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Study of late-Mesozoic magmatic rocks and their related copper-gold-polymetallic deposits in the Guichi ore-cluster district, Lower Yangtze River Metallogenic Belt, East China

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ABSTRACT
The Guichi ore-cluster district in the Lower Yangtze River Metallogenic Belt hosts extensive Cu–Au–Mo polymetallic deposits including the Tongshan Cu–Mo, Paodaoling Au, Matou Cu–Mo, Anzishan Cu–Mo, Guilinzheng Mo and Zhaceqiao Au deposits, mostly associated with the late Mesozoic magmatic rocks, which has been drawn to attention of study and exploration. However, the metallogenic relationship between magmatic rocks and the Cu–Au-polymetallic deposits is not well constrained. In this study, we report new zircon U–Pb ages, Hf isotopic, and geochemical data for the ore-bearing intrusions of Guichi region. LA-ICP-MS U–Pb ages for the Anzishan quartz diorite porphyrite is 143.9 ± 1.0 Ma. Integrated with previous geochronological data, these late Mesozoic magmatic rocks can be subdivided into two stages of magmatic activities. The first stage (150–132 Ma) is characterized by high-K calc-alkaline intrusions closely associated with Cu–Au polymetallic ore deposits. Whereas, the second stage (130–125 Ma) produced granites and syenites and is mainly characterized by shoshonite series that are related to Mo–Cu mineralization. The first stage of magmatic rocks is considered to be formed by partial melting of subducted Palaeo-Pacific Plate, assimilated with Yangtze lower crust and remelting Mesoproterozoic crust/sediments. The second stage of magmatism is originated from partial melting of Mesoproterozoic-Neproterozoic crust, mixed with juvenile crustal materials. The depression cross to the uplift zone of the Jiangnan Ancient Continent forms a gradual transition relation, and the hydrothermal mineralization composite with two stages have certain characteristics along the regional fault (Gaotan Fault). Guichi region results from two episodes of magmatism probably related to tectonic transition from subduction of Palaeo-Pacific Plate to back-arc extensional setting between 150 and 125 Ma, which lead to the Mesozoic large-scale polymetallic mineralization events in southeast China.

1. Introduction
The Lower Yangtze River Metallogenic Belt (LYRMB) in central eastern China is an important metallogenic belt, comprising several ore clusters such as Edong, Jiurui, Anqing-Guichi, Luzong, Tongling, Ningwu, and Ningzhen (Figure 1) (Chang et al. 1991). The Guichi ore-cluster district, which is located in the transition zone between the Lower Yangtze Fold and the Jiangnan Ancient Continent (Figure 1) (Song et al. 2014), has not been well studied as only a few metallic deposits had been found. However, recent focused exploration efforts have resulted in the discovery of several new deposits such as Gaojiabang W–Mo deposit (Jiang et al. 2009), Guilinzheng Mo deposit (Chen 2016), Mashi Cu deposit, and Paodaoling Au deposit (Duan et al. 2012). Most of these deposits are considered to be genetically related to the Late Jurassic-Early Cretaceous igneous rocks (Zhang et al. 2011; Duan et al. 2012, 2015; Song et al. 2014; Zhu et al. 2014; Nie et al. 2016; Yang et al. 2016a). Many of the ore-bearing igneous rocks are porphyries with adakitic characteristics (Wang et al. 2006; Ling et al. 2009; Liu et al. 2010a; Sun et al. 2012; Xie et al. 2017a). However, the ore-hosting rocks of Guilinzheng Mo deposit are related to A-type granites (Chen 2016), which is uncommon in the LYRMB. Thus, the petrogenesis of these rocks may provide important information on the ore mineralization of LYRMB. Since there is little systematic regional study on the Guichi region, their nature and origin are still controversial, and are considered to be the products of

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intracontinental magmatism (Hou and Yang 2009; Lv et al. 2014) or of the subduction of the Palaeo-Pacific Plate (Sun et al. 2007a, 2010; Ling et al. 2009; Liu et al. 2010a; Yang et al. 2016a).

Previous research utilized geochronology and isotopic evidence to reveal the origin of Mesozoic magmatic rocks in Guichi region (Wu et al. 2012; Yang and Zhang 2012; Song et al. 2014), but the petrographic and geochemical characteristics of the Mesozoic intrusive bodies and the relationship between magmatism and polymetallic metallization remains unstudied. Research on ore genesis and modelling are particularly necessary because shallow ore deposits have largely been discovered, while deeper or hidden ore deposits will become future exploration targets in the Guichi ore-cluster district.

The objectives of this study are (1) to describe and summary the geological characteristics, magmatic-metallogenic ages, petrochemistry, ore deposit geochemistry, and fluid characteristics of the typical deposits in the Guichi region in order to summarize a metallogenic model for the Guichi region; (2) to understand the tectonic setting and establish the geochronological framework of the Guichi region; and (3) to discuss the relationships between the ore mineralization and the Late Jurassic-Early Cretaceous tectono-thermal event.

2. Geological setting

Eastern China consists of three main tectonic blocks, that is, the North China Craton, the Yangtze Block and Cathaysia Block (Figure 1). The Yangtze Block is separated from the North China Craton to the north by the Triassic Dabie-Sulu Orogeny (Li et al. 1993) and from the Cathaysia Block to the south by the Jiangshan–Shaoxing Fault (Zhang et al. 2005). The LYRMB is located on the northern margin of the Yangtze Block along the middle and lower reaches of the Yangtze River, extending 400 km from Hubei province in the southwest to Jiangsu province in the northeast. The Yangtze Block is made up of the Archaean to Palaeoproterozoic high-grade metamorphic TTG (tonalite, trondhjemite, and granodiorite) gneisses, metasedimentary rocks, and amphibolites (e.g. the Kongling complex near the Yangtze Gorge Dam; Gao et al. 1999; Qiu et al. 2000) and variably deformed, low- to middle-grade metamorphosed rocks with late Palaeoproterozoic to early Neoproterozoic ages around the southern margin of the Yangtze Block. The Neoproterozoic magmatic rocks developed along the southern margin of the Yangtze Block are composed of the ca. 1134–968 Ma Grenvillian oceanic crust as indicated by ophiolites in southern Anhui and north-eastern
Jiangxi Province (Chen et al. 1991; Li et al. 1997), the ca. 970–890 Ma Shuangxiwu magmatic arc (Li et al. 2009), the ca. 850 Ma Shenwu dolerites (Li et al., 2008), and the mid-Neoproterozoic (ca. 820–790 Ma) Nanhua rift volcano-sedimentary sequences and syn-rifting igneous intrusions (Li et al. 2008).

