Early Yanshanian post-orogenic granitoids in the Nanling region

——Petrological constraints and geodynamic settings

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Abstract Early Yanshanian magmatic suites predominate absolutely in the Nanling granite belt. They consist mainly of monzogranite and K-feldspar granite. There occur associations of early Yanshanian A-type granitoids (176 Ma—178 Ma) and bimodal volcanic rocks (158 Ma—179 Ma) in southern Jiangxi and southwestern Fujian in the eastern sector of the granite belt and early Yanshanian basalts (177 Ma—178 Ma) in southern Hunan in the central sector of the belt. Both the acid end-member rhyolite in the bimodal volcanic rock association and A-type granitoids in southern Jiangxi have the geochemical characteristics of intraplate granitic rocks and the basic end-member basalt of the association is intraplate tholeiite, while the basaltic rocks in southern Hunan include not only intraplate tholeiite but also intraplate alkali basalt. Therefore the early Yanshanian magmatic suites in the Nanling region are undoubtedly typical post-orogenic rock associations. Post-orogenic suites mark the end of a post-collision or late orogenic event and the initiation of Pangaea break-up, indicating that a new orogenic Wilson cycle is about to start. Therefore it may be considered that the early Yanshanian geodynamic settings in the Nanling region should be related to post-orogenic continental break-up after the Indosinian orogeny and the break-up did not begin in the Cretaceous.

Keywords: granite, post-orogenic, early Yanshanian, Nanling.

It was generally considered that pre-Late Cretaceous geodynamic settings in southeastern China during the Late Mesozoic were related to the subduction of the Kula plate or Izanagi plate^[1-7], belonging to Andean-type continental margins^[8,9] and after the end of the subduction in the Late Cretaceous, the lithosphere began to extend, inducing eruption of bimodal volcanic rocks^[10] and emplacement of A-type granitoids^[11,12] along the coastal areas of Zhejiang and Fujian. Therefore geologists proposed that the earliest break-up of the continent of southeastern China during the Mesozoic took place in the late Yanshanian, ~120 Ma—140 Ma ago^[13-15]. In this paper we suggest that the early Yanshanian granitoids in the Nanling region have the typical characteristics of post-orogenic granite associations; especially the occurrence of early Yanshanian A-type volcanic-intrusive complexes and bimodal volcanic rock associations in southern Jiangxi and occurrence of contemporaneous basaltic magmatism in southwestern Fujian, northeastern Guangdong and southern Hunan suggest that extensional break-up of the lithosphere took place in South

China in the early Yanshanian, i.e. Jurassic.

1 Geological settings

Geographically, Nanling refers to a general E-W-trending mountain system composed of the Yuechengling, Dupangling, Mengzhuling, Qitianling and Dayuling on the Hunan-Guangxi, Hunan-Guangdong and Jiangxi-Guangdong borders (fig. 1) and is a divide between the Yangtze drainage system and the Zhujiang drainage system.

Since the Early Palaeozoic this region has undergone strong influences of the Caledonian orogeny, Indosinian orogeny and Yanshanian tectono-magmatism, forming granitoids of different ages and rich mineral resources. The Indosinian orogeny occurring in the Middle Triassic brought about the final complete amalgamation of the Yangtze plate and Cathaysian plate^[16,17], thus giving rise to the unifying South China continent. Afterwards the region entered the stage of intraplate continental dynamic evolution.

In this region granitic rocks predominate absolutely, with small amount of basaltic rocks exposed. Three granite belts traverse the region from east to west^[18] and affect Hunan, Guangxi, Jiangxi, Guangdong and Fujian. The Nanling region is also an important production base of W, Sn, Bi, REE, U, Cu, Pb and Zn minerals, where large numbers of large and superlarge rare metal and nonferrous metal deposits have been controlled^[19].

2 Distribution characteristics of granitoids of different ages in the Nanling region

The Nanling granitoids and mineral resources have long been studied and many important achievements have been scored^[18–23]. On the basis of previous studies, combining with our recent study of A-type granitoids and bimodal volcanic rocks in the eastern sector of the Nanling region, i.e. southern Jiangxi, and 99 isotopic age data of granitoids published in the last ten-odd years (table 1)^[23–52], we have further determined the ages and distribution characteristics of granitoids in the Nanling region (which is largely confined to latitudes 26°—23°20′N and longitudes 110°—118°E, covering an area of ~210000 km², where granite bodies extend obviously in an E-W direction) (fig. 1) and got the following understanding.

- (1) Caledonian granitoids mainly distribute in the Hunan-Jiangxi, Fujian-Jiangxi and Guangxi-Guangdong border areas in the Wuyi and Yunkai Caledonian uplifts^[16] and in the Hunan-Guangxi border area near the suture zone between the Yangtze plate and Cathaysian plate. They do not show the pattern of E-W-trending belt-like distribution. Hercynian-Indosinian granitoids generally occur in areas adjoining the Caledonian uplifts and their peripheral Hercynian depressions^[16], e.g. the border areas of Fujian, Jiangxi, Guangdong and Hunan on the peripheries of the Wuyi Caledonian uplift and southern Guangxi and the Guangxi-Guangdong border area on the peripheries of the Yunkai Caledonian uplift. They do not show the pattern of E-W-trending belt-like distribution either.
 - (2) Granitoids at the first stage (180 Ma—155 Ma) of the early Yanshanian mainly distribute

Table 1 Isotopic ages of Nanling granites

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55 Qingxi biotite granite 147 U-Th-Pb Yie Bodan et al., 1986 ^[31]						Granite Subject Group, 1989[23]			
56 Jingwei biotite granite 145 U-Th-Pb Yie Bodan et al., 1986 ^[31]	56	Jingwei	biotite granite	145					

