup of South China continent, and the microcontinent represented by the Qinling Complex could not be collided with the NCC along the position of the Kuanping Group at this period (e.g., Lu et al., 2003; Wu and Zheng, 2013). Consequently, the Neoproterozoic magmatism in the Qinling orogen can be considered as records of the early (Proterozoic) magmatic events inherited from the breakup of the Gondwana supercontinent in Paleozoic. In recent year, the Neoproterozoic granitoids were also found within and in the southern margin of the NCC (e.g., Zhai et al., 2014), including hornblende-bearing granites in the Nangrim Block of Korea (1195 Ma, Zhao et al., 2006). These magmatic events are weak and seem to be just related to breakup magmatic events (Zhai et al., 2014). As a whole, the Qinling Neoproterozoic magmatic events are similar to the coeval magmatic events in and around the South China and Tarim cratons, and in the Alxa Blok as well as in the southeastern Baltic Sea and eastern India (e.g., Boger et al., 2000; Jayananda et al., 2000). All of them are likely the response to the assembly and breakup of the Rodinia supercontinent (e.g., Zheng et al., 2013). Accordingly, the Qinling Neoproterozoic tectonomagmatic events are considered to belong to a part of magmatic events related to the assembly and breakup of the Rodinia supercontinent, rather than a part of the Qinling orogen characterized by Paleozoic to Mesozoic orogenic processes.

3 Paleozoic three stages of magmatism—Deep subduction to collision

3.1 Structure, origin and evolution of Paleozoic three-stage granitoid plutons

The Paleozoic granitoids in the Qinling orogen mainly formed at three stages of 507–470, 460–422 and 415–400 Ma (Figure 4, Wang T et al., 2009, 2013, Zhang et al., 2013) on the basis of their zircon U–Pb ages, rock associations and deformation.

The first stage (507–470 Ma) granitoids mainly outcropped in the eastern NQB (Shangnan area) and were intruded into the Qinling Complex. These granitoids, including gneissic granodiorites, tonalites and plagiogranites, are dominated by I-type, with a few S-type granitoid plutons. Mafic rocks are also developed in this period such as the Fushui mafic complex (500–476 Ma, Zhang et al., 2014). These granitoids are characterized by Sr/Y ratios from 50 to 123, high $\varepsilon_{\mathrm{Nd}}(t)$ values (1.5–1.9) but low $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}(t)$ ratios (0.7030–0.7042), suggesting more juvenile crust components in their sources. The S-type granitoids, represented by the Piaochi pluton, are mainly monzogranites and show foliations. They are depleted in Ba but rich in Rb and Th. Their negative $\varepsilon_{\mathrm{Nd}}(t)$ values vary from −8.8 to −8.2 and T_{DM2} from 1.92 to 1.73 Ga, similar to those of inherited zircons and some rocks from the Qinling Complex (2.07–1.90 Ga). Zircon $\varepsilon_{\mathrm{Hf}}(t)$ values of these rocks range from −13.8 to −5.9



Location in the Qinling	Granitoid associatio	Geochemical feature	Nd isotope	structure feature	Tectonic setting and evolution
Occasionally occur in the North Qinling	I-type granite			Elliptoid, irregular, a little to undeformation	?
Middle segment of the North Qinling, intruded in the Qinling Complex Erliangping and Danfeng groups, e.g. Zhangjiadazhuang pluton	I-type granite diorite, Qz-diorite, granodiorite, monzonitic granite	A/NKC=0.77−1.1 Na_2O/K_2O=~1 δEu=0.72−0.82 low Sr/Y ratio	$\varepsilon_{Nd}(t)$=−2.3 to 5.1	Round, irregular, a little to undeformation	Post collision
In the North Qinling, intruded in the Qinling Complex, Erliangping and Danfeng groups, e.g. Huichizi pluton	I-type granite granodiorite, tonalite, monzonitic granite	A/CNK=1−1.2 Na_2O/K_2O >1 δEu=0.8−1.2 some pluton with high Sr but low Y	$\varepsilon_{Nd}(t)$=−1.5 to 1 $\varepsilon_{Hf}(t)$=+3.4 to 8.4	Irregular, a little undeformation rocks with gneissic structure	Collision
East segment of the North Qinling, intruded into the Qinling Complex, Erliangping and Danfeng groups, e.g. Xizhuanghe and Piaochi pluton	I-type granite, Occasionally S-type granodiorite, gneissic diorite, plagioclase granite	I-type: A/NKC=1.01−1.08 Na_2O/K_2O=1.1−1.5 δEu=0.78−1 S-type: A/CNK=1.05−1.10 $Na_2O/K_2O<1$ δEu= 0.12−0.78	S-type $\varepsilon_{Nd}(t)$=−8.8 to −8.2; $\varepsilon_{Hf}(t)$= −5.9 to −13.8	Linear, irregular, strongly deformed in early, weakly deformed in late, rocks with gneissic structure	Subduction

Figure 4 Paleozoic granitoid evolution in the Qinling orogeny. Age data after Wang et al. (2013), original age data see the references in Wang et al. (2013).

and their crustal Hf model ages ($T_{\rm DM}^{\rm C}$) from 2.33 to 1.84 Ga, also similar to those of the Qinling Complex. These indicate that the S-type granitoids were probably derived from the Qinling Complex. Moreover, many folds and deformed leucogranitic dikes occur in the Qinling Complex and are regarded as the partial melting of the gneisses of the complex (Zhang et al., 2013). Clearly, the S-type granitoids of the first stage are closely related to continental crust anatexis.

The second stage (460–422 Ma) granitoids, main parts of the Paleozoic granitoids in the orogen, are widely distributed in the NQB, particularly in its eastern part, and intruded into the Qinling Complex, Erlangping and Danfeng groups. These plutons usually show elliptical or irregular shapes and vary in sizes, small for early (460–450 Ma) plutons and large for later (450–422 Ma) ones, accompanied by mafic plutons (443–434 Ma). The granitoids, including biotite granodiorites, tonalites, quartz diorites and monzogranites, are of I-type affinity. They have ^{87}Sr/^{86}Sr(t) ratios of 0.7036 to 0.706, $\varepsilon_{\rm Nd}(t)$ values of −1.5 to 1 and Mg$^{\#}$ of 0.30 to 0.52, and are depleted in HFSEs (Nb, Zr, Ti) with low Cr content (<129 ppm). These characteristics are very similar to the magmas by the partial melting of mafic eclogite (e.g., Rapp, 1995; Rapp et al., 2008). On the other hand, the granitoids of the Huichizi pluton have many inherited zircons and show large variation in Hf isotopic compositions. All those support that these granitoids were derived from anatexis of crust with the involvement of mantle component.