The LYRMB is characterized by extensive late Mesozoic magmatism and ore deposits, and is thus one of the most important regions of giant Mesozoic magmatic activity and mineralization in eastern China (Chang et al. 1991; Chen et al. 1991; Mao et al. 2011; Sun et al. 2012). In the past decade, a large amount of high quality chronological data for these magmatic rocks has been published, and these late Mesozoic magmatic rocks can be subdivided into three stages of development (Xie et al. 2008; Wu et al. 2012; Mao et al. 2014; Yang et al. 2014; Yan et al. 2015; Zhou et al. 2015). The first stage (148–133 Ma) involved the emplacement of high-K calc-alkaline intrusions that are closely associated with Cu–Au–Mo poly-metallic ore deposits (Wang et al. 2004, 2007, 2015; Li et al., 2007; Xie et al. 2011a, 2012a, 2012b, 2015; Hu et al. 2017; Wu et al. 2017; Zhang et al. 2017a). The second stage (133–127 Ma) is characterized by shoshonitic volcanic and subvolcanic rocks that are closely associated with iron ore deposits (Wang et al. 2006; Yan et al. 2009; Yuan et al. 2011; Xie et al. 2011b; Deng et al. 2012). The third stage (127–123 Ma) produced syenites and granites defined as A-type granitoids (Xing and Xu 1994; Li et al. 2012; Yang et al. 2016b, 2017; Wang et al. 2017; Xie et al. 2017b), which occurs along both sides of the Yangtze River and are related to small-scale uranium and gold mineral deposits (Mao et al. 2011). The ore deposits throughout the LYRMB mainly consist of contemporaneous skarn, porphyry and strata-bound poly-metallic (Cu, Au, Fe, Mo, Zn, Pb, and Ag) deposits. Dating of the ore-forming minerals indicates that they formed in the Early Cretaceous (146–133 Ma) (Sun et al. 2003; Li et al. 2007; Ling et al. 2009; Liu et al. 2010a; Hu et al. 2017; Wu et al. 2017; Xie et al. 2017a). The host intrusions are mainly dioritic adakite-like rocks and have emplacement ages identical to the formation ages of associated deposits, indicative of spatial and temporal association with ore deposits.

Guichi region is situated in the Anging-Guichi ore-cluster district, as the transitional zone between the Lower Yangtze Fold and the Jiangnan Ancient Continent (Figure 1). The upper cover is composed of Nanhua system-Early Triassic strata. Indosinian-Yanshanian orogeny produced NNE-trending folds, NNE-trending faults, and compressions. During the late Mesozoic period, the Guichi region became active again, which has long been interpreted as an extensional stage with abundant magmatism (Liu et al. 2012; Wu et al. 2012; Song et al. 2014; Zhou et al. 2015; Yang et al. 2016a, 2016b; Xie et al. 2017a).

Intensive intermediate acidic rocks and associated hydrothermal activity yielded several poly-metallic mineralization occurrences (Chang et al. 1991; Tang et al. 1998). Extensive marine deposition including clastic rocks, carbonates, and evaporates developed during the Silurian to Middle Triassic periods. The strata, which are closely related to the metal deposits, are Carboniferous carbonate, Permian limestone and black shale, and Triassic carbonate and argillaceous rock (Zhai et al. 1992). The Late Jurassic-Early Cretaceous magmatic rocks (J–K) are abundant in the Guichi region, forming more than 36 intrusive bodies with outcrop area of 346 km², such as Qingyang-Jiuhuashan complex intrusion, Huayuangong intrusion, Maotan intrusion, and Tanshan intrusion (Figure 1).

Three major types of Mesozoic magmatic rocks occur in Guichi region (Table 1, Figure 1): granite (-porphyry), granodiorite–diorite porphyrite, and volcanic rocks. The granite (-porphyry) associations are pale yellow to red in colour, consisting of granites, granite porphyry, syenogranite, and alkali-feldspar granite. The granodiorite–diorite porphyrite associations are brown or grey, consisting of granodiorite (porphyry), diorite porphyrite, and pyroxene dierite. The volcanic rocks are composed of dacite. The Guichi region contains diverse ore deposit types (Yang et al. 2016a; Table 2). In particular, the porphyry-, skarn-, and hydrothermal type deposits constitute the majority of the Cu–Au–Mo–Pb–Zn–Ag metallogeny (Figure 1, Table 2), and are closely associated with the Late Jurassic-Early Cretaceous tectono-thermal events. In this study, we have focused on the major Cu–Mo–Au deposits, including the Tongshan Cu–Mo (skarn and strata-bound type), Paodaoling Au (porphyry type), Matou Cu–Mo (porphyry type), Anzishan Cu–Mo (porphyry and skarn type), Guilinzheng Mo (skarn type), and Zhaceqiao Au (epithermal type) deposits (Figure 1, Table 3).

3. Geological characteristics of the typical deposits

3.1. Zhaceqiao Au deposit

The Zhaceqiao Au deposit is located in the conjunction belt between the Yangtze Fold belt and Jiangnan transition zone (Figure 1). There are six ore-blocks, namely Niutougaojia, Luyuan, Chengtan, Yaocun, Dongbian, and Yangmeijian (Figure 2). The strata exposed in the mine are of Cambrian Qingkeng, Tuanshan,
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<td>Guniujiang</td>
<td>Monzonite</td>
<td>131.3 ± 2.4</td>
<td>LA-ICP-MS</td>
<td>−2.50</td>
<td>Wu et al. (2012)</td>
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<tr>
<td>Guniujiang</td>
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<td>LA-ICP-MS</td>
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<td>Wu et al. (2012)</td>
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<tr>
<td>Guniujiang</td>
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<td>130.1 ± 1.3</td>
<td>LA-ICP-MS</td>
<td>Xie et al. (2012b)</td>
<td></td>
</tr>
<tr>
<td>Tanshan</td>
<td>Syenogranite</td>
<td>131.4 ± 2.2</td>
<td>LA-ICP-MS</td>
<td>−5.83</td>
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</tr>
<tr>
<td>Tanshan</td>
<td>Syenogranite</td>
<td>129.8 ± 1.8</td>
<td>LA-ICP-MS</td>
<td>−5.73</td>
<td>Wu et al. (2012)</td>
</tr>
</tbody>
</table>

(Continued)
Table 1. (Continued).

<table>
<thead>
<tr>
<th>Locality</th>
<th>Lithology</th>
<th>Age (Ma)</th>
<th>Method</th>
<th>ε(t)</th>
<th>Reference</th>
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<tr>
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<td>Li et al. (2012)</td>
</tr>
<tr>
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</tr>
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<td>Song et al. (2014)</td>
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<td>LA-ICP-MS</td>
<td>−4</td>
<td>Yang and Zhang (2012)</td>
</tr>
<tr>
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<tr>
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<td>Li et al. (2012)</td>
</tr>
<tr>
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<td>LA-ICP-MS</td>
<td>−7.27</td>
<td>Yang et al. (2016b)</td>
</tr>
<tr>
<td>Huayuangong</td>
<td>Quartz syenite</td>
<td>126.2 ± 1.2</td>
<td>LA-ICP-MS</td>
<td>−4</td>
<td>Yang et al. (2016b)</td>
</tr>
<tr>
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<td>Huayuangong</td>
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<td>LA-ICP-MS</td>
<td>−0.56</td>
<td>Liu et al. (2012)</td>
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<td>LA-ICP-MS</td>
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<td>Li et al. (2012)</td>
</tr>
<tr>
<td>Maotan</td>
<td>Alkali-feldspar granite</td>
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<td>LA-ICP-MS</td>
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<td>Li et al. (2012)</td>
</tr>
<tr>
<td>Maotan</td>
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<td>LA-ICP-MS</td>
<td>−4.75</td>
<td>Duan et al. (2015)</td>
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<td>LA-ICP-MS</td>
<td>−8.94</td>
<td>Yang and Zhang (2012)</td>
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<td>Maotan</td>
<td>Alkali-feldspar granite</td>
<td>126.2 ± 3.3</td>
<td>LA-ICP-MS</td>
<td>−4.46</td>
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<tr>
<td>Guicheng</td>
<td>Granite</td>
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<td>LA-ICP-MS</td>
<td>−9.5</td>
<td>Yang and Zhang (2012)</td>
</tr>
<tr>
<td>Dayanchong</td>
<td>Alkali-feldspar granite</td>
<td>131.9 ± 2.8</td>
<td>LA-ICP-MS</td>
<td>−2.84</td>
<td>Yang and Zhang (2012)</td>
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<tr>
<td>Dayanchong</td>
<td>Alkali-feldspar granite</td>
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<td>LA-ICP-MS</td>
<td>−5.05</td>
<td>Yang and Zhang (2012)</td>
</tr>
<tr>
<td>Liwan</td>
<td>Diorite</td>
<td>123.4 ± 2.4</td>
<td>LA-ICP-MS</td>
<td>−11.85</td>
<td>Duan et al. (2015)</td>
</tr>
<tr>
<td>Meijie</td>
<td>Dacite</td>
<td>131.7 ± 1.4</td>
<td>SIMS</td>
<td>−8.94</td>
<td>Yang and Zhang (2012)</td>
</tr>
<tr>
<td>Meijie</td>
<td>Dacite</td>
<td>130.6 ± 0.9</td>
<td>SIMS</td>
<td>−4.46</td>
<td>Yang and Zhang (2012)</td>
</tr>
<tr>
<td>Meijie</td>
<td>Dacite</td>
<td>127.4 ± 1.0</td>
<td>SIMS</td>
<td>−9.5</td>
<td>Yang and Zhang (2012)</td>
</tr>
<tr>
<td>Meijie</td>
<td>Dacite</td>
<td>131.6 ± 0.9</td>
<td>SIMS</td>
<td>−2.84</td>
<td>Yang and Zhang (2012)</td>
</tr>
<tr>
<td>Meijie</td>
<td>Dacite</td>
<td>128.8 ± 0.9</td>
<td>SIMS</td>
<td>−5.05</td>
<td>Yang and Zhang (2012)</td>
</tr>
<tr>
<td>Meijie</td>
<td>Dacite</td>
<td>127.2 ± 0.9</td>
<td>SIMS</td>
<td>−11.85</td>
<td>Duan et al. (2015)</td>
</tr>
</tbody>
</table>