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Serial Locality Rock name Age/Ma Method Data sources						(Continued)
58 Longwo granodiorite 165 Rb-Sr Zhao Zijie et al., 1987 ^[57] 59 Luogang biotite granite 128 Rb-Sr Yie Bodan et al., 1986 ^[51] 60 Shangdianzi biotite granite 128 Rb-Sr Yie Bodan et al., 1986 ^[51] 61 Lianhusahan granodiorite 412 Rb-Sr Yie Bodan et al., 1986 ^[51] 63 Anxi granodiorite 412 Rb-Sr Chen Periong, 1988 ^[52] 64 Aigao biotite granite 256 Rb-Sr Chen Periong et al., 1987 ^[53] 65 Baimianshi two-mica granite 250 Rb-Sr Chen Periong et al., 2000 ^[53] 66 Dafuzhu biotite K-feldspar granite 176 Rb-Sr Regional Geological Research Party of Jiangxi, 1990 ^[6] 68 Zhaibei biotite K-feldspar granite 176 Rb-Sr Rb-Sr Rb-Sr Party of Jiangxi, 1990 ^[6] Regional Geological Research Party of Jian		Locality	Rock name	Age/Ma	Method	
59 Luogang biotite monzogranite 126 U-Th-Pb Vie Bodan et al., 1986 137 Rb-Sr Vie Bodan et al., 1986 138 13	57	Baipu	biotite granite	139	U-Th-Pb	Yie Bodan et al., 1986 ^[31]
	58	Longwo	granodiorite	165	Rb-Sr	Zhao Zijie et al., 1987 ^[37]
61 Lianhushan granite 137 Rb-Sr Yie Bodan et al., 1986 ^[31]	59	Luogang	biotite monzogranite	126	U-Th-Pb	Yie Bodan et al., 1986 ^[31]
	60	Shangdianzi	biotite granite	128	Rb-Sr	
62 Shangyou biotite granite 377 K-Ar Granic Subject Group, 1989 ^[23] 63 Anxi granodiorite 412 Rb-Sr Chen Peirong et al., 1989 ^[83] 64 Aigao biotite Kreldspar granite 250 Rb-Sr Chen Peirong et al., 1989 ^[83] 66 Dafuzhu biotite Kreldspar granite 216 Rb-Sr Chen Peirong et al., 1989 ^[83] 67 Dafuzhu biotite Kreldspar granite 176 Rb-Sr Chen Peirong et al., 1989 ^[83] 68 Zhaibei biotite Kreldspar granite 176 Rb-Sr Chen Peirong et al., 1989 ^[83] 70 Guanxi biotite Kreldspar granite 176 Rb-Sr Chen Peirong et al., 1989 ^[83] 71 Zhudong two-mica alkaline-feldspar granite 176 Rb-Sr Huang Dianhao et al., 1989 ^[84] 72 Keshubei biotite Kreldspar granite 158 Rb-Sr Sun Gongan et al., 1989 ^[84] 73 Dajishan muscovite alkaline-feldspar granite 157 Rb-Sr Sun Gongan et al., 1989 ^[84] 75 Dajishan			granite	137	Rb-Sr	Yie Bodan et al., 1986 ^[31]
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63 Anxi granodiorite 412 Rb-Sr. Chen Peirong, 19986 ³³ 64 Ajgao biotite granite 250 Rb-Sr. Chen Peirong et al., 1989 ³⁸ 65 Baimianshi two-mica granite 250 Rb-Sr. Chen Peirong et al., 1989 ³⁸ 66 Dafuzhu biotite K-feldspar granite 216 Rb-Sr. Regional Geological Research Party of Jiangxi, 1990 ⁰¹ 68 Zhaibei biotite K-feldspar granite 176 Rb-Sr. Regional Geological Research Party of Jiangxi, 1990 ⁰¹ 70 Guanxi biotite K-feldspar granite 176 Rb-Sr. Fen Chunfel Geological Research Party of Jiangxi, 1990 ⁰¹ 71 Zhudong two-mica Keldspar granite 176 Rb-Sr. Fen Chunfel geriong et al., 1989 ⁰¹² 71 Zhudong two-mica Keldspar granite 148 Rb-Sr. Huang Dianhao et al., 1989 ⁰¹² 71 Zhidong two-mica Keldspar granite 159 Rb-Sr. Snb Gongan et al., 1989 ⁰¹⁴ 72 Keshabei biotite K-feldspar granite 167 Rb-Sr. Sun Gongan et al., 1989 ⁰¹⁴	62	Shangyou	biotite granite	377	K-Ar	Granite Subject Group, 1989 ^[23]
65 Baimianshi two-mica granite 250 Rb-Sr Chen Peirong et al., 2000 ^[59] 66 Dafuzhu biotite K-feldspar granite 230 Rb-Sr Regional Geological Research Parry of Jiangxi, 1990 ^[6] 67 Dafuzhu biotite k-feldspar granite 178 Rb-Sr Regional Geological Research Parry of Jiangxi, 1990 ^[6] 68 Zhaibei biotite K-feldspar granite 176 Rb-Sr Chen Peirong et al., 1989 ^[6] 70 Quanxi biotite granite 176 Rb-Sr Huang Dianhao et al., 1989 ^[6] 71 Zhudong two-mica alkaline-feldspar granite 148 Rb-Sr Huang Dianhao et al., 1989 ^[6] 72 Keshubei biotite granite 158 Rb-Sr Huang Dianhao et al., 1989 ^[6] 73 Dajishan muscovite alkaline-feldspar granite 161 Rb-Sr Sun Gongan et al., 1989 ^[6] 74 Dajishan two-mica K-feldspar granite 161 Rb-Sr Sun Gongan et al., 1989 ^[6] 75 Dajishan biotite monzogranite 157 Rb-Sr Sun Gongan et al., 1989 ^[6]	63	Anxi	granodiorite	412	Rb-Sr	Chen Peirong, 1998 ^{c)}
66	64	Aigao	biotite granite	256	Rb-Sr	Chen Peirong et al., 1989 ^{[38}]
67 Dafuzhu biotite monzogranite 230 Kb-St Party of Jiangxi, 1990 ⁴⁹ 68 Zhaibei biotite K-feldspar granite 176 Kb-St Party of Jiangxi, 1990 ⁴⁹ 68 Zhaibei biotite K-feldspar granite 176 Kb-St Chen Peirong et al., 1998 ⁴⁴⁰ 70 Guanxi biotite alkaline-feldspar granite 176 Kb-St Huang Dianhao et al., 1989 ⁴⁴¹ 71 Zhudong two-mica alkaline-feldspar granite 186 Kb-St Huang Dianhao et al., 1989 ⁴⁴² 71 Zhudong two-mica alkaline-feldspar granite 187 Kb-St Huang Dianhao et al., 1989 ⁴⁴³ 72 Keshubei biotite granite 158 Kb-St Huang Dianhao et al., 1989 ⁴⁴³ 73 Dajishan muscovite alkaline-feldspar granite 159 Kb-St Sun Gongan et al., 1989 ⁴⁴³ 74 Dajishan two-mica K-feldspar granite 161 Kb-St Sun Gongan et al., 1989 ⁴⁴³ 75 Dajishan biotite M-feldspar granite 167 Kb-St Sun Gongan et al., 1989 ⁴⁴³ 76 Xihuashan biotite K-feldspar granite 151 Kb-St Chen Zhixiong et al., 1989 ⁴⁴⁴ 77 Xihuashan biotite K-feldspar granite 159 Kb-St Chen Zhixiong et al., 1989 ⁴⁴⁴ 80 Sanbiao biotite granite 139 Kb-St Chen Zhixiong et al., 1989 ⁴⁴⁴ 81 Lanshan quartz syenite 156 K-Ar Haiquin et al., 1999 ⁴⁴⁵ 82 Shangchun monzogranite 166 Kb-St Chen Zhixiong et al., 1989 ⁴⁴⁶ 83 Zhongchun two-mica monzogranite 167 Rb-St Chen Zhixiong et al., 1989 ⁴⁴⁷ 84 Yuanling biotite granite 153 K-Ar Mei Yongwen et al., 1994 ⁴⁶⁰ 85 Jiuqu two-mica granite 169 U-Th-Pb Regional Geological Research Party of Jiangxi, 1990 ⁹⁰ 86 Danguanzhang biotite monzogranite 144 Rb-St Haiquin et al., 1990 ⁴⁷¹ 87 Maoziding biotite monzogranite 123 Kb-St He Bochu et al., 1990 ⁴⁷¹ 88 Yanbei granite 123 Kb-Sr He Bochu et al., 1990 ⁴⁷¹ 89 Yanbei granite 123 Kb-Sr He Bochu et al., 1990 ⁴⁷¹ 99 Weipu biotite monzogranite 146 Kb-Sr Granite Subject Group, 1980 ²³¹ 90 Zhenfengding biotite monzogranite 146 Kb-Sr Granite Subject Group, 1980 ²³¹ 91 Weipu biotite monzogranite 146 Kb-Sr Granite Subject Group, 1980 ²³¹ 94 Yongding granite 146 Kb-Sr Granite Subject Group, 1980 ²³¹ 95 Hetian biotite monzogranite 146 Kb-Sr Granite Subject Group, 1980 ²³¹ 96 Juzhou K-feldspar granite 1	65	Baimianshi	two-mica granite	250	Rb-Sr	Chen Peirong et al., 2000 ^[39]