The third stage granitoids, including diorites, quartz diorites, granodiorites and monzogranites, are located in the middle segment of the NQB and are dominantly I-type. These granitoids show lower ^{87}Sr/^{86}Sr(t) ratios (0.7049–0.706) but higher $\varepsilon_{\rm Nd}(t)$ values (−2.3 to 5.1) than those of second stage and have Mg$^{\#}$ of 0.3 to 0.49 and Cr contents of 7 to 14 ppm, but the diorites with Cr of 9 to 434 ppm. Their sources are interpreted as juvenile components contaminated with old crust. The juvenile components were possibly derived from the newly underplating mafic magmatic rocks or the early mafic rocks intruded in the root of the orogen. Furthermore, the granitoids display weak deformation or none deformation, coincident with those formed in a weak contractional, post-collisional setting.

3.2 Tectonic setting of Paleozoic magmatism—Subduction-collision

The Qinling orogen is characterized by subduction or collision along the Shangdan suture (Meng and Zhang, 1999, 2000; Dong et al., 2011a) or Erlangping suture (e.g., Xue et al., 1996a, 1996b; Ratschbacher et al., 2003) during the early Paleozoic. But the specific timing and processes are still unclear. The three-stage granitoid associations (505–470, 460–422 and 415–400 Ma) and their evolution reveal three-stage orogenic processes.

The first stage of granitoids, developed in the east segment of the NQB, occurred from Cambrian to Early Ordovician (507–470 Ma), and are dominated by I-type granites with subordinate S-type ones. UHP metamorphic rocks such as eclogite (bearing diamond) occur in the northern margin of the Qinling Complex (ca. 490 Ma, Hu et al., 1994; Yang et al., 2003, 2005), and UHP metamorphic rocks derived from continental rocks (ca. 500 Ma, Liu et al., 2010) also occur in the southern margin and middle segment of the Qinling Complex, and they were simply interpreted as a result of plate subduction and collision. Therefore, the mafic intrusions (e.g., Fushui complex, Zhang et al., 2014) and I-type granitoids with arc characteristics suggest a subductional setting. The ca. 500 Ma S-type granitic rocks are coeval with HP metamorphic rocks. The interpretation for this is controversial and there have been at least two explanations. Zhang and Zheng (2013) suggested a deep subduction derived from continent-continental collision at this period, implying that the Shangdan Ocean (Paleo-Tethys Ocean) had been closed. However, whether or not the Shangdan Ocean was closed at this time is an open question, and it needs further evidence for the disappearance of this ocean. The second explanation is an arc-continental collision model (e.g., Wu and Zheng, 2013), implying the collision of the Qinling Complex (or NQB) with Erlangping arc. But this model is difficult to interpret the UHP metamorphism in the southern margin of the Qinling Complex. It seems impossible for a small continent (Qinling Complex) to be subducted under an arc (Erlangping) and to cause UHP metamorphism. We here propose another interpretation, that is, a part of the continent rocks of the NQB was dragged into deep level due to the bidirectional subduction of the Paleo-Tethys Ocean (Shangdan Ocean) and possible Erliangping Ocean, resulted in partial melting of crustal sources and formed (S-type) granitic magmas (e.g., Wang et al., 2013) and UHP metamorphism. This deep subduction occurred along a continent margin. Follow this explanation, a part of the possible Erlangping magmatic arc and Qinling Complex magmatic arc are all part of the huge magmatic arc associated with the subducted Paleo-Tethys Ocean. Under continued subduction, parts of the small continents, represented by the Qinling Complex, might be subducted to deep level and underwent UHP metamorphism. Almost at the same time or immediately thereafter, anatexis occurred during uplift and then formed the S-type granites. Meanwhile the Qinling microcontinent (represented by the Qinling Complex) might be collided with the Erlangping arc. The present models as most studies proposed (e.g., Dong et al., 2011a, 2015; Wu and Zheng, 2013) for the Qinling orogen suggest that the Paleo-Tethys Ocean (Shangdan Ocean) did not closed at this time.

Moreover, the collisional setting for the second stage granitoids also evidences the above interpretation for the first stage granitoids. The second stage granitoid plutons show elliptoid or irregular shapes and weak deformation.

Some plutons, such as the Huichizi pluton, are of adakite-like characteristics, and are interpreted as product of the partial melting of thickened crust (Li et al., 2001). It should be noted that (1) several well-mapped middle Paleozoic plutons within the Qinling Complex show eastward moving of their intrusive centers, indicating eastward movement of magmatism; (2) metamorphism of the Qinling Complex had obvious decompressing phenomenon; (3) structural mapping and analysis indicate dextral-thrust in the Zhuxia tectonic zone along the northern margin of the Qinling Complex and sinistral-thrust in the Shangdan tectonic zone along the southern margin of the Qinling Complex. The above pieces of evidence consistently coincide with orogen-parallel oblique westward ductile extrusion and uplift of the Qinling Complex (Wang et al., 2005), suggesting a collisional and extrusive setting. In other words, the Shangdan Ocean had closed and the continent blocks of both sides had collided along the Shangdan suture.

4 Early Mesozoic magmatism-subduction or collision of the Qinling terrane and SCC

4.1 Two stages of Early Mesozoic magmatism

Early Mesozoic (Triassic) granitoids occurred intensively in the Qinling orogen, especially in the West Qinling. They are grouped by 250–235 and 235–185 Ma, based on zircon U-Pb ages (42 ages), granitoid associations and region geology (Figures 5 and 6).

The first stage (250–235 Ma) granitoids are mainly exposed in the western part of the West Qinling, occasionally in its center, and consist of I-type quartz diorites and plagiogranites. They have $\varepsilon_{\rm Nd}(t)$ values from −9.5 to −6.31 and some of them show high Sr/Y ratios (Jin et al., 2005; Zhang et al., 2008).