Table 2. Major ore deposit types in the Guichi area.

<table>
<thead>
<tr>
<th>Deposit type</th>
<th>Major ore control factor</th>
<th>Ore composition</th>
<th>Occurrence of ore body</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skarn type</td>
<td>Stratabound</td>
<td>Pb, Zn, Cu, Ag, Mo</td>
<td>Conformity-type</td>
<td>Huangshanting Pb–Zn deposit</td>
</tr>
<tr>
<td>Contact type</td>
<td>Syenogranite in S–O stripping, quartz diorite porphyrite, K-feldspar, granodiorite porphyrite</td>
<td>Fe, Pb–Zn– (Au, Ag), Cu–Mo–W, Pb–Zn–Cu– (Ag)</td>
<td>Unconformity type</td>
<td>Tongkeng, Dingchongpo, Anzishan, Yaojia, Jitoushan, Liwan, Donghu, Tonglingpo copper deposit</td>
</tr>
<tr>
<td>Compound type</td>
<td>Contact zone + stratabound, contact zone between limestone of Qixia formation and terrane, limestone of Huanglong and Chuanshan formation, layered ore body composed of dolomite</td>
<td>Cu–Fe–S–(Au, Ag) – Mo</td>
<td>Conformity-, unconformity type</td>
<td>Tongshang copper deposit</td>
</tr>
<tr>
<td>Porphyry type</td>
<td>Baseline fracture side, granodiorite porphyrite, quartz diorite porphyrite, dacite porphyrite</td>
<td>Cu–Mo–(Au, Ag)</td>
<td>Unconformity type</td>
<td>Anzishan-Niubeiji, Mashui, Matou, Paodaoling, Guinizheng, Wushui</td>
</tr>
<tr>
<td>Hydrothermal type</td>
<td>Shear fracture anticline with NE-trending, granodiorite porphyrite-quartz diorite porphyrite, structure fracture zone</td>
<td>Pb–Zn–Cu–Ag, Cu–Fe–S–(Pb, Zn), Au–Ag–Cu, Mo–Pb–Zn–Cu–Ag, Cu–Fe–(Au, Ag)Fe–Au</td>
<td>Conformity-, unconformity type</td>
<td>Guanchong, Zilaishan, Fengshuling, Liwan, Zhujiaochang, Xuqiao, Diling, Dishuiya, Huashan</td>
</tr>
<tr>
<td>Weathering-infiltration type</td>
<td>D-C surface and interlayer fault</td>
<td>Cu–Fe–(Au, Ag)Fe–Au</td>
<td>Conformity-type</td>
<td>Liefengshou, Matou, Yuejinshan, Xiushuihao</td>
</tr>
</tbody>
</table>
Table 3. Characteristics of the main typical deposits in Guichi area.

<table>
<thead>
<tr>
<th>Name</th>
<th>Tongshan</th>
<th>Matou</th>
<th>Anzishan</th>
<th>Zhaceqiao</th>
<th>Guilinzheng</th>
<th>Paodaoling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposit and type</td>
<td>Cu–Mo, skarn and stratabound porphyry</td>
<td>Cu–Mo, porphyry</td>
<td>Cu–Mo, porphyry-skarn</td>
<td>Au, shallow epithermal</td>
<td>Mo-polymer, skarn</td>
<td>Au, porphyry</td>
</tr>
<tr>
<td>Size and grade</td>
<td>Intermediate, 1.14% Cu</td>
<td>Intermediate, 1.14% Cu</td>
<td>Small, 0.64% (Cu), 0.073% (Mo)</td>
<td>Small, 1.53 g/t</td>
<td>Large, 150,000 t, 0.127%</td>
<td>30 t, 1.85 g/t</td>
</tr>
<tr>
<td>Mineralization-related rocks</td>
<td>Granodiorite and quartz monzonite porphyry</td>
<td>Granodioritic porphyry</td>
<td>Quartz diorite porphyrite</td>
<td>Granite porphyry</td>
<td>Granite porphyry</td>
<td>Paodaling porphyry and Wushi porphyry</td>
</tr>
<tr>
<td>Host rocks</td>
<td>Carboniferous-Permian sandstone, shale, chert, limestone dolostone</td>
<td>Silurian–Devonian clastic sedimentary rocks</td>
<td>Silurian sand shale and Ordovician carbonate</td>
<td>Marble limestone of Honghuayuan Formation</td>
<td>Ordovician Lunshan and Wufeng Formation</td>
<td>The Silurian Gaolijian Formation strata</td>
</tr>
<tr>
<td>Structural setting</td>
<td>West of the Tongling-Guichi synclinorium and on the western part of the southern limb of the Mushan anticline</td>
<td>Contact zone between Shimenling anticline with NNE-trending and NNE-trending fold</td>
<td>Intersection area of Tongshan-Anzishan deep fault, Gaotan-Anzishan basement fault and Donghu-Anzishan basement fault</td>
<td>NNE-, NE-, and near EW-trending faults</td>
<td>Huangshanling anticline</td>
<td>NE-trending faults and folds, the porphyry and its hosting siltstone</td>
</tr>
<tr>
<td>Ore body location</td>
<td>Cu-bearing porphyries, Cu-bearing skarns and Cu-bearing pyrites developed along the contact zones between the main intrusion and the limestone, siliceous limestone, silty limestone and calcareous shaleand</td>
<td>Copper-bearing ore body developed in the contact zone between Matou granodioritic porphyry and sandstone of Silurian Fentou Group; Mo-bearing ore body existed in the fissures between Matou intrusion and the surrounding rock, occurred as ore-bearing quartz vein and molybdenite vein</td>
<td>Cu ore bodies developed in skarn dolomite marble and skarn in the contact zone, Mo ore bodies are mainly distributed in the quartz diorite porphyry</td>
<td>Structural fracture zone</td>
<td>Skarn in the top of Ordovician Tangtou Formation, and contact zone between Guilingzheng granite porphyry and Ordovician Lunshan Formation strata</td>
<td>The Au ore bodies developed along cracks and fractures</td>
</tr>
<tr>
<td>Ore minerals</td>
<td>Chalcopyrite, pyrite, magnetite, pyrrhotite</td>
<td>Chalcopyrite, molybdenite, pyrite, magnetite</td>
<td>Chalcopyrite, molybdenite, pyrite, pyrrhotite</td>
<td>Pyrite, arsenopyrite</td>
<td>Molybdenite, sphalerite, scheelite, pyrrhotite, chalcopyrite</td>
<td>Pyrite, arsenopyrite, limonite, haematite</td>
</tr>
<tr>
<td>Petrogenic age</td>
<td>145–146 Ma</td>
<td>140–147 Ma</td>
<td>139–150 Ma</td>
<td>142–148 Ma</td>
<td>127 Ma</td>
<td>141–147 Ma</td>
</tr>
<tr>
<td>Metallogenic age</td>
<td>150.98 ± 0.78 Ma (the Re–Os isotopic ages of molybdenite and pyrite)</td>
<td>148–149 Ma (the Re–Os isotopic ages of molybdenite)</td>
<td>136 Ma (Ar–Ar dating of sericite)</td>
<td>127.5 Ma (the Re–Os isotopic age of molybdenite)</td>
<td>141–147 Ma Early Cretaceous</td>
<td>141–147 Ma Early Cretaceous</td>
</tr>
</tbody>
</table>
Yangliugang, Huangboling Formation, Ordovician Guniuian, Honghuayuan, Lunshan Formation, Silurian Fengtou and Gaojibian Formation, and Nanhua system. The marble limestone of Ordovician Honghuayuan Formation is the major wall-rocks of the deposit. The major faults consist of Dongzhi fault, Sangangjian-Yangmeiqiao anticline, Huashan-Yanghu basement fault, and NEE-trending Gaotan Fault, with the major structure being a series of NNE-, NE-, and EW-trending fault (Figure 2). These faults have undergone multiphase activities and control the distribution of lithologies and ore bodies.