68 Zhaibei biotite K-feldspar granite 178 Rb-Sr Chen Peirong et al., 1990 ⁽⁴⁾ 69 Pitou biotite K-feldspar granite 176 Rb-Sr Acceptable 170 Guanxi biotite alkaline-feldspar granite 176 Rb-Sr Huang Dianhao et al., 1989 ⁽⁴²⁾ 71 Zhudong two-mica alkaline-feldspar granite 188 Rb-Sr Huang Dianhao et al., 1989 ⁽⁴²⁾ 72 Keshubei biotite granite 158 Rb-Sr Huang Dianhao et al., 1989 ⁽⁴²⁾ 73 Dajishan muscovite alkaline-feldspar granite 159 Rb-Sr Sun Gongan et al., 1989 ⁽⁴³⁾ 74 Dajishan biotite monzogranite 161 Rb-Sr Sun Gongan et al., 1989 ⁽⁴³⁾ 75 Dajishan biotite M-feldspar granite 151 Rb-Sr Sun Gongan et al., 1989 ⁽⁴³⁾ 76 Xihuashan biotite K-feldspar granite 151 Rb-Sr Sun Gongan et al., 1989 ⁽⁴⁴⁾ 78 Xihuashan biotite K-feldspar granite 151 Rb-Sr Chen Zhixiong et al., 1989 ⁽⁴⁴⁾ 79 Piaotang biotite granite 156 K-Ar Li Huaqin et al., 1989 ⁽⁴⁴⁾ 80 Sanbiao biotite granite 156 K-Ar Li Huaqin et al., 1993 ⁽⁴⁴⁾ 81 Lanshan quartz syenite 175 U-Th-Pb 82 Shangchun monzogranite 146 Rb-Sr Regional Geological Research Party of Jiangxi, 1990 ⁽⁹⁾ 84 Yuanling biotite granite 169 U-Th-Pb 85 Jiuqu two-mica monzogranite 169 U-Th-Pb 86 Danguanzhang biotite granite 123 Rb-Sr He Bochu et al., 1990 ⁽⁴⁷⁾ 88 Tongkengzhang granite 123 Rb-Sr He Bochu et al., 1990 ⁽⁴⁷⁾ 88 Tongkengzhang granite 123 Rb-Sr He Bochu et al., 1990 ⁽⁴⁷⁾ 89 Yanbei granite 123 Rb-Sr He Bochu et al., 1990 ⁽⁴⁷⁾ 90 Zhenfengding biotite monzogranite 146 Rb-Sr Chen Eniming et al., 1990 ⁽⁴⁷⁾ 91 Weipu biotite monzogranite 145 Rb-Sr Lingangi Bureau of Geology and Mineral Resources, 1984 ⁽⁹⁾ 91 Weipu biotite monzogranite 123 Rb-Sr He Bochu et al., 1990 ⁽⁴⁷⁾ 91 Weipu biotite monzogranite 146 Rb-Sr Chen Eniming et al., 1990 ⁽⁴⁷⁾ 92 Wuying granite 123 Rb-Sr Lingangi Bureau of Geology and Mineral Resources, 1985 ⁽⁹⁾ 93 Xiaotao granite 146 Rb-Sr Chen Eniming et al., 1999 ⁽⁴⁸⁾ 94 Yongding granite 146 Rb-Sr Chen Eniming et al., 1999 ⁽⁴⁹⁾ 95 Heltian biotite monzogranite 146 Rb-Sr Granite Subject Group, 1980 ⁽²³⁾ 96 Juzhou K-feldspar granite 158 Rb-Sr Mao Jianren et al	66	Dafuzhu	biotite K-feldspar granite	230	Rb-Sr	Party of Jiangxi, 1990 ^{d)}
69 Pitou biotite K-feldspar granite 176 Rb-Sr Fan Chunfang et al., 2000 ^[41] 70 Guanxi biotitie alkaline-feldspar granite 176 Rb-Sr Huang Dianhao et al., 1989 ^[42] 71 Zhudong two-mica alkaline-feldspar granite 148 Rb-Sr Chen Peirong, this paper 173 Dajishan muscovite alkaline-feldspar granite 158 Rb-Sr Chen Peirong, this paper 174 Dajishan two-mica K-feldspar granite 161 Rb-Sr Sun Gongan et al., 1989 ^[43] 81 Dajishan biotite monzogranite 167 Rb-Sr Sun Gongan et al., 1989 ^[43] 81 Sun Gongan et al., 1989 ^[43] 82 Sun Gongan et al., 1989 ^[43] 83 Sun Gongan et al., 1989 ^[43] 84 Rb-Sr Chen Zhixiong et al., 1989 ^[44] 86 Sanbiao biotite K-feldspar granite 151 Rb-Sr Chen Zhixiong et al., 1989 ^[44] 87 Piaotang biotite granite 156 K-Ar Li Huaqin et al., 1989 ^[44] 80 Sanbiao biotite K-feldspar granite 156 K-Ar Li Huaqin et al., 1989 ^[44] 80 Sanbiao biotite granite 153 K-Ar Mei Yongwen et al., 1994 ^[46] 81 Lanshan quartz syenite 175 U-Th-Pb Regional Geological Research Party of Jiangxi, 1990 ^[60] 82 Shangchun two-mica monzogranite 166 Rb-Sr Regional Geological Research Party of Jiangxi, 1990 ^[60] 85 Jiuqu two-mica granite 166 U-Th-Pb Mineral Resources, 1984 ^[60] 188 Tongkengzhang 88 Tongkengzhang 89 Yanbei granite 123 Rb-Sr Mei Yongwen et al., 1990 ^[47] 1990 Wipu biotite granite 123 Rb-Sr Mei Yongwen et al., 1990 ^[47] 1990 Wipu biotite monzogranite 166 Rb-Sr Ling Hongfei et al., 1990 ^[47] 1990 Wipu biotite monzogranite 166 Rb-Sr Ling Hongfei et al., 1990 ^[47] 1990 Wipu biotite monzogranite 166 Rb-Sr Ling Hongfei et al., 1990 ^[47] 1990 Wipu biotite monzogranite 146 Rb-Sr Charles Subject Group, 1980 ^[23] 1990 Wipu biotite monzogranite 146 Rb-Sr Granite Subject Group, 1980 ^[23] 1990 Wipu Botite monzogranite 166 Rb-Sr Ling Hongfei et al., 1990 ^[47] 1991 Weipu biotite monzogranite 160 Rb-Sr Ling Hongfei et al., 1990 ^[47] 1991 Weipu biotite monzogranite 146 Rb-Sr Granite Subject Group, 1980 ^[23] 1991 Polyang granite 146 Rb-Sr Granite Subject Group, 1980 ^[23] 1991 Polyang granite 146 Rb-Sr Granite Subject	67	Dafuzhu	biotite monzogranite	216	Rb-Sr	Party of Jiangxi, 1990 ^{d)}
69	68	Zhaibei	biotite K-feldspar granite	178	Rb-Sr	Chen Peirong et al., 1998 ^[40]
70 Guanxi biotite alkaline-feldspar granite 71 Zhudong two-mica alkaline-feldspar granite 148 Rb-Sr Huang Dianhao et al., 1989 ^[42] 72 Keshubei biotite granite 158 Rb-Sr Chen Peirong, this paper 73 Dajishan muscovite alkaline-feldspar granite 159 Rb-Sr Sun Gongan et al., 1989 ^[43] 74 Dajishan two-mica K-feldspar granite 161 Rb-Sr Sun Gongan et al., 1989 ^[43] 75 Dajishan biotite monzogranite 167 Rb-Sr Sun Gongan et al., 1989 ^[43] 75 Dajishan biotite monzogranite 167 Rb-Sr Sun Gongan et al., 1989 ^[43] 76 Xihuashan biotite K-feldspar granite 151 Rb-Sr Chen Zhixiong et al., 1989 ^[44] 77 Xihuashan biotite K-feldspar granite 148 Rb-Sr Chen Zhixiong et al., 1989 ^[44] 78 Xihuashan biotite K-feldspar granite 156 K-Ar Li Huaqin et al., 1993 ^[44] 79 Piaotang biotite granite 156 K-Ar Li Huaqin et al., 1993 ^[45] 80 Sanbiao biotite granite 156 K-Ar Hei Yongwen et al., 1994 ^[46] 81 Lanshan quartz syenite 175 U-Th-Pb Regional Geological Research Party of Jiangxi, 1990 ^[6] 82 Shangchun monzogranite 168 Rb-Sr Regional Geological Research Party of Jiangxi, 1990 ^[6] 83 Zhongchun two-mica monzogranite 169 U-Th-Pb Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] Jiangxi Bureau of Geology and Mineral R	69	Pitou	biotite K-feldspar granite	176	Rb-Sr	Fan Chunfang et al., 2000 ^[41]