The second stage granitoids with clustering at 225–200 Ma are major constituents of the Early Mesozoic granitoids.

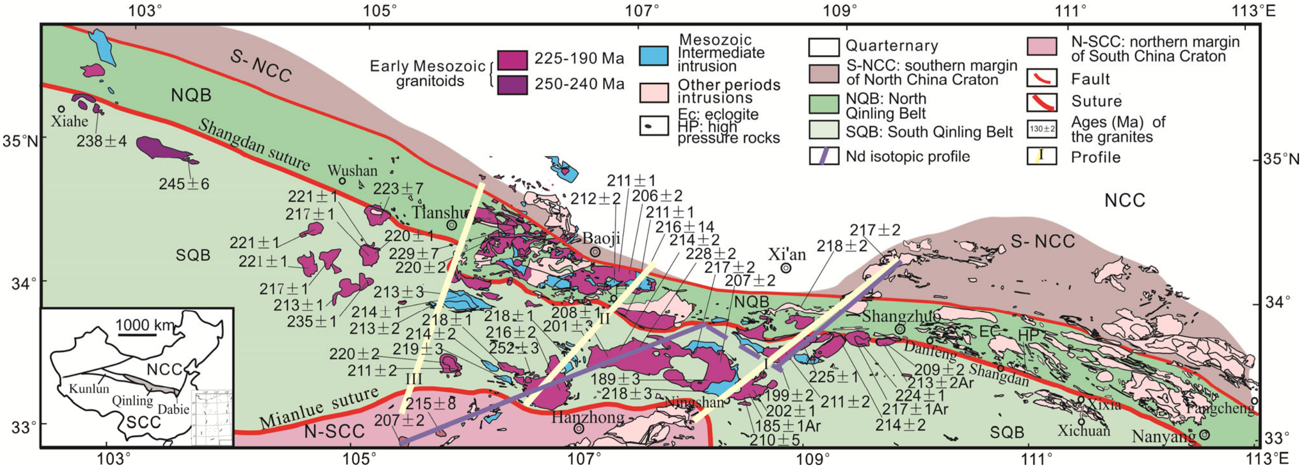
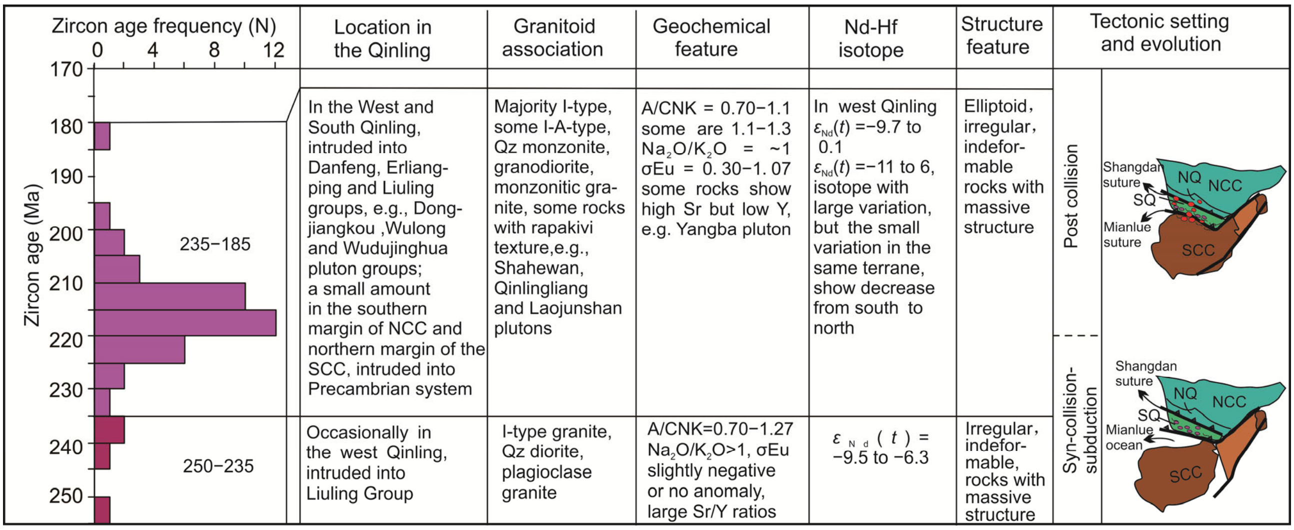


Figure 5 Zircon ages and distribution of the Early Mesozoic granitoids in the Qinling orogeny. Most age data after Wang et al. (2013), original age data see the references in Wang et al. (2013), some ages after Meng et al. (2013), Lv et al. (2014), Nie et al. (2015), Wang S A et al. (2015), and Yang et al. (2015).



Zircon age frequency (N)	Location in the Qinling	Granitoid association	Geochemical feature	Nd-Hf isotope	Structure feature	Tectonic setting and evolution
235−185	In the West and South Qinling, intruded into Danfeng, Erliangping and Liuling groups, e.g., Dongjiangkou ,Wulong and Wudujinghua pluton groups; a small amount in the southern margin of NCC and northern margin of the SCC, intruded into Precambrian system	Majority I-type, some I-A-type, Qz monzonite, granodiorite, monzonitic granite, some rocks with rapakivi texture,e.g., Shahewan, Qinlingliang and Laojunshan plutons	A/CNK = 0.70−1.1 some are 1.1−1.3 Na_2O/K_2O = ~1 σEu = 0. 30−1. 07 some rocks show high Sr but low Y, e.g. Yangba pluton	In west Qinling $\varepsilon_{\rm Nd}(t)$ =−9.7 to 0.1 $\varepsilon_{\rm Nd}(t)$ =−11 to 6, isotope with large variation, but the small variation in the same terrane, show decrease from south to north	Elliptoid, irregular, indeformable rocks with massive structure	Post collision
250−235	Occasionally in the west Qinling, intruded into Liuling Group	I-type granite, Qz diorite, plagioclase granite	A/CNK=0.70−1.27 Na_2O/K_2O>1, σEu slightly negative or no anomaly, large Sr/Y ratios	$\varepsilon_{\rm Nd}(t)$ = −9.5 to −6.3	Irregular, indeformable, rocks with massive structure	Syn-collision-subduction

Figure 6 Evolution of Early Mesozoic granitoids in the Qinling orogeny. Data source is the same as Figure 5.