The Late Jurassic-Early Cretaceous magmatic rocks in the mine include middle-shallow granodiorite, granodiorite porphyry, diorite porphyrite, dacite porphyrite, and granite porphyry. In addition to granodiorite, other rocks generally have strong alteration and formed pyrite-bearing sericite. The wall-rocks are of contact metamorphism, such as skarnization and marbleization. The ore bodies are hosted in the structural fracture zone. And the gold mineralization had a close relationship with post-magmatic hydrothermal alteration, and then the gold was enriched and deposited under the continuous magmatic activity and hydrothermal action. The homogeneous temperature of quartz-hosted fluid inclusions is 110–245°C with an average value of ca. 160°C, and the salinity is 0.4–4.0%NaCl_eqv with an average of 2.3% NaCl_eqv, suggesting the ore-forming fluid characterizes low temperature and low salinity. The δ¹⁸O and δD isotopic compositions of quartz from gold ore are −1.57 to 4.6‰ and −73 to −54‰, respectively, indicating that the ore-forming fluids mainly come from magmatic hydrothermal sources mixed with meteoric water (Nie et al. 2017). The Zhaceqiao gold deposit is predominantly characterized by low temperature and hydrothermal.

### 3.2. Tongshan Cu–Mo deposit

The Tongshan copper deposit as a typical of many ore-bearing plutons in the Anqing-Guichi district of the LYRMB is located at the margin of Guichi district, which is in the Lower Yangtze fold belt at the northern part of the Yangtze Craton (Figure 1). The intrusion is structurally located at the bend in the Tongshan arc-shaped structure in the southeastern flank of the Laoshan anticline (Figure 3). Strata in the area mainly comprise sedimentary rocks of the Upper Silurian siltstone of the Maoshan anticline (Figure 3). The surrounding country rocks are Silurian-Devonian clastic sediments and Carboniferous-Permian carbonate rocks. In the contact zone, the rocks...
are mainly marble, dolomitic marble, hornfels, calcareous skarn, and magnesian skarn. Ore-bearing strata mainly include the limestones from the Huanglong-Chuanshan Formation of Carboniferous and the Lower Permian Qixia Formation (Zhou 2003). Prominent faults strike E–W, N–S, and NE–SW, representing favourable sites for mineralization.

The Tongshan intrusion is mainly composed of quartz diorite, quartz monzonite porphyry, and granodiorite (outcrop area: ca. 2 km², Yu and Yuan 1999). Granodiorite is most closely related to copper sulphide mineralization. The granodiorite yields a zircon LA-ICP-MS U–Pb age of 146.3 ± 3.2 Ma (Yu et al. 2014). SHRIMP zircon U–Pb dating indicated that the quartz monzonite porphyry was emplaced at 145.1 ± 1.2 Ma (Zhang et al. 2011). The major ore types of the Tongshan copper deposit is Cu-bearing porphyries, Cu-bearing skarns, and Cu-bearing pyrites, among which the Cu-bearing skarns are related to the calc-alkaline porphyries (Yu and Yuan 1999). Major ore minerals include chalcopyrite, pyrite, magnetite, and pyrrhotite.

3.3. Matou Cu–Mo deposit

The Matou Cu–Mo–(±W) deposit is located in the Meicun Village, Guichi district. The main strata units include Ordovician to Middle Triassic marine clastic sedimentary rocks and carbonates, Late Triassic to Jurassic swamp-facies continental sedimentary rocks and intercalated coal beds, and Cretaceous evaporites, red beds, and terrestrial volcanic rocks. The exposed country rocks at the Matou deposit (Figure 4(a)) are Silurian–Devonian clastic sedimentary rocks, with the granodiorite porphyry emplaced into the Silurian clastic rocks. Faults are widely developed in the mine, mainly NE–NNE-, NW-, NEE-, and NS-trending. These faults are extensional, transtensional, or transpressional with limited extension at depth and have little influence on the continuity of the major deposits.

The ore-hosting intrusions are the Xiachong granodiorite porphyry. Zircon SIMS U–Pb dating of ore-bearing granodiorite porphyry yields 145.1 ± 1.2 Ma (Zhu et al. 2014). The ore body is hosted both within the porphyries and the inner and outer contact zone of the surrounding
rocks. The ore zone (1200 m long and 300–400 m wide) is NNE-trending. The ore type is mainly composed of molybdenite-quartz vein type, chalcopyrite-quartz vein type, film-like molybdenite type, and disseminated type. Mineralization temperature is mainly restricted to 120–438°C, with salinity being 0.2–47.2% NaCl eqv (Wang 2012). The δ34S values of the pyrite, molybdenite range from 1.2‰ to 9.0‰ (Wang 2012), indicating that the ore-forming materials were mainly magma-derived. The δ18O- and δD values from hydrothermal vein-type quartz are, 10.03–11.18 and 0.59–1.74 (Wang 2012), respectively, indicating that the ore-forming fluids were mainly derived from magmatic hydrothermal fluids, with an addition of meteoric water at the late stage.

3.4. Paodaoling Au deposit

The Paodaoling Au deposit is located ~20 km south of Chizhou city (Figure 1). More than 30 tons of gold reserves have been confirmed (Duan et al. 2012), and the ore bodies may extend along strike to a greater depth. The main ore body is controlled by the NE-trending faults (Figure 4(b)). The ore-hosting rocks are surrounded by the Silurian siltstone of the Gaojiabian Formation, which were influenced by Late Jurassic-Early Cretaceous magmatic intrusion and later stage tectonic activity, and were commonly developed with silicification and pyritization (Chen and Ying 2002). Sulphide-bearing veins commonly contain realgar, orpiment, arsenopyrite, galena, and sphalerite. Hydrothermal alteration had caused mineralization along cracks and fractures and formed the Au ore bodies (Duan et al. 2012).