71 Zhudong two-mica alkaline-feldspar granite 148 Rb-Sr Huang Dianhao et al., 1989 ^[42] 72 Keshubei biotite granite 158 Rb-Sr Chen Peirong, this paper 73 Dajishan muscovite alkaline-feldspar granite 159 Rb-Sr Sun Gongan et al., 1989 ^[43] 75 Dajishan biotite monzogranite 161 Rb-Sr Sun Gongan et al., 1989 ^[43] 75 Dajishan biotite monzogranite 167 Rb-Sr Sun Gongan et al., 1989 ^[43] 76 Xihuashan biotite K-feldspar granite 151 Rb-Sr Chen Zhixiong et al., 1989 ^[44] 78 Xihuashan biotite K-feldspar granite 139 Rb-Sr Chen Zhixiong et al., 1989 ^[44] 79 Piaotang biotite granite 156 K-Ar Chen Zhixiong et al., 1989 ^[44] 80 Sanbiao biotite granite 153 K-Ar Mei Yongwen et al., 1989 ^[44] 81 Lanshan quartz syenite 175 U-Th-Pb Regional Geological Research Party of Jiangxi, 1990 ^[6] 83 Zhongchun	70	Guanxi	biotite alkaline-feldspar granite	176	Rb-Sr	Huang Dianhao et al., 1989 ^[42]
72 Keshubei biotite granite 158 Rb-Sr Chen Peirong, this paper 73 Dajishan muscovite alkaline-feldspar granite 161 Rb-Sr Sun Gongan et al., 1989 ^[43] 74 Dajishan biotite monzogranite 161 Rb-Sr Sun Gongan et al., 1989 ^[43] 75 Dajishan biotite Kreldspar granite 151 Rb-Sr Chen Zhixiong et al., 1989 ^[44] 76 Xihuashan biotite K-feldspar granite 151 Rb-Sr Chen Zhixiong et al., 1989 ^[44] 78 Xihuashan biotite K-feldspar granite 139 Rb-Sr Chen Zhixiong et al., 1989 ^[44] 78 Xihuashan biotite granite 156 K-Ar Li Huaqin et al., 1989 ^[44] 80 Sanbiao biotite granite 156 K-Ar Li Huaqin et al., 1989 ^[44] 81 Lanshan quartz syenite 175 U-Th-Pb Regional Geological Research Party of Jiangxi, 1990 ^[6] 82 Shangchun two-mica monzogranite 133 Rb-Sr Regional Geological Research Party of Jiangxi, 1990 ^[6] 83	71	Zhudong	two-mica alkaline-feldspar granite	148	Rb-Sr	Huang Dianhao et al., 1989 ^[42]
74 Dajishan two-mica K-feldspar granite 161 Rb-Sr Sun Gongan et al., 1989 ^[43] 75 Dajishan biotite monzogranite 167 Rb-Sr Sun Gongan et al., 1989 ^[43] 76 Xihuashan biotite K-feldspar granite 151 Rb-Sr Chen Zhixiong et al., 1989 ^[44] 78 Xihuashan biotite K-feldspar granite 139 Rb-Sr Chen Zhixiong et al., 1989 ^[44] 79 Piaotang biotite granite 156 K-Ar Li Huaqin et al., 1999 ^[44] 80 Sanbiao biotite granite 153 K-Ar Mei Yongwen et al., 1989 ^[44] 81 Lanshan quartz syenite 175 U-Th-Pb Regional Geological Research Party of Jiangxi, 1990 ^[6] 82 Shangchun two-mica monzogranite 133 Rb-Sr Regional Geological Research Party of Jiangxi, 1990 ^[6] 84 Yuanling biotite granite 169 U-Th-Pb Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6] 85 Jiuqu two-mica granite 144 Rb-Sr Jiangxi Bureau of Geology and Mineral Resources, 1984 ^[6]	72	Keshubei	biotite granite	158	Rb-Sr	Chen Peirong, this paper
74 Dajishan two-mica K-feldspar granite 75 Dajishan biotite monzogranite 76 Xihuashan biotite K-feldspar granite 77 Xihuashan biotite K-feldspar granite 78 Xihuashan biotite K-feldspar granite 79 Piaotang biotite granite 80 Sanbiao biotite granite 81 Lanshan quartz syenite 81 Lanshan quartz syenite 82 Shangchun monzogranite 83 Zhongchun two-mica monzogranite 84 Yuanling biotite granite 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding biotite monzogranite 88 Tongkengzhang granite 89 Tongkengzhang granite 80 Sanbiao 81 Lanshan quartz syenite 81 Lanshan quartz syenite 82 Shangchun 83 Zhongchun 84 Yuanling biotite granite 85 Jiuqu two-mica granite 86 Danguanzhang biotite granite 87 Maoziding biotite monzogranite 88 Tongkengzhang granite 89 Yanbei granite 80 Danguanzhang biotite monzogranite 80 Sanbiao biotite granite 81 Lanshan quartz syenite 81 Lanshan quartz syenite 82 Shangchun two-mica monzogranite 83 Zhongchun two-mica monzogranite 84 Yuanling biotite granite 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding biotite monzogranite 88 Tongkengzhang granite 89 Yanbei granite 80 Zhenfengding biotite monzogranite 80 Zhenfengding biotite monzogranite 80 Zhenfengding biotite monzogranite 80 Zhenfengding granite 80 Zhenfengding granite 80 Sanbiao biotite monzogranite 80 Sanbiao biotite monzogranite 80 Lanshan quartz syenite 81 Lanshan quartz syenite 81 Lanshan quartz syenite 82 Shangchun monzogranite 83 Zhongkenu del al., 1990 ^[47] 84 Yuanling biotite monzogranite 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding biotite monzogranite 88 Tongkengdhang granite 89 Yanbei granite 80 Zhenfengding biotite monzogranite 80 Zhenfengding biotite monzogranite 80 Zhenfengding granite 81 Lanshan 82 Zhongchun del al., 1990 ^[47] 83 Xiaotao granite 84 Yuanling del al., 1990 ^[47] 85 Zhou Xunruo et al., 1990 ^[47] 86 Juzhou K-feldspar granite 87 Rh-Sr Granite Subject Group, 1989 ^[23] 88 Xinchun geode granite 89 Xinchun geode granite 80 Zhou Xunruo et al.,	73	Dajishan	muscovite alkaline-feldspar granite	159	Rb-Sr	Sun Gongan et al., 1989 ^[43]
75 Dajishan biotite monzogranite 76 Xihuashan biotite K-feldspar granite 77 Xihuashan biotite K-feldspar granite 78 Xihuashan biotite K-feldspar granite 79 Piaotang biotite granite 80 Sanbiao biotite granite 81 Lanshan quartz syenite 82 Shangchun monzogranite 83 Zhongchun two-mica monzogranite 84 Yuanling biotite granite 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding granite 88 Tongkengzhang granite 89 Yanbei granite 80 Danguanzhang biotite monzogranite 80 Sanbiao 81 Lanshan quartz syenite 82 Shangchun two-mica monzogranite 83 Zhongchun two-mica monzogranite 84 Yuanling biotite granite 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding granite 88 Tongkengzhang granite 89 Yanbei granite 80 Zhongchang biotite monzogranite 80 Zhongchang granite 81 Lanshan quartz syenite 82 Shangchun two-mica monzogranite 84 Yuanling biotite granite 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding granite 88 Tongkengzhang granite 89 Yanbei granite 80 Zhongchang biotite monzogranite 80 Zhongchang granite 81 Lanshan 81 Lanshan quartz syenite 82 Shangchun two-mica monzogranite 84 Yuanling biotite monzogranite 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding granite 88 Tongkengzhang granite 89 Yanbei granite 80 Zhongchang granite 80 Zhongchangchangchangchangchangchangchangcha	74	Dajishan	two-mica K-feldspar granite	161	Rb-Sr	Sun Gongan et al., 1989 ^[43]