They widely occur in the West Qinling and South Qinling, occasionally in the East Qinling. These granitoids consist of quartz diorites, quartz monzonites, granodiorites and monzogranites with I-type, I-A-type and even A-type affinities. These granitoids are accompanied with the coeval lamprophyre dikes, suggesting a bimodal association (Wang et al., 2007). Sr-Nd-Hf isotopic compositions of the granitoids show a large variation, with $^{87}Sr/^{86}Sr(t)$ values from 0.70419 to 0.70989, $\varepsilon_{Nd}(t)$ from −9.7 to 0.1 and $\varepsilon_{Hf}(t)$ from −11 to 6, corresponding T_{DM2} of Meso- to Neo-proterozoic (Jiang et al., 2010; Qin et al., 2010; Gong et al., 2009a, 2009b), suggesting Proterozoic sources for them. On contrast, the granitoids in the southern margin of the NCC have very low $\varepsilon_{Nd}(t)$ and $\varepsilon_{Hf}(t)$ values with T_{DM2}^{C} of 2.8–1.8 Ga (Ding et al., 2011; Qi et al., 2012), indicating Archeozoic component sources for these granitoids. These characteristics reveal that the sources for granitoids in the different terranes or blocks are largely depend on the compositions of the terranes or blocks (Wang et al., 2013).

Additionally, some Early Mesozoic granitoids are adakite-like and rapakivi-textured granitoids. The adakite-like granitoids (235–215 Ma) are earlier than the common granitoids (225–210 Ma) (Zhang et al., 2008) and the rapakivi-textured and A-type granitoids produced finally at late upper Triassic (Wang et al., 2013).

4.2 Tectonic setting of the Early Mesozoic magmatism —Subduction or collision?

The tectonic setting of the Early Mesozoic granitoids is still controversial. It is generally interpreted as a syn-orogenic (Sun et al., 2002) or a collision-related setting (Lu, 2000). Most researchers considered that the first stage granitoids were related to subduction of the Mianlue Ocean (Meso-Tethys Ocean) and the second to the late syn-collisional to post-collisional setting of the amalgamation of the SCC and South Qinling micro-block (e.g., Zhang et al., 2008; Dong et al., 2011a, 2011b; Wang et al., 2013). Some researchers proposed that all the Early Mesozoic granitoids were resulted from northward subduction of the Meso-Tethys (Mianlue) Ocean. The major evidence for it was the composition polarity of the Early Mesozoic granitoids, such as from peraluminous S-type to metaluminous I-type granitoids from southwest (SW) to northeast (NE), parallel to the subduction direction (Chen, 2010; Li et al., 2015).

In order to assess this interpretation, we do statistics on ages of the Early Mesozoic granitoids in three profiles across the Qinling orogen (Figure 7). The results indicate that the ages of the Early Mesozoic granitoids do not have much change from the SW to NE across the Qinling orogen, that is, from the northern margin of the SCC to SQB to NQB then to southern margin of the NCC (some even showing an opposite polarity, e.g., profile III in Figure 7).

Statistics of geochemical data also have been done along the age profiles. The ratios of A/CNK and K_2O/Na_2O do not display a polarity change from the SQB through the NQB to the southern margin of the NCC (Figures 8 and 9). A/CNK ratios show a large variation in the SQB in the three profiles, from metaluminous to slightly peraluminous and mostly being slightly peraluminous. The variations of A/CNK ratios in the NQB are much smaller than those in the SQB. However, different profiles show different changes, but most of the A/CNK ratios are around 1.0. The ratios of K_2O/Na_2O of the granitoids in the SQB vary largely, but the changes are quite similar among different profiles. In the NQB the different profiles show different changes in K_2O/Na_2O ratios, such as in profile I the ratios are higher than 1.0, while in profiles II and III less than 1.0, particularly the granitoids in the southern margin of the NCC (Figure 9). The K_2O/Na_2O ratios do not increase for granitoids occurring in the south of Shangdan suture, where directly affected by subduction of the Mianlue Ocean, although the ratios seem to be increased from the SQB to NQB in profile I.

It is notable that $\varepsilon_{Nd}(t)$ values of the granitoids are somewhat decreased from SW to NE across the Qinling orogen. However, the decrease of crust components are not

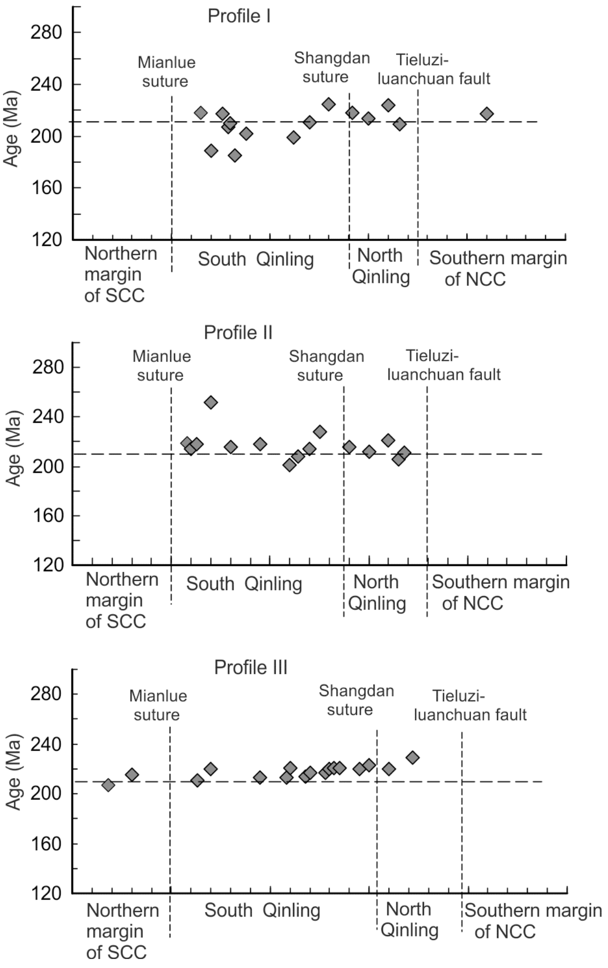


Figure 7 Age variation of the Early Mesozoic granitoids across the Qinling orogeny. Locations of profiles are in Figure 6. Data source is same as in Figure 4.