Magmatism in study region was mainly in the Early Cretaceous, including the Paodaoling porphyry, the Huayuangong intrusion (Figure 4(b)). The porphyry (outcrop area: ca. 1 km²) is closely associated with the Au mineralization, which is in the shape of a belt with dendritic intrusion with NE 40–50° direction, dipping NW with angles of 45–60°. LA-ICP-MS zircon U–Pb dating of the ore-bearing porphries has yielded 141–140 Ma ages (Duan et al. 2012). The Au ore bodies occur mainly in the dacite porphyry, and only a few smaller ore bodies are hosted by the Silurian Gaojiabian Formation (Figure 4(b)). The average thickness of the ore bodies is 12–20 m, with Au content of 1.4–2.6 g/t. Gold-hosting minerals include mainly pyrite, followed by arsenopyrite, limonite and hematite, and minor sphalerite, jamesonite, glue pyrite and marcasite, plus fewer galena, chalcopyrite, and leucospinite, and trace petzite natural gold.

3.5. Anzishan Cu–Mo deposit

The Anzishan Cu–Mo deposit is located in Meijie Town, Guichi area. Folds and faults are present in the mine, with the major fold being the Gaotan-Anzishan anticline (Figure 1), whose limbs comprise mainly of Ordovician Lunshan Formation and Silurian sequences. The Silurian and Ordovician sequences are the principal wall-rock and contains of sand shale and carbonate. Tongshan-Anzishan deep fault, Gaotan-Anzishan basement fault, and Donghu-
Anzishan basement fault control the emplacement of magmatic intrusion and fluid transportation. Intrusive rock types include Qingyang granodiorite, Anzishan quartz diorite porphyrite, and Niubeiji granodiorite porphyry controlled by the Gaotan-Anzishan fault, as well as dikes of granite porphyry, quartz diorite porphyry, and granodiorite porphyry. Among these rock types, Anzishan quartz diorite porphyry is the porphyry Cu ore-bearing rocks.

The main types of the deposit are porphyry and skarn type. The copper ore bodies mainly occur in the contact zone between the Anzishan quartz diorite porphyry and the Lower Ordovician dolomite, whereas the Mo ore bodies develop in Anzishan quartz diorite porphyry. The S and lead isotopic values of the pyrite, chalcopyrite, and molybdenite indicate that the ore-forming materials are derived from mantle-crust magma mixed with meteoric water and the ore-forming fluids are from deep magmatic water, with an addition of groundwater and meteoric water extracted from the wall-rock (Bureau of Geology and Mineral Resources of Anhui Province 2005).

3.6. Guilinzheng Mo deposit

This is a medium skarn deposit with a reserve of 151,606 t Mo (average grade: 0.127%). The Guilinzheng Mo deposit is situated at the deep of the Huangshanling Pb–Zn deposit. Lithological sequences exposed in the mine are Silurian Gaojiabian Formation, Ordovician Wufeng, Tangtou, Baota, Datianba, Honghuayuan, and Lunshan Formation (Figure 5). These sequences trend SE with dip angles of 8°–44° (Chen 2016). The major structure in the mine is the Huangshanling anticline. Major faults are SE- (45°–55°) and NNE- (50°–75°) trending. The Huangshanling anticline controls the emplacement of the granitoids and ore bodies.

The ore-causative granitoids are made up of granite porphyry, which is located in the deep of the mine and intruded into the southeast limb of the Huangshanling anticline and the carbonate sequences of Lunshan Formation. Granite porphyry comprises of K-feldspar (40–60%), quartz (35–40%), plagioclase (5–10%), and minor biotite (<5%), with accessory minerals including magnetite, apatite, zircon and sphene. The age of the zircon LA-ICP-MS U–Pb dating of granite porphyry is 126.8 ± 1.4 Ma, whereas the Re–Os dating of the molybdenite is 127.5 Ma indicating the mineralization age (Chen 2016). Mo ore bodies mainly occur in the contact zone between intrusion and Ordovician limestone, Ordovician carbonaceous siliceous shale, and granite porphyry. The ore minerals are made up of molybdenite, sphalerite, scheelite, pyrrhotite, and chalcopyrite, whereas the Mo occurs in molybdenite. The Re contents of molybdenite vary from 1.692 to 112.1 ppm, with an average value of 38.65 ppm, showing that the ore-forming materials are mainly derived from crust (Chen 2016).

4. Sample descriptions and analytical methods

4.1. Sample description

For our work, nine granodiorite samples (03TS) and three quartz diorite porphyrite samples (15LTJ) were collected from Tongshan Cu–Mo deposit and Anzishan Cu–Mo deposit, respectively. The Tongshan granodiorite has a porphyritic texture with ~60% phenocrysts. The phenocrysts are plagioclase (42–45%), hornblende (8–12%), biotite (~5%), K-feldspar (~2%), and quartz (~2%). The matrix is microcrystalline with a crystal size of <0.1 mm, which comprises quartz (20–25%),

Figure 5. Simplified geological map (a) and the No.41 cross-section (b) of the Guilinzheng Mo deposit (Chen 2016).
K-feldspar (~15%), and accessory minerals (~1%) of magnetite, titanite, apatite, zircon, and allanite. The Anzishan quartz diorite porphyrite has a porphyritic texture and massive structure. The phenocrysts are hornblende (5–10%), plagioclase (50–60%), biotite (~5%), and quartz (15–20%). Polysynthetic twins and oscillatory zoning characterize the plagioclase. The matrix has a micro-poikilitic texture with a crystal size of 0.2–0.5 mm, which comprises K-feldspar, quartz, and accessory minerals of magnetite, pyrite,apatite, and zircon.

Zircons were separated from one of the fresh samples from Tongshan Cu–Mo deposit, Anzishan Cu–Mo deposit and Zhaceqiao Au deposit, and were used for LA-ICP-MS U–Pb dating and LA-MC-ICP-MS Hf isotope analysis.

### 4.2. Major and trace elements

Whole rock major and trace elements were analysed at the ALS Mineral Laboratory in Guangzhou. Fresh samples were powdered using an agate mill to grain size b200 mesh. Major elements were determined using X-ray fluorescence (XRF) spectrometry with standard deviations within 5%. The detailed methodology is as follows: Loss of ignition was determined after igniting sample powders at 1000°C for 1 h. A calcined or ignited sample (0.9 g) was added to 9.0 g of Lithium Borate Flux (Li2B4O7–LiBO2), mixed well and fused in an auto fluxer between 1050°C and 1100°C. A flat molten glass disc was prepared from the resulting melt. This disc was then analysed by wavelength-dispersive XRF spectrometry using an AXIOS Minerals spectrometer. Trace elements, including rare earth element (REE), were determined by inductively coupled plasma mass spectrometry (ICP-MS) of solutions on an Elan DRC-II instrument (Element, Finnigan MAT) after 2-day closed beaker digestion using a mixture of HF and HNO3 acids in Teflon screw-cap bombs. Detection limits, defined as 3 s of the procedural blank, for some critical elements are as follows (ppm): Th (0.05), Nb (0.2), Hf (0.2), Zr (2), La (0.5), and Ce (0.5). The uncertainties in the analysis for most elements were less than ±10% (Supplementary Table 1). Major element, trace element, and REE analytical results are listed in Supplementary Table 2.