76 Xihuashan biotite K-feldspar granite 77 Xihuashan biotite K-feldspar granite 78 Xihuashan biotite K-feldspar granite 79 Piaotang biotite K-feldspar granite 79 Piaotang biotite granite 80 Sanbiao biotite granite 81 Lanshan quartz syenite 82 Shangchun monzogranite 83 Zhongchun two-mica monzogranite 84 Yuanling biotite granite 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding biotite granite 88 Tongkengzhang granite 89 Yanbei 80 Danguanzhang biotite monzogranite 81 Lanshan 82 Shangchun two-mica granite 84 Yuanling biotite monzogranite 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding biotite monzogranite 88 Tongkengzhang granite 89 Yanbei 80 Danguanzhang biotite monzogranite 81 Danguanzhang biotite monzogranite 81 Danguanzhang biotite monzogranite 82 Shangchun two-mica granite 83 Danguanzhang biotite monzogranite 84 Rb-Sr Regional Geological Research Party of Jiangxi, 1990 ⁶⁰ Jiangxi Bureau of Geology and Mineral Resources, 1984 ⁶¹ Jiangxi Bureau of Geology and Mineral Resources, 1984 ⁶² Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶¹ Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶¹ Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶² Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶³ Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶⁴⁷ Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶⁴⁷ Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶⁴⁸ Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶⁴⁹ Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶⁴⁹ Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶⁴⁹ Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶⁴⁹ Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶⁴⁹ Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶⁴⁹ Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶⁴⁹ Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶⁴⁹ Jiangxi Bureau of Geology and Mineral Resources, 1995 ⁶⁴⁹ Jiangxi Bureau of Geology and Mineral Resources,	75		biotite monzogranite	167	Rb-Sr	Sun Gongan et al., 1989 ^[43]
77 Xihuashan biotite K-feldspar granite 78 Xihuashan biotite K-feldspar granite 79 Piaotang biotite Granite 80 Sanbiao biotite granite 81 Lanshan quartz syenite 81 Lanshan quartz syenite 82 Shangchun monzogranite 83 Zhongchun two-mica monzogranite 84 Yuanling biotite granite 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding biotite granite 88 Tongkengzhang granite 89 Yanbei 89 Yanbei 89 Yanbei 89 Yanbei 89 Wipu biotite monzogranite 80 Dayang granite 80 Sanbiao 81 Lanshan quartz syenite 81 Lanshan quartz syenite 82 Shangchun two-mica monzogranite 83 Zhongchun two-mica monzogranite 84 Yuanling biotite granite 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding biotite granite 88 Tongkengzhang granite 89 Yanbei granite 80 Zhongchun two-mica granite 80 Danguanzhang biotite monzogranite 81 Lanshan quartz syenite 82 Shangchun two-mica granite 83 Zhongchun two-mica granite 84 Yuanling 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding biotite granite 88 Tongkengzhang granite 89 Yanbei granite 80 Sanbiao 80 Zhongchun 81 Lanshan quartz syenite 81 Lanshan quartz syenite 81 Lanshan quartz syenite 82 Shangchun 83 Rb-Sr He Bochu et al., 1990 ^[47] 84 Rb-Sr Mei Yongwen et al., 1990 ^[47] 85 Jiangxi Bureau of Geology and Mineral Resources, 1984° 123 Rb-Sr He Bochu et al., 1990 ^[47] 124 Rb-Sr He Bochu et al., 1990 ^[47] 125 Rb-Sr He Bochu et al., 1990 ^[47] 126 Chen Riming et al., 1999 ^[48] 127 She-Sr Ling Hongfei et al., 1999 ^[48] 128 Wuping granite 129 Wuping granite 120 Rb-Sr Ling Hongfei et al., 1999 ^[48] 129 Wuping granite 120 Rb-Sr Ling Hongfei et al., 1999 ^[48] 121 Rb-Sr Ling Hongfei et al., 1999 ^[48] 122 Rb-Sr Granite Subject Group, 1980 ^[23] 123 Rb-Sr Granite Subject Group, 1980 ^[23] 124 Yongding granite 125 Rb-Sr Granite Subject Group, 1980 ^[23] 125 Rb-Sr Granite Subject Group, 1980 ^[23] 126 Juzhou K-feldspar granite 127 Rb-Sr Zhou Xunruo et al., 1988 ^[23]	76	Xihuashan	biotite K-feldspar granite	151	Rb-Sr	Chen Zhixiong et al., 1989 ^[44]
78 Xihuashan biotite K-feldspar granite 79 Piaotang biotite granite 80 Sanbiao biotite granite 81 Lanshan quartz syenite 81 Lanshan quartz syenite 82 Shangchun monzogranite 83 Zhongchun two-mica monzogranite 84 Yuanling biotite granite 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding biotite granite 88 Tongkengzhang granite 89 Yanbei granite 80 Danelanglang biotite granite 81 Lanshan 82 Shangchun two-mica monzogranite 84 Yuanling biotite granite 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding biotite granite 88 Tongkengzhang granite 89 Yanbei granite 80 Zhenfengding biotite monzogranite 81 Shangching biotite granite 82 Shangchun two-mica granite 83 Jiuqu two-mica granite 84 Yuanling biotite granite 85 Jiuqu two-mica granite 86 Danguanzhang biotite monzogranite 87 Maoziding biotite granite 88 Tongkengzhang granite 89 Yanbei granite 80 Yanbei granite 81 Jiuqu biotite granite 81 Jiuqu biotite granite 82 Shangchun 83 Rb-Sr He Bochu et al., 1990 ^[47] 84 Rb-Sr He Bochu et al., 1990 ^[47] 85 Jiangxi Bureau of Geology and Mineral Resources, 1985 ^[5] 86 Danguanzhang biotite monzogranite 87 Maoziding biotite granite 88 Tongkengzhang granite 89 Yanbei granite 80 Zhenfengding biotite monzogranite 80 Zhenfengding biotite monzogranite 80 Zhenfengding biotite monzogranite 80 Zhenfengding biotite monzogranite 80 Zhenfengding granite 81 Sh-Sr Ling Hongfei et al., 1999 ^[48] 81 Weipu biotite monzogranite 82 Shangchun 83 Kiaotao granite 84 Rb-Sr Ling Hongfei et al., 1999 ^[49] 85 Hetian biotite monzogranite 86 Rb-Sr Granite Subject Group, 1989 ^[23] 87 Dayang granite 88 Sh-Sr Mao Jianren et al., 1998 ^[51] 88 Sh-Sr Mao Jianren et al., 1998 ^[52]	77	Xihuashan	biotite K-feldspar granite	148	Rb-Sr	Chen Zhixiong et al., 1989 ^[44]
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a) Wang Yuachang Goological and geochemical characteristics of Guidang rock hody and genesis study of No. 330 da		•	granodiorite			