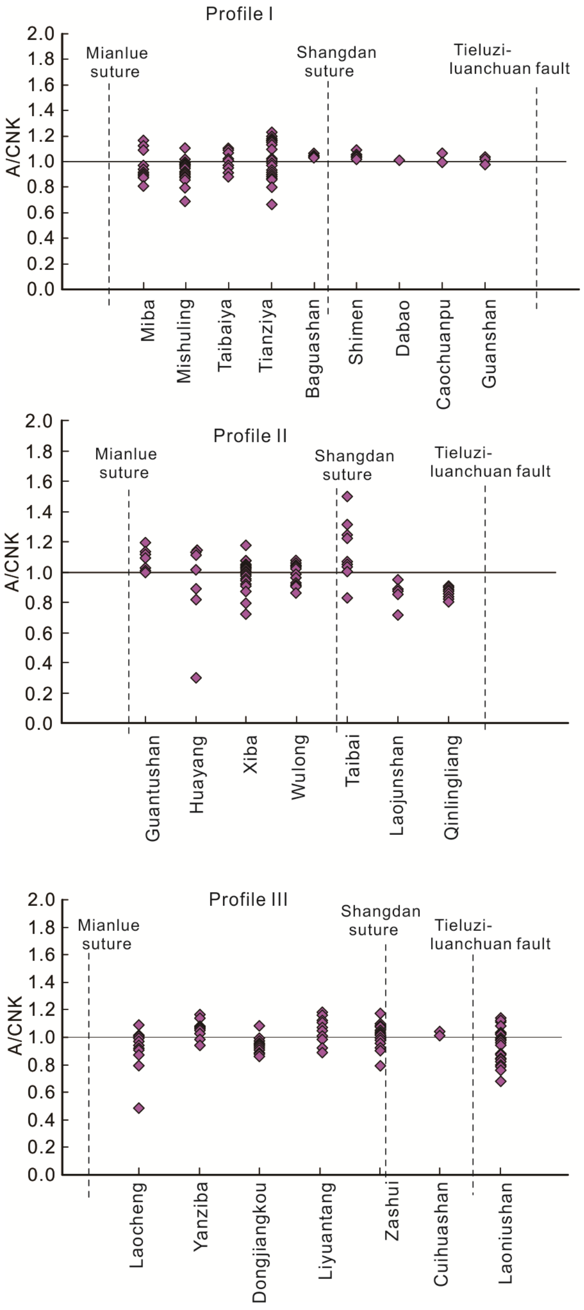


Figure 8 A/CNK ratios of the Early Mesozoic granitoids across the Qinling orogeny. Locations of profiles are in Figure 6. Data source: Jin and Ju (1990); Xiao et al. (2000, 2014); Zhang C L et al. (2002, 2005); Zhang Y et al. (2002); Zhang H F et al. (2005, 2006); Wang X X et al. (2003, 2011); Wang J et al. (2008a, 2008b); Wang Y F et al. (2012); Hu et al. (2004); Li et al. (2004, 2005, 2006, 2007); Bi et al. (2006); Qin et al. (2007, 2009); Gong et al. (2009a, 2009b); Tian et al. (2009); Jiang et al. (2010); Luo et al. (2010); Qin (2010); Ding et al. (2011); Liu et al. (2011, 2014); Liu Z D et al. (2013); Qi et al. (2012); Wei (2011); Dong et al. (2012); Yang et al. (2012); Meng et al. (2013); Ren et al. (2014); Lv et al. (2015); Zhou et al. (2015).

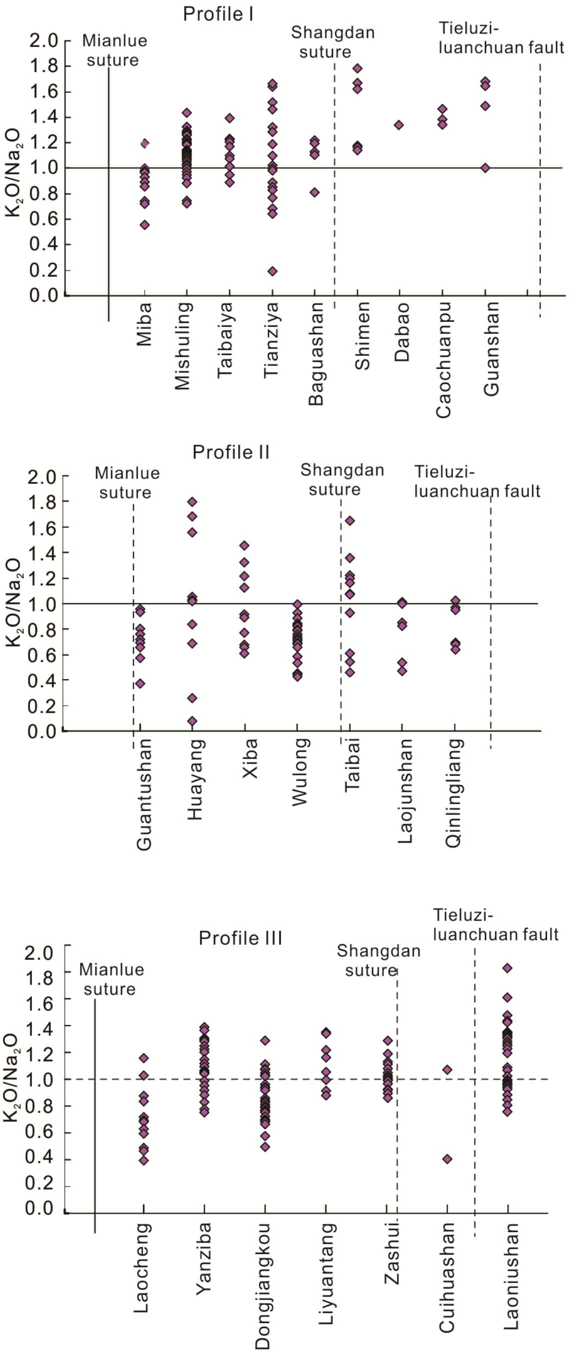


Figure 9 K_2O/Na_2O ratios of the Early Mesozoic granitoids across the Qinling orogeny. Locations of profiles are in Figure 6. Data source is the same as Figure 8.