### 4.3. Zircon U–Pb isotopes analyses

Zircon grains were separated from samples Anzishan quartz diorite porphyrite, Tongshan granodiorite, and Zhaceqiao intrusive rocks mounted in epoxy resin, polished down to near half sections, and then photographed in reflected and transmitted light. The transmitted and reflected light images of the grains were photographed, and cathodoluminescence (CL) images of the zircons were taken using micro-probe JEOL JXA-8100 electron microanalyses at CAS Key Laboratory of Crust-Mantle Materials and Environments in University of Science and Technology of China, Hefei. The U-Pb isotopic composition of zircons were analysed by an Agilent 7500a ICP-MS coupled with a Resonetic Resolution 50-M ArF-Excimer laser source (λ = 193 nm) at CAS Key Laboratory of Crust-Mantle Materials and Environments in University of Science and Technology of China, following the procedures outlined by Tu et al. (2011). The ablated spot diameter of the ion beam was set at ~32 μm. Each analysis comprises a background acquisition interval of approximately 19 s and a signal acquisition of about 40 s. U, Th, and Pb concentrations were calibrated using NIST SRM610 as the external standard. All measurements were performed using zircon 91500 as the standard for optimizing the instrument. Analyses of every four samples were followed by those of two of standard samples (91500 and NIST SRM610). The standard operating procedures have been described in detail by Li et al. (2009). The calculation of zircon isotope ratios and trace elements was performed by ICPMSDataCal 9.6 (Liu et al. 2008a, 2010b), and the data were treated with the ISOPLOT programme of Ludwig (2003). The uncertainties for individual analyses (ratios and ages) are quoted at the 1σ level, whereas the errors in the Concordia and weighted mean ages are quoted at the 2σ level. Error ellipses in Figure 6 correspond to the input errors reported in Supplementary Table 3. The data quality was monitored by the 91500 standard measurements. Dating of 91500 resulted in 1067 ± 10 Ma Concordia age (MSWD = 0.3, n = 5) and weighted averages 206Pb/238U age of 1067 ± 15 Ma (MSWD = 3.8), which agrees with the reference value of 1065.0 ± 0.6 Ma (Wiedenbeck et al. 1995).

### 4.4. Zircon Lu–Hf isotopes

After zircon U–Pb isotope measurement, the in-situ analyses of Lu–Hf isotopes was conducted on a Nu Plasma HR multiple-collector inductively coupled plasma mass spectrometer (MC-ICP-MS), equipped with a GeoLas2005 193 nm excimer ArF laser-ablation system, at the State Key Laboratory of Continental Dynamics in Northwest University. The instrumental conditions and data acquisition were described by Yuan et al. (2008). Hafnium isotopes were measured on the MC-ICP-MS instrument with a beam diameter
of 44 μm, 8 Hz repetition rate, and a laser power of 90 mJ. The corrections to raw Lu–Hf isotopic data followed the protocols of Yuan et al. (2008). Isobaric interference of $^{176}\text{Lu}$ on $^{176}\text{Hf}$ was corrected by measuring the intensity of the interference-free $^{172}\text{Lu}$ isotope and using a recommended $^{176}\text{Lu}/^{172}\text{Hf}$ ratio of 0.02655 to calculate $^{176}\text{Lu}/^{177}\text{Hf}$ ratios. The isobaric interference of $^{176}\text{Yb}$ on $^{176}\text{Hf}$ was corrected by measuring the interference-free $^{172}\text{Yb}$ isotope and using a recommended $^{176}\text{Yb}/^{172}\text{Yb}$ ratio of 0.5886 (Chu et al. 2002). In doing so, a mean $^{173}\text{Yb}/^{171}\text{Yb}$ ratio for the analysed spot itself was automatically used in the same run to calculate a mean $\beta_{\text{Yb}}$ value, and then the $^{176}\text{Yb}$ signal intensity was calculated from the $^{173}\text{Yb}$ signal intensity and the mean $\beta_{\text{Yb}}$ value (Iizuka and Hirata 2005). All the Lu–Hf isotope results are reported in 2σ error. Zircons 91500 and GJ-1 were used as the reference standard during our routine analyses, with mean $^{176}\text{Hf}/^{177}\text{Hf}$ ratios of $0.282316 \pm 0.000009$ and $0.282022 \pm 0.000012$, respectively, coincident with the recommended values of

Figure 6. Zircon U–Pb concordia diagram for the intrusive rocks in Guichi region and representative cathodoluminescence (CL) images of dated zircon crystals.
0.282306 ± 0.000010 for 91500 (Woodhead et al. 2004) and 0.282015 ± 0.000019 for GJ-1 (Elhlou et al. 2006) within analytical errors, respectively. In the calculation of $\varepsilon_{\text{Hf}}(t)$, the recommended decay constant value of $^{176}\text{Lu}$ is $1.867 \times 10^{-11}$ year$^{-1}$, the $^{176}\text{Lu}/^{177}\text{Hf}$ and $^{176}\text{Hf}/^{177}\text{Hf}$ values of chondrite are 0.0336 and 0.282785, respectively (Bouvier et al. 2008).

5. Results

5.1. Zircon U–Pb dating

Zircon U–Pb isotope data for intrusive rocks from Tongshan and Anzishan copper deposits and Zhaceqiao gold deposit are presented in Supplementary Table 3. Errors on individual analyses are cited as 1σ, and the weighted mean $^{206}\text{Pb}/^{238}\text{U}$ ages are quoted at the 90% confidence level. The zircon grains are subhedral to euhedral and prismatic morphology and show typical oscillatory magmatic zoning (Figure 6). Concentric zoning typical of magmatic zircons is common and some inherited cores can also be observed under CL images. The Anzishan quartz diorite porphyrite produced a weighted mean age of 143.9 ± 1.0 Ma (MSWD = 0.49, $n = 17$) (Figure 6(a)). Whereas, the Tongshan granodiorite yielded a weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age of 144.6 ± 2.2 Ma (MSWD = 1.05, $n = 15$) (Figure 6(b)). Two samples from the Zhaceqiao granodioritic porphyries gave weighted mean $^{206}\text{Pb}/^{238}\text{U}$ ages of 143.8 ± 3.0 Ma (MSWD = 0.11, $n = 8$) and 148.3 ± 1.7 (MSWD = 0.12, $n = 18$) (Figure 6(d),f), respectively. Zircons from the Zhaceqiao granodiorite and diorite porphyrite yielded weighted mean $^{206}\text{Pb}/^{238}\text{U}$ ages of 145.4 ± 1.6 Ma (MSWD = 0.23, $n = 22$) and 142.8 ± 2.3 Ma (MSWD = 1.01, $n = 8$) (Figure 6(e,f)), respectively. All the samples contain inherited zircons with concordant ages ranging from 444 to 2116 Ma (Supplementary Table 3).

Together with previous research (Table 1), the magmatic zircon U–Pb ages range from 123 to 150 Ma, indicating a protracted period of magmatism during the Late Jurassic-Early Cretaceous in the Guichi area. Thus, these late Mesozoic magmatic rocks can be subdivided into two stages of development (Table 1, Figure 7(a)). The first stage (150–132 Ma) is characterized by high-K calc-alkaline intrusions that are closely associated with Cu–Au polymetallic ore deposits. Whereas, the second stage (130–125 Ma) produced granites and syenites and is

![Figure 7](image-url)
mainly characterized by shoshonite series that are related to Mo–Cu mineralization.

5.2. Whole-rock geochemistry

The whole-rock major and trace elements of Tongshan granodiorite and Anzishan quartz diorite porphyrite are listed in Supplementary Table 2. For detailed comparison, we have also included literature data from magmatic rocks of the Guichi area.