a) Wang Xuecheng, Geological and geochemical characteristics of Guidong rock body and genesis study of No. 339 deposit, Doctoral Thesis of Nanjing University, unpublished, 1986. b) Deng Ping et al., Tectonic-magma activity of granite and uranium mineralization series, northern Guangdong Province, Uranium Geology of South China, 2000, 17(1-2): 32—43. c) Chen Peirong, Geodynamic settings, petrogenesis and evolution of Early Yanshanian bimodal volcanic-intrusive complexes in south Jiangxi Province, Doctoral Thesis of Nanjing University, unpublished, 1998. d) Regional Geological Research Party of Jiangxi, Granitic magmatism and its relationship with mineralization in Huichang region, Jiangxi Province, unpublished, 1990. e) Jiangxi Bureau of Geology and Mineral Resources, Explanatory notes on the geological map of Zhushanwei (1:50000) (in Chinese), unpublished, 1984. f) Jiangxi Bureau of Geology and Mineral Resources, Explanatory notes on the geological map of Kongtian (1:50000) (in Chinese), unpublished, 1995.

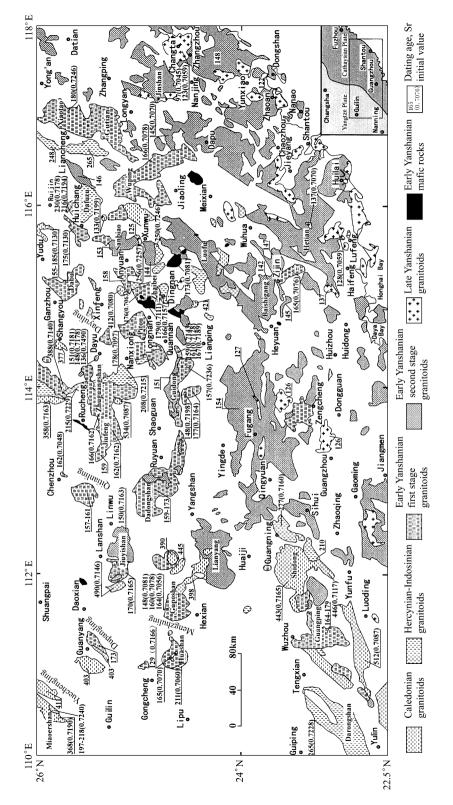


Fig. 1. Distribution of granitoids in the Nanling region.

in the northern Nanling Mountains (e.g. the Dupangling-Jiuyishan-Qitianling-Zhuguangshan-Dabu-Gutian rock belt and the Huashan-Guposhan-Guidong-Zhaibei-Wuping rock belt) and also outcrop sporadically in southern Nanling Mountains. Granitoids of this stage extend markedly in an E-W direction. Granitoids at the second stage (155 Ma—140 Ma) of the early Yanshanian mainly distribute in the southern Nanling Mountains (e.g. the Lianyang-Fogang-Baishigang-Hetian-Dapu rock belt), while in the northern part magmatism weakened. They also notably distribute in an E-W direction. The centre of early Yanshanian magmatism migrated from north to south.

- (3) Late Yanshanian granitoids (140 Ma—70 Ma) principally distribute along the coastal areas of Fujian and Guangdong provinces, parallel to the coastline, and generally extend in an NE direction.
- (4) The bulk part of the Nanling granite belt consists of early Yanshanian granitoids, which distribute in an E-W-trending belt, parallel to the general strike of the Nanling Mountains. It is evident that early Yanshanian granitoids are the main factor for determining the Nanling granite belt and the Nanling mountain system.

3 Petrological constraints on early Yanshanian post-orogenic magmatism in the Nanling region

3.1 Characteristics of rock associations of early Yanshanian granitoids in the Nanling region Statistics of the exposed area of granitoids in Hunan, Guangxi, Guangdong and Jiangxi and their adjacent areas by Shi Mingkui et al. (1993)^[16] indicates that early Yanshanian granitoids consist dominantly of granodiorite, monzogranite, K-feldspar granite and syenite with a small amount of alkali feldspar granite, of which monzogranite and K-feldspar granite predominate (table 2). This type of rock association is entirely comparable to typical post-orogenic granite suites, e.g. the Taourirt suite of Hoggar, Algeria related to the Pan-African orogeny and the Mont-Blanc-Aar-Gotthard suite related to Variscan orogeny in western-central Europe^[54]. The Taourirt post-orogenic suite of Hoggar is dominantly granitic, with scarce basic to intermediate rocks, and there appears a Daly gap. Granitoids may fall into four rock associations (table 3), G1 monzogranite, G2a monzogranite and syenogranite, G2b alaskite (alkali feldspar granite) and G3 alkali feldspar syenite and granite, with G2a predominating. Granodiorite is widespread in the Mont-Blanc-Aar-Gotthard suite^[54]. Apparently, early Yanshanian granitoids in the Nanling region are strikingly similar not only in rock type but also in rock-forming and accessory mineral assemblages and isotopic composition to granitic rocks of the Taourirt post-orogenic suite (table 3). In addition, early Yanshanian basaltic magmatism also occurred in the Nanling region, for example, the basalt exposed in southern Jiangxi and southern Hunan has been determined to have isotope ages in the range of 158 Ma—179 Ma (table 4), and intermediate rocks are rare and there appears a Daly gap. Therefore early Yanshanian granitoids in the Nanling region have the typical characteristics of post-orogenic suites.