observed (that is, there is no any change from peraluminous S-type to metaluminous I-type granitoids), whereas an opposite change is identified. For instance, $\varepsilon_{\mathrm{Nd}}(t)$ values of the granitoids gradually decrease from the SQB to the southern margin of the NCC and with small change within the same terranes or blocks. It suggests that $\varepsilon_{\mathrm{Nd}}(t)$ values are probably controlled by deep components of different terranes, e.g., the granitoids with lowest $\varepsilon_{\mathrm{Nd}}(t)$ values are located in the southern margin of the NCC (Figure 10).

Geochemical features are closely related to rock types. The rock types of the Early Mesozoic granitoids are quartz monzonites, granodiorites and monzogranites. Showing unchanged rock types from the SQB to NQB and no compositional polarity in the three profiles. Consequently, their

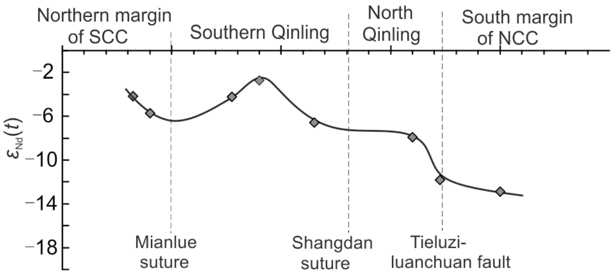


Figure 10 $\varepsilon_{Nd}(t)$ values of the Early Mesozoic granitoids across the Qinling orogen. Locations of profiles are in Figure 6. Data after Wang et al. (2013).

forming ages, rock types and geochemical features of the Early Mesozoic granitoids do not show any polarity change related to subduction. In addition, it should be stressed that compositional polarity of granitoids should be studied in the same tectonic unit or terrane since the compositions of granitoids are controlled predominately by the deep crustal components of different terranes instead of subduction process. For instance, it was previously considered that the Paleozoic granitoids in the Qinling orogen had polarity (e.g., Luo et al., 1993) but more and more researches indicate that this phenomenon is not obvious or does not exist (e.g., Lu, 1998).

Actually, rock types and geochemical compositions of the Early Mesozoic granitoids can temporally be divided into two stages, showing evolution in time at the same terrane or area. The early stage rock association consists of quartz diorites, quartz monzonites and granodiorites and the late monzogranites and rapakivi-textured granitoids. It seems more reasonable to interpret this evolution as a result of the regional tectonic evolution from subduction-related to collision-related (Zhang et al., 2008; Dong et al., 2011b; Wang et al., 2013). Tectonic setting cannot be determined only by geochemical features of granitoids. A comprehensive study of structural pattern, deformation, rock association, geochemical characteristics and regional geology (following) indicates that the granitoids, at least the second stage, occur in a late syn-collisional or post-collisional setting.

(1) Geology of plutons. The Early Mesozoic granitoid plutons are not deformed and cut across region structures. Some plutons show features of stitching plutons (see Han et al., 2010), such as the Shahewan pluton in the Shangdan suture and Guangtuoshan in the Mianlue suture (see Figure 1), suggesting post-kinematic pluton characteristics.

(2) Rock association. The early granitoid association consists mainly of quartz diorites and quartz monzonites and the late monzogranites and some rapapkivi-textured granitoids, such as the Shahewan, Laojunshan and Qinlingliang plutons with the ages of 209 to 214 Ma (Lu et al., 1996; Wang X X et al., 2011). It is generally accepted that rapapkivi-textured granitoids occur in an extensional or stable tectonic settings (e.g., Haapala and Rämö, 1999; Wang X X et al., 2011). Granitoid types change from I- to I- and I-A- or even A-type from early to late. It is in accordance with the common trend of granitoids of collision-related tectonics. Besides, many coeval magamtic enclaves occur in the Early Mesozoic granitoid plutons and some coeval lamprophyre dikes are intruded into the plutons and adjacent strata (ca. 219 Ma Wang et al., 2007), constituting bimodal rock associations.

(3) Geochemistry. The $\varepsilon_{Nd}(t)$ values of the granitoids increase from early to late, suggesting the juvenile components increase with time. This evolution is consistent with increasing underplating of mantle-derived mafic magma from syn-collision to post-collision (Wang et al., 2013).