The first-stage samples are mainly diorite and granodiorite, and span a range of 54.62–70.99 wt.% SiO$_2$ with Na$_2$O content (1.28–4.65 wt.%) and K$_2$O/Na$_2$O ratios (0.53–2.80). On the QAP and K$_2$O versus SiO$_2$ diagrams, the samples mostly plot in the fields of the diorite, Q-monzodiorite, and granodiorite and belong to the high-K calc-alkaline series (Figure 8(a,c)). The second-stage samples have relatively high SiO$_2$ (63.91–76.67 wt.%) and medium Al$_2$O$_3$ contents (11.64–15.89 wt.%), and they mainly plot in the fields of the granite, quartz monzonite, and syenogranite and belong to the shoshonite series (Figure 8(b,d)).

The total REE content of the Guichi intrusive rocks ranges from 59.0 to 510 ppm, with a mean value of 177 ppm. All the samples display LREE enrichment and HREE depletion, with weak positive to obvious negative Eu anomalies (Figure 9(a,c)). In the N-MORB-normalized incompatible trace element spider diagrams (Figure 9(b)),

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**Figure 8.** QAP diagram (after Streckeisen 1976) (a, b) and SiO$_2$ versus K$_2$O diagram (after Peccerillo and Taylor 1976) (c, d) of intrusive rocks from Guichi area. Data sources: Zhang et al. (2011), Liu et al. (2012), Nie et al. (2016), Zhu et al. (2014), Wang (2012), Song et al. (2014), Wang (2015), Chen (2014), Duan et al. (2012), He (2013), Liu (2015), Gao (2016), Yang et al. (2016b), Li et al. (2012), Duan et al. (2015).
all samples show similar patterns with enrichments in the LREEs and large ion lithophile elements (LILEs) such as Rb, Th, U, and depletion in the high field-strength element (HFSEs) such as Nb, Ta, P, and Ti, all of which indicates arc magmatism or crustal affinities. The first-stage samples show a variable enrichment in Sr and lower Y contents (8.6–21.4 ppm), clearly different from the high Y signature (26.3–61.6 ppm) that characterizes the second-stage samples (Figure 9(b,d)). On the Sr/Y versus Y and YbN versus (La/Yb)N diagram (Figure 10(a,b)), most of the first-stage samples plot in the adakite field, whereas, on the 10000*Ga/Al versus Nb and 10000*Ga/Al versus Y diagrams, the second-stage samples plot in the A-type granite field (Figure 10(c,d)).

5.3. In situ zircon Hf isotopes

Zircon Lu–Hf isotopic compositions of Zhaceqiao granodiorite porphyry are given in Supplementary Table 4. For the Zhaceqiao intrusion, the zircons with Mesozoic ages give measured $\epsilon_{Hf}(t)$ values that range from −28 to 1.8 (average −4.4), corresponding to two-stage Hf model ages ($t_{DM2}$) of 1081–2965 Ma (Supplementary Table 4). The zircon $\epsilon_{Hf}(t)$ values of Tongshan granodiorite are from −7.6 to −2.1, corresponding to two-stage Hf model ages ($t_{DM2}$) of 1138–1422 Ma (Supplementary Table 4).

6. Discussion

6.1. Geochronological framework

The large dataset obtained for this study and literatures makes it possible for the first time to give an objective geochronological framework for Mesozoic magmatism in Guichi region since the previous data were sporadic. The zircon U–Pb ages of Guichi region yield two age groups of 150–132 Ma and 130–125 Ma (Table 1; Figure 7(a)). The first episode mainly is composed of diorite and granodiorite porphyries (e.g. Tongshan, Matou, Anzishan, Paodaoling, Zhaceqiao, Zhaojikou, Huangshanling, Xuqiao deposits). All of them are characterized by adakitic rocks (Figure 10(a,b)) and occur mainly as small batholiths, including the Matou and Qingyang intrusions that are associated with Cu–Au deposits. The second episode is comprised of granites, granite porphyries, and dacites, including the largest intrusion, such as Jiuhuashan, Huayuangong, Maotan, and Tanshan plutons. The rocks are mostly enriched in alkali feldspar, with lesser amounts of mafic minerals, and are granite, syenogranite, alkali feldspar granite, syenite in composition. Some of these rocks have obvious features of A-type granites (Figure 10(c,d)) and related to Mo–Cu mineralization.
In contrast to the Guichi region, considerable geochronological data have been reported for the magmatic rocks from other regions in the LYRMB. Previous studies show that magmatic activity in the LYRMB can be divided into an earlier stage (148–130 Ma, Anqing, Tongling and Shaxi mining districts) and a later stage (130–106 Ma; Chuzhou and Ningzheng mining districts) (Yang et al. 2014). These data indicate the presence of a long-term magmatic event lasting from 152 to 120 Ma (Figure 7(c); Wang and McDougall 1980; Chen et al. 1991; Liu et al. 2010a; Li et al. 2012; Wu et al. 2012; Yang and Zhang 2012; Song et al. 2014; Yang et al. 2014; Wang et al. 2017; Wu et al. 2017; Yang et al. 2017).

The zircon ages in this study suggest that the Cu–Au–Mo deposits are products of magmatism and developed during the Early Cretaceous. The granitoid ages and age of Cu–Au–Mo mineralization (ca. 128–150 Ma) are synchronous and consistent with a peak ore-forming peak period at this time in the LYRMB (Figure 7). It follows that the Transitional Cu–Au–Mo Metallogenic Belt between the Lower Yangtze Fold and the Jiangnan Ancient Continent in which Guichi is located, and the LYRMB underwent simultaneous magmatic hydrothermal mineralization activity during the Early Cretaceous. Zhou et al. (2006) showed that there were two transformation periods (160–170 Ma and ca. 145 Ma) in the Yangtze Plate dynamic system in the Early Jurassic. Tectonic-magmatism occurred against a compressional background and was strongly activated in the northeastern Jiangxi in the northern Jiangnan Ancient Continent during the period 160–170 Ma. At this stage, the magmatism in southern Anhui was only weakly activated. After ca. 145 Ma, the Jiangnan Ancient Continent had the same tectonic setting as the LYRMB, with an extension background following an intracontinental orogeny. The Guichi magmatism is consistent with the LYRMB, beginning with porphyries associated with ore deposits and then dominated by ore-barren volcanic rocks and granites. This is very important because it would be helpful to identify whether there is any origin relationship between the two periods of magmatism. In summary, the magmatic zircon U–Pb ages of Guichi region range from 123 to 150 Ma, indicating a protracted period of magmatism during the Late Jurassic-Early

Figure 10. Sr/Y versus Y (a), (La/Yb)$_N$ versus Yb$_N$ (b), 10000*Ga/Al versus Nb (c) and 10000*Ga/Al versus Y (d) classification diagrams (Whalen et al. 1987; Defant and Drummond 1990; Castillo 2012) for magmatic rocks of the Guichi region. Data sources are the same as in Figure 8.
Cretaceous in the Guichi area. Thus, these late Mesozoic magmatic rocks can be subdivided into two stages of development (Table 1, Figure 7(a)), which may represent two independent magmatic activities. The first stage (150–132 Ma) is characterized by high-K calc-alkaline intrusions that are closely associated with Cu–Au polymetallic ore deposits. Whereas, the second stage (130–125 Ma) produced granites and syenites and is mainly characterized by shoshonite series that are related to Mo–Cu mineralization.

6.2. Origin of two episode rocks

6.2.1. First-stage high-K calc-alkaline intrusions

The first-stage magmatic rocks show consistent arc-like trace element distribution patterns with enrichments in LILEs and LREEs but depletion in HFSEs (Figure 9(b)), and have adakitic geochemical features similar to other Mesozoic adakites observed in the LYRMB (Wang et al. 2006; Ling et al. 2009; Liu et al. 2010a; Xie et al. 2012a, 2012b, 2017a; Deng et al. 2016; Hu et al. 2017).