					3				
Age	Alkali feldspar granite	K-feldspar granite	Monzo- granite	Grano- diorite	Granite porphyry	Grano- diorite porphyry	Syenite	Total area	Proportion (%) in total area of Nanling granitoids ^{b)}
$\overline{\mathbf{J}_3}$		543	19406	352	401	7	94	20803	28.16
J_2	1	1520	8030	80		4		9635	13.04
J_1	10	226	5216					5452	7.38
Rock proportion (%) in J granitoids	0.03	6.38	90.98	1.20	1.12	0.03	0.26		

Table 2 Early Yanshanian granitoids and their exposed areas^{a)}/km² in Hunan, Guangxi, Guangdong and Jiangxi and adiacent areas

a) Data from Shi Mingkui et al. (1993)¹¹⁶. Hunan, Guangxi, Guangdong and Jiangxi and adjacent areas refer to the region between latitudes 23°20′—26°40′ and longitudes 107°—117°. The nomenclature of K-feldspar granite in the table is given by the Institute of Geochemistry, Chinese Academy of Sciences (1979), being equivalent to syenogranite^[53], plotted in Field 3a in the QAP triangle diagram. b) The total area proportions of these rocks were recalculated by us excluding Precambrian granitoids far from the study region.

Table 3 Mineralogy and petrology of early Yanshanian granitoids in the Nanling region

		Post-orogenic granitoids related to the late Pro-
	Early Yanshanian granitoids in the Nanling region	terozoic Pan-African orogeny (Taourirt suite of Hoggar, Algeria)
Rock types	Basalt, diabase (dykes) and gabbro (stocks)	Gabbro and diorite (stocks and enclaves)
	Granodiorite	G1: monzogranite
	Monzogranite and K-feldspar granite (predominant)	G2a: monzogranite and syenogranite (predominant)
	Alkali feldspar granite	G2b: alaskite (alkali feldspar granite)
	Syenite	G3: alkali feldspar syenite and granite
Rock-forming mineralogy	Granodiorite: qartz + plagioclase + K-feldspar + Biotite + hornblende	G1: qartz + K-feldspar + plagioclase + Hornblende + biotite
	Monzogranite: quartz + K-feldspar + plagioclase + biotite \pm hornblende	G2a: quartz + K-feldspar + plagioclase + biotite ± hornblende
	K-feldspar granite: quartz + K-feldspar + plagio- clase + biotite \pm protolithionite \pm hornblende	G2b: quartz + K-feldspar + albite + protolithio- nite-zinnwaldite
	Alkali feldspar granite: K-feldspar \pm albite \pm	G3: alkali feldspar ± quartz ± plagioclase + he-
	plagioclase + quartz \pm arfvedsonite \pm biotite	denbergite + hastingsite-hornblende + biotite± grunerite±riebeckite
Accessory mineralogy ^{a)}	Granodiorite: zircon + allanite + sphene + ilmenite + magnetite + apatite + monazite + tourmaline + garnet	G1: zircon + allanite + sphene + ilmenite + magnetite + apatite
	Monzogranite: zircon + allanite + sphene + ilmenite + magnetite + apatite + thorite + fergusonite + columbite-tantalite + monazite + tourmaline + fluorite +	G2a: zircon + allanite + sphene + ilmenite + magnetite + apatite + thorite + fergusonite + monazite + xenotime
	garnet K-feldspar granite: zircon + allanite + sphene +ilmenite+magnetite + apatite + thorite + colum- bite-tantalite + monazite + tourmaline + fluorite	G2b: zircon + allanite + sphene + fluorite + topaz \pm tourmaline \pm garnet
	Alkali feldspar granite: zircon + apatite + columbite-tantalite + garnet	G3: zircon + thorite + allanite + chevkinite + ilmenite + magnetite + apatite + fluorite
Isotopic ratios	Sri = 0.7048—0.7240	Sri = 0.706—0.723
Emplacement age	180 Ma—140 Ma	570 Ma—520 Ma

a) Accessory minerals with a content <1 g/t are excluded. The statistics of the rock-forming and accessory mineral assemblages is based on 5 granodiorite bodies, 27 monzogranite bodies, 20 K-feldspar granite (equivalent to syenogranite commonly used internationally) bodies and 7 alkali feldspar granite bodies (after Granite Subject Group of the Nanling Project, 1989^[23]; Chen Peirong, 1998, Doctoral Thesis of Nanjing University, unpublished). The Sri values correspond with the rock bodies with Rb-Sr ages in fig. 1.

Locality	Rock name	Method	No. of samples	MSWD	Age/Ma	Data sources
Xunwu, S Jiangxi	Tholeiite	Whole-rock Rb-Sr isochron	5	0.7	173 ± 5.5	This paper
Xunwu, S Jiangxi	Tholeiite	Whole-rock Rb-Sr isochron			179	Lai, 1996 ^[55]
Longnan, S Jiangxi	Tholeiite	Whole-rock Rb-Sr isochron	5	2.84	179 ± 8.4	This paper
Longnan, S Jiangxi	Tholeiite	Whole-rock Rb-Sr isochron	6	1.90	173.7 ± 2.5	This paper
Longnan, S Jiangxi	Tholeiite	Whole-rock Rb-Sr isochron			175.5	Lai, 1996 ^[55]
Longnan, S Jiangxi	Tholeiite	Whole-rock K-Ar dilution			162.8 ± 4.8	Wu et al., 1998 ^[56]
Longnan, S Jiangxi	Tholeiite	Whole-rock K-Ar dilution			157.8 ± 5.7	Wu et al., 1998 ^[56]
Yizhang, S Hunan	Tholeiite	40 Ar- 39 Ar			178.0 ± 3.6	Zhao et al. 1998 ^[57]
Ningyuan, S Hunan	Alkali basalt	Whole-rock K-Ar dilution			177	Zhao et al. 1998 ^[57]
Ningyuan, S Hunan	Alkali basalt	Whole-rock K-Ar dilution			177	Zhao et al. 1998 ^[57]

Table 4 Isotopic ages of early Yanshanian basalts in the Nanling region

3.2 Occurrence of early Yanshanian A-type granitoids in the Nanling region

Now it has been ascertained that there occur early Yanshanian A-type granitoids in southern Jiangxi in the eastern sector of the Nanling Mountains, e.g. the Zhaibei rock body in Dingnan County and the Pitou rock body in Longnan County^[40,58]. The latter contains the alkaline dark-colored minerals aegirine and arfvedsonite, and their Rb-Sr isochron age is 176 Ma and 178 Ma respectively. The two rock bodies are mainly composed of K-feldspar granite, which are metaluminous (ANKC = 0.94-1.08, with an average of 0.98), rich in silica (SiO₂ = 71.06%-76.74%) and alkalis (Na₂O+K₂O = 7.93%-9.80%), and have higher FeO^T/MgO(%) value (9.60 —145.00), lower CaO and MgO contents (0.10%-1.16% and 0.01%-0.25% respectively), higher REE (Σ REE = 271.35-724.97 mg/g) and high-field-strength element (HFSE) (e.g. Y, Zr, Nb etc.) abundances. Their geochemical characteristics are the same as those of A-type granitoids, but notably different from those of I- and S-type granitoids in the region (fig. 2).