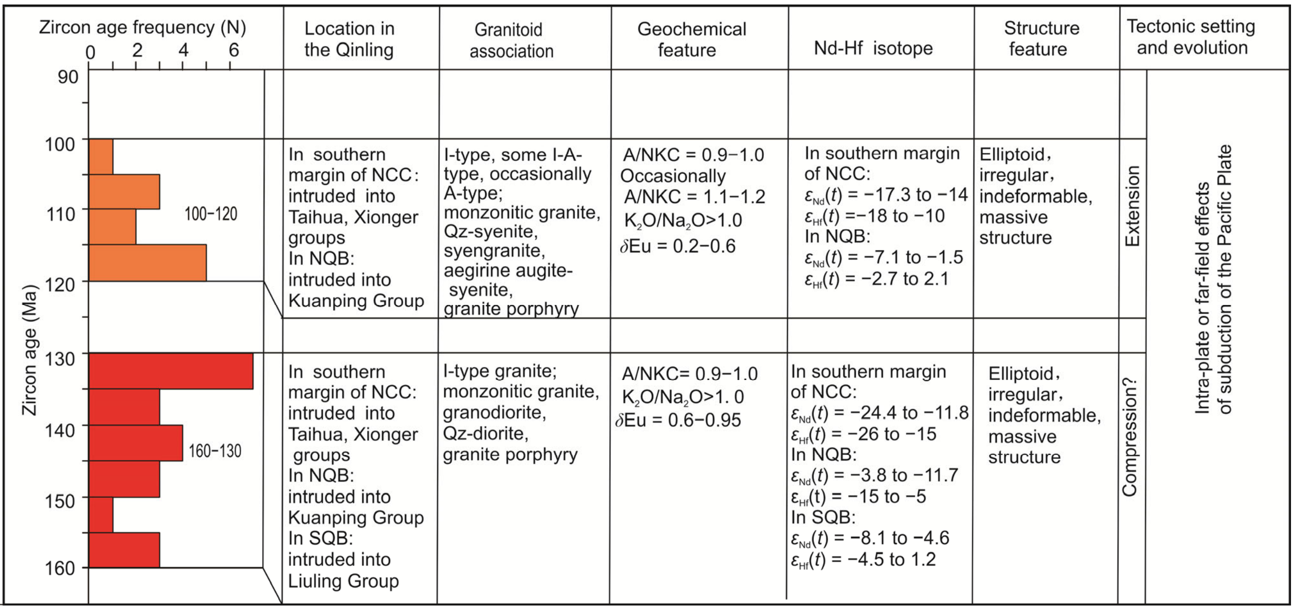
(4) Regional geology. UHP metamorphism occurred from 246 to 244 Ma in the Dabie region (Ames et al., 1993, 1996; Li et al., 1993; Hacker et al., 2000; Liu and Xue, 2007) and the syn-collision is at least in ca. 245 Ma (e.g., Zheng, 2008). Considering the Dabie orogen being not far away from the Qinling orogen, the time differences for the point collision in the Dabie to entire collision by a scissors-like process in the Qinling orogen seems not too long (Zhang et al., 2001). Therefore, the peak time for the collision in the Qinling is probably similar to that in the Dabie, and some pieces of evidence have showed that the collision might take place during ca. 242 to 221 Ma (Li et al., 1996), mainly in Middle Triassic (Ladinian, 234–227 Ma, Zhang et al., 2001). The ages of second stage granitoids were emplaced during 225–185 Ma, ca. 10 to 30 Ma later of the peak collision time. In addition, the ages for retrograde HP mafic granulites in Fuping area of the Qinling is ca. 214 Ma (Liang et al., 2013). All above suggest that the second stage granitoids occurred in a post-collisional setting, or a late syn-collisional setting.

5 Late Mesozoic magmatism—Within plate magmatic event

5.1 Two-stage Late Mesozoic granitoids

Late Mesozoic granitoids are also very developed in the Qinling orogen, especially in the East Qinling, mainly located in the southern margin of the NCC and NQB as batholiths or small plutons and occasionally in the SQB. They can be divided into two stages: 160–130 and 120–100 Ma (Figure 11) (Wang X X et al., 2011, 2013).

The first stage (160–130 Ma) granitic association is predominantly I-type granitoids with some I-A-type ones. Granitic batholiths consist mainly of monzogranites, subordinate granodiorites and quartz diorites with mafic magmatic enclaves. The small plutons are composed of K-feldspar granitic porphyries and granitic porphyries. Their whole-rock $^{87}Sr/^{86}Sr(t)$ values are from 0.69800 to 0.72205, $\varepsilon_{Nd}(t)$ from −24.4 to −11.8 and T_{DM2} from 2.06 to 1.65Ga, showing a large variation. Zircon $\varepsilon_{Hf}(t)$ values of the granitoids range



Location in the Qinling	Granitoid association	Geochemical feature	Nd-Hf isotope	Structure feature	Tectonic setting and evolution	
In southern margin of NCC: intruded into Taihua, Xionger groups In NQB: intruded into Kuanping Group	I-type, some I-A-type, occasionally A-type; monzonitic granite, Qz-syenite, syengranite, aegirine augite-syenite, granite porphyry	A/NKC = 0.9–1.0 Occasionally A/NKC = 1.1–1.2 $K_2O/Na_2O>1.0$ δEu = 0.2–0.6	In southern margin of NCC: $\varepsilon_{Nd}(t)$ = −17.3 to −14 $\varepsilon_{Hf}(t)$ =−18 to −10 In NQB: $\varepsilon_{Nd}(t)$ = −7.1 to −1.5 $\varepsilon_{Hf}(t)$ = −2.7 to 2.1	Elliptoid, irregular, indeformable, massive structure	Extension	Intra-plate or far-field effects of subduction of the Pacific Plate
In southern margin of NCC: intruded into Taihua, Xionger groups In NQB: intruded into Kuanping Group In SQB: intruded into Liuling Group	I-type granite; monzonitic granite, granodiorite, Qz-diorite, granite porphyry	A/NKC= 0.9–1.0 $K_2O/Na_2O>1.0$ δEu = 0.6–0.95	In southern margin of NCC: $\varepsilon_{Nd}(t)$ = −24.4 to −11.8 $\varepsilon_{Hf}(t)$ = −26 to −15 In NQB: $\varepsilon_{Nd}(t)$ = −3.8 to −11.7 $\varepsilon_{Hf}(t)$ = −15 to −5 In SQB: $\varepsilon_{Nd}(t)$ = −8.1 to −4.6 $\varepsilon_{Hf}(t)$ = −4.5 to 1.2	Elliptoid, irregular, indeformable, massive structure	Compression?	

Figure 11 Evolution of Late Mesozoic magmatism. Age data after Wang et al. (2013), original age data see the references in Wang et al. (2013).

from 37.7 to −5.7 with most values between −23.4 and −5.7 and T_{DM}^C from 3.5 to 1.6 Ga, mainly from 2.7 to1.6 Ga.

In the NQB, granitoids of this stage are monzogranites with I-type features. Their $^{87}Sr/^{86}Sr(t)$ values change from 0.70573 to 0.70815 and $\varepsilon_{Nd}(t)$ range from −11.7 to −3.8 with corresponding variable T_{DM2} from 0.99 to 1.57 Ga. Zircon $\varepsilon_{Hf}(t)$ values of the granitoids vary from −17.4 to −7.3 with T_{DM}^C of 2.3 to 1.7 Ga.