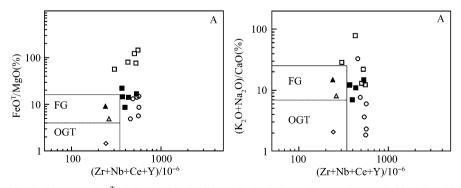


Fig. 2. Zr+Nb+Ce+Y versus FeO^T/MgO and $(Na_2O+K_2O)/CaO$ discriminant diagram for granitoids (after Whalen et al., $1987)^{[59]}$. A = field for A-type granitoids; FG = field for fractionated felsic granitoids; OGT = field for unfractionated M-, I- and S-type granitoids. \Box , Zhaibei rock body; \blacksquare , Pitou rock body; \bigcirc , rhyolite in bimodal volcanic rock associations; \bigcirc , I-type granitoids in the region; \triangle , S-type granitoids in the region; \blacktriangle , fractionated S-type granitoids in the region.

3.3 Occurrence of early Yanshanian bimodal volcanic-intrusive complexes in the Nanling region

In the eastern sector of the Nanling Mountains there occur early Yanshanian bimodal volcanic associations in the Changpu basin and Baimianshi basin in Xunwu County and the Dongkeng basin and Linjiang basin in Longnan County, southern Jiangxi, and the Pankeng basin in Yongding County, southwestern Fujian^[60,61]. The basic end-member basalt has isotopic ages ranging from 158 Ma to 179 Ma (table 4) and the acid end-member rhyolite has Rb-Sr isochron ages of 165 Ma—178 Ma (based on three isochrons) (Chen Peirong, 1998, Doctoral Thesis of Nanjing University, unpublished; Kong Xinggong, 2001, Doctoral Thesis of Nanjing University, unpublished). In the Zhaibei A-type granite body (176 Ma) there are many small gabbro bodies, e.g. the Chebu rock body, whose geochemical characteristics are the same as those of the basic end-member basalt in bimodal volcanic suites. They, being products of the same source but different facies, form bimodal intrusive rocks together with the Zhaibei A-type granitoids.

In the bimodal volcanic rock associations in southern Jiangxi and southwestern Fujian, basalt is enriched in incompatible elements, especially HFSE such as Nb, Ta, Ce, Zr, Hf, Sm and Ti, so it is intraplate tholeite (fig. 3). Rhyolite is metaluminous (average ANKC = 0.99) and enriched in HFSE such as Zr, Hf, Ti and Y and REE such as La, Ce, Nd, Sm, Tb and Yb, exhibiting the geochemical characteristics of A-type granitoids^[64] (fig. 2).

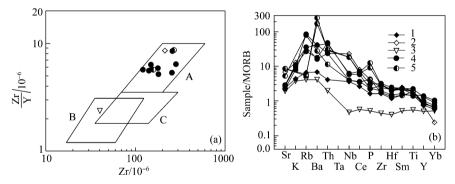


Fig. 3. Zr-Zr/Y and incompatible element MORB normalized patterns (after Pearce, 1973, 1982)^[62,63]. A, Intraplate basalt; B, island arc basalt; C, middle oceanic roof basalt; 1, Intraplate tholeiite; 2, intraplate alkali basalt; 3, volcanic arc tholeiite; 4, basalt of southern Jiangxi^[60]; 5, basalt of southern Hunan^[57].

Moreover, there occur early Yanshanian basalts in Rucheng, Daoxian, Ningyuan and Yizhang counties, southern Hunan. Their ⁴⁰Ar-³⁹Ar ages are 175 Ma—178 Ma^[65,57] and geochemical characteristics are the same as those of intraplate tholeite and intraplate alkali basalts (fig. 3).

4 Discussion and conclusions

4.1 Geodynamic settings of the Nanling region during the early Yanshanian

"Post-orogenic" stands for the subsequent tectono-magmatic episode occurring after the end of an orogenic Wilson cycle, when the geodynamic context becomes entirely intraplate^[54]. It is characterized by motion of the welded terranes according to the same pole of rotation and emplacement of magmatic suites along shear zones in reactivated transcurrent tectonic regimes.

Post-orogenic suites mark the end of a post-collision or late orogenic event, i.e. the late stage of an orogenic Wilson cycle, and the initiation of Pangaea break-up, and indicate that a new Wilson cycle is about to start.

Early Yanshanian magmatic suites predominate absolutely in the Nanling granite belt. They consist mainly of monzogranite and K-feldspar granite (syenogranite). There occur associations of early Yanshanian A-type granitoids (176 Ma-178 Ma) (the Pitou rock body contains alkaline dark-colored minerals) and bimodal volcanic rocks (158 Ma-179 Ma) in the eastern sector of the granite belt. Both the acid end-member rhyolite in the bimodal volcanic rock association and A-type granitoids have the geochemical characteristics of intraplate granitic rocks (fig. 4) and the basic end-member basalt of the association is intraplate tholeiite, while early Yanshanian basaltic rocks in southern Hunan include not only intraplate tholeiite but also intraplate alkali basalt (fig. 3). The Fogang rock body (~154 Ma)——the south belt of the Nanling granite belt——is also considered by some people as A-type granitoids^[68]. Therefore the early Yanshanian magmatic suites in the Nanling region are undoubtedly typical post-orogenic rock associations. Bimodal volcanic-intrusive complexes and A-type granitoids and their related alkaline complexes are the most direct evidence for the ascent of the asthenosphere, thinning of the lithosphere and initiation of extensional rifting of the continental crust^[69–76]. Thus it may be considered that the early Yanshanian geodynamic setting in the Nanling region should be related to post-orogenic continental break-up.

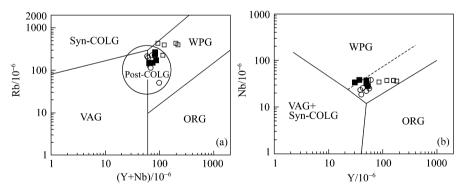


Fig. 4. Y-Nb and Y+Nb-Rb tectonic discriminant diagrams (after Pearce et al., 1984, 1996)^[66,67] (symbols as in fig. 2).

4.2 Conclusions

The bulk granite bodies of the Nanling granite belt originated in the early Yanshanian, and extends in an E-W direction and constitute the main constraint on the formation of the Nanling mountain system.

Early Yanshanian granitoids in the Nanling region have the mineralogical and petrological characteristics of post-orogenic granitoids and there occur A-type granitoids, bimodal volcanic rocks and basaltic magmatism, which suggests that extensional break-up of the lithosphere took place in the region during the early Yanshanian.

Geologists have to reconsider the timing of the action of the subduction of Palaeo-Pacific plate on the continent margin of South China and how deep it may have influenced the interior of the continent, i.e. the geodynamic settings of the widespread Late Mesozoic granitoids and rich mineral resources in the Nanling region. Therefore, it is necessary now to study the geology and origin of mineral deposits in the Nanling region, particularly such important scientific subjects as the origin of granitoids and crust-mantle interaction, as well as the geodynamic setting of the E-W-trending Nanling tectono-magmato-metallogenic belt and its tectonic framework (whether it belongs to the Pacific or Tethys tectonic domains) and evolution.

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