In the SQB, the granitoids of this stage consist of diorites, quartz diorites and granitic porphyries. Their $\varepsilon_{Nd}(t)$ values and T_{DM2} are from −8.1 to −4.6 and 1.28 to1.12 Ga, respectively, showing an insignificant variety of Nd isotopic composition.

The second stage granitoids (120–100 Ma) are of I- and I-A-type, even A-type in the southern margin of the NCC. The batholiths are chiefly composed of monzogranites, but the small plutons consist of quartz diorite porphyries, amphibole-quartz syenites, syengranites, aegirine-augite syenites and granitic porphyries. $\varepsilon_{Nd}(t)$ values of the granitoids range from −17.3 to −14.0 with T_{DM2} of 1.88 to 1.70 Ga

In the NQB, the granitoids of this stage are characterized by I-type monzogranites and K-feldspar granites. Their $^{87}Sr/^{86}Sr(t)$ values are from 0.70492 to 0.70688 and $\varepsilon_{Nd}(t)$ from −7.1 to −1.5 with T_{DM2} of 1.65 to 0.79 Ga.

$\varepsilon_{Nd}(t)$ and $\varepsilon_{Hf}(t)$ values of the Late Mesozoic granitoids show a large variation, with $\varepsilon_{Nd}(t)$ values from −18.7 to −1.5 and $\varepsilon_{Hf}(t)$ from −26.3 to 0.1. Nd-Hf isotopic mapping for the Late Mesozoic granitoids in the Qinling orogen indicates that $\varepsilon_{Nd}(t)$ and $\varepsilon_{Hf}(t)$ values of the granitoids are relatively consistent in the same tectonic unit or terrane, suggesting that Nd-Hf isotopic compositions are closely related to deep components of tectonic units or terranes (Wang X X et al., 2011, 2013, 2015). $\varepsilon_{Nd}(t)$ and $\varepsilon_{Hf}(t)$ values of the granitoids increase from the southern margin of the NCC to SQB, implying that juvenile components increase gradually in deep crust towards this direction (Wang X X et al., 2011, 2013, 2015).

5.2 Tectonic setting of the Late Mesozoic magmatism —Circum-Pacific zone?

The evolutional characteristics of the Late Mesozoic granitoids from I- to I-A- and A-type from first to second stage suggests a tectonic transform from contraction to extension during the Jurassic/Cretaceous times. This tectonic transform is consistent with that in the Dabie orogen (Ma et al., 2003), eastern China (Dong et al., 2007) and even northeastern Asian (Wang T et al, 2011, 2012, 2015). It suggests that the Qinling orogen and whole eastern China as well as northeastern Asian share the same geodynamics system in Late Mesozoic. Accordingly, the magmatism of the Late Mesozoic in the Qinling orogen (Jurassic-Cretaceous) is considered as an important part of the huge magmatic belt of the eastern China, possibly associated with the far-field effect of subduction along the western margin (present direction) of the Paleo-Pacific plate. The NW distributional direction of the Late Mesozoic magmatic belt in the Qinling orogen seems different from that in NE Paleo-Pacific zone, and this could be interpreted as magmatic emplacement being controlled by NW pre-existing tectonic faults and zones in the Qinling orogen.

6 Conclusions

Based on the zircon ages, rock associations, evolution of genetic types and deformation of the granitoids as well as region geology, the evolution of magmatism and tectonic settings in the Qinling orogen can be summarized as following.

(1) Neoproterozoic granitoids changed from strongly deformed S-type (979–911 Ma) to weakly deformed I-type (894–815 Ma) and finally to undeformed A-type (759–711 Ma) in the Qinling orogen is consistent with a tectonic evolution from syn-collision to post-collision, showing that some old continent terranes or blocks within the Qinling orogen recorded the Neoproterozoic tectonomagmatic events similar to those in the SCC and adjacent old continent blocks. These events were most likely in response to the assemblage and breakup of the Rodinia supercontinent. The old continent terrane or block in the Qinling was involved into the Phanerozoic Qinling orogen. Consequently, the Neoproterozoic magmatism recorded in the old terrane in the Qinling might not belong to the product of the Qinling orogenic process.

(2) The Paleozoic magmatism can be subdivided into three stages (507–470, 460–422 and 415–400 Ma), corresponding to the bidirectional subduction to collision processes of the Shangdan (Paleo-Tethys) and Erliangping oceans. The first stage granitoids are characterized by S- and I-types, accompanied by mafic intrusions with arc features and UHP metamorphism. The granitoids were probably derived from the partial melting of continental rocks dragged to a deep level and exhumation later during subduction along a continental margin (the Qinling Complex to NCC). The second stage granitoids are mainly of I-type affinity and some plutons show the eastward movement of their intrusion centers. All these pieces of evidence, together with the oblique westward ductile extrusion and uplift of the Qinling Complex, support a collisional setting. The third stage granitoids, consequently, occurred in a post-collisional setting.

(3) The Early Mesozoic granitic rocks can be summarized as two stages (250–240 and 225–185 Ma). The first stage granitoids are composed of I-type granitoids, and probably formed in a subductional setting during the closure of the Mianlue (Meso-Tethys) Ocean. The second stage granitoids are characterized by I- and I-A-type granitoids, some of which are adakite-like (235–215 Ma) or rapapkivi-textured (210–217 Ma) granitoids. The magmatism of this stage occurred in a late syn-collisional or post-collisional setting. The genetic types of the granitoids change from I- to I-A-type from the first to second stage. The Early Mesozoic granitoids in the Qinling orogen do not show any regular age and compositional polarities related to the northward subduction of the Mianlue Ocean.

(4) The Late Mesozoic magmatism also shows two distinct stages (158–130 and 120–100 Ma). The genetic types of the granitoids change from I- to I-A- and A-type from early to late, corresponding to the transition from contractional to extensional setting during Jurassic/Cretaceous time. These magmatic rocks probably belong to the huge magmatic belt in the eastern China along the western Pacific margin, i.e., intra-continent magmatism related to a far-field effect of the subduction of Paleo-Pacific plate or intra-continent magmatism. The Late Mesozoic NW magamtic belt in the Qinling orogen is different from the NE Paleo-Pacific magamtic belt, and it may be a result of magmatic emplacement along the pre-existed tectonic faults and zones in the Qinling orogen.

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