The petrogenesis of these adakites in the LYRMB has been under debate in the past decade. Several genetic views have been proposed to account for the origin of these adakitic rocks, including: partial melting of the delaminated lower continental crust, followed by interaction with the mantle peridotites (Xu et al. 2002; Wang et al. 2004, 2006, 2007); fractional crystallization of basaltic magmas possibly coupled with crustal contamination (Xie et al. 2008; Li et al. 2009); partial melting of subducting oceanic slabs (Sun et al. 2007a, 2011; Liu et al. 2010a; Ling et al. 2011); ridge subduction between the Pacific plate in the south and Izanagi plate in the north (Ling et al. 2009; Sun et al. 2010; Luo et al. 2017).

The MgO contents of the Guichi adakitic rocks range from 1.01 to 3.96 wt.%, which is typical for adakites derived from slab melting in subduction zones (Defant and Kepezhinskas 2001). The Mg	extsuperscript{#} is a useful index for discriminating melts of crust origin from those that have interacted with the mantle. Melts from the basaltic lower continental crust are characterized by low Mg	extsuperscript{#} (<0.4) regardless of melting degrees, whereas those with Mg	extsuperscript{#} >0.4 can only be obtained with a mantle component involved (Rapp and Watson 1995). The dioritic rocks from Guichi and other places in the LYRMB have relatively high Mg	extsuperscript{#} (0.36–0.59) (Liu et al. 2010a), indicating the involvement of mantle components.

High Sr/Y and (La/Yb)	extsubscript{N} values are two important parameters in the identification of adakites (Defant and Drummond 1990; Martin et al. 2005; Moyen 2009). Guichi adakitic rocks have high Sr/Y ratios (20.2–85.1, with an average value of 38.3) and relatively low (La/Yb)	extsubscript{N} values (6.5–29.8, average 16.4), which are consistent with those of other LYRMB intrusive rocks and Cenozoic adakites from Vizcaino Peninsula in Mexico (Aguillón-Robles et al., 2001). In the Sr/Y versus (La/Yb)	extsubscript{N} diagram, most of the Guichi samples fall in the field defined by circumb-Pacifical adakites, which are dramatically different from adakites from the Dabie Mountains (Figure 12(b)). The former was derived from slab melting, whereas the latter was formed through lower continental crust melts. The enrichment of Sr, lack of negative Eu anomalies together with depleted Y and HREE (Figure 9) and highly varied (La/Yb)	extsubscript{N} (Figure 10), indicate the existence of garnet rather than plagioclase as a residue in the source (Defant and Kepezhinskas 2001). The strong depletion of Nb, Ta, and Ti (Figure 9(b)) suggests that the source has residual rutile (Xiong 2006).

The Sr–Nd compositions of the Guichi adakitic rocks can directly reveal their source features. Isotope compositions of adakitic rocks derived from oceanic crust are usually depleted with 86Sr/88Sr < 0.7040 (Defant and Drummond 1990), thus the slightly enriched isotope compositions (87Sr/86Sr = 0.707–0.710, εNd (t) = −8.7 to −5.0) of the Guichi adakitic rocks could be attributed to the involvement of old crust materials in their genesis. The old crustal materials involved in the petrogenesis of the Guichi adakitic rocks could be subducted sediments or continental materials incorporated in the source during partial melting, or added by magma mixing or crustal contamination. Initial Sr–Nd isotopic compositions of the Guichi adakitic rocks plot between MORB and enriched mantle (Figure 13), but are dramatically different from those of the Yangtze lower crust, which are consistent with those of the LYRMB adakites, but different from those of Dabie adakites. The Sr–Nd isotope compositions have been attributed to contamination of slab melts by enriched mantle components or the lower crust (Ling et al. 2009, 2011). Meanwhile, the Sr–Nd isotopic signatures of Guichi and LYRMB adakites are typically displaced toward the EM2 end member, reflecting the important role of sediments in magma source (Figure 13) (Liu et al. 2010a; Deng et al. 2016). The enriched Sr–Nd isotopic characteristics of Guichi adakites are best explained by slab melts with assimilation of enriched mantle components.

The Pb isotopic compositions also provide important constraints on the sources of these adakites. The Guichi adakitic rocks are characterized by high radiogenic Pb isotopes with 206Pb/204Pb = 17.40–19.73, 207Pb/204Pb = 15.47–16.62, and 208Pb/204Pb = 37.83–39.67, which mostly plot in the field of MORB and EM2, distinguished from those Dabie/STLF adakites with low radiogenic Pb
isotope ratios (Figure 14). Some samples are plotted in or near the field of marine sediments (Figure 14), also implying contribution of subducted sediments. The Sr–Nd–Pb isotopic features suggest that the Guichi adakitic rocks are derived from a mixture of sediments and basaltic oceanic crust.

The zircon Lu–Hf isotopic values suggest that adakitic rocks from the Guichi region have a large variation of $\varepsilon_{\text{Hf}}(t)$ values from −27.9 to 9.47, with centralized values of between −18 and −4 (Figure 11), and Mesoproterozoic Hf model ages ($T_{\text{DM2}}$) ranging from 1000 to 3900 Ma (Figure 11) with centralized values of between 1300 and 1800 Ma (Figure 11). This interpretation that the Guichi adakitic rocks were formed by the melting mixing of magmas derived from a metasomatized lithospheric mantle and Archaean crust, and which then assimilated some Neoproterozoic crust.

Considering the geochemical signatures discussed above, we propose that the Guichi adakitic rocks could derived from partial melting of subducted Palaeo-Pacific Plate, assimilated with Yangtze lower crust and remelting Meso-Neoproterozoic crust/sediments.

6.2.2. Second-stage A-type intrusions

The second-stage magmatic rocks of Guichi region contain high total alkalis ($K_2O + Na_2O = 7.51–9.66$ wt.%), A/ CNK and relatively low $Al_2O_3$ contents, with enrichment in REEs, and extreme depletion in Ba, Sr, P, Ti and Eu ($Eu*/Eu = 0.05–0.76$) and no Nb–Ta anomalies. Based on these characteristics, second-stage magmatic rocks from Guichi region can be classified as A-type granitoids (Figure 10(c,d)).

Two prevalent petrogenetic models for A-type magmas have been proposed: (1) crystal fractionation of basaltic magma with or without crustal contamination (Anderson et al. 2003; Mushkin et al. 2003) and (2) partial melting of specific crustal protolithes (Collins et al. 1982; Creaser et al. 1991).

Zircon Hf model ages ($T_{\text{DM2}}$) of the Guichi A-type granites range from 900 to 1700 Ma (Figure 11), suggesting that the Guichi granitic magma formed by partial melting of Meso-Neoproterozoic crust, which is also supported by the Meso-Neoproterozoic inherited zircons.

The Ce/Pb and Nb/Ta ratios of these A-type granites are within the range of 1.6–5.8 and 8.2–15.8, respectively, which are lower than those of primitive mantle (Ce/Pb = 9 and Nb/Ta = 17.5) but similar to the continental crust (Ce/Pb = 4 and Nb/Ta = 11–12) (Green 1995), suggesting their derivation from a crustal source. Their Nd ($T_{\text{DMC}} = 1.3–1.8$ Ga) model ages and zircon Hf model ages ($T_{\text{DM2}} = 0.9–2.0$ Ga) further suggest that the A-type granites were generated from Mesoproterozoic-Neoproterozoic crustal materials. A

Figure 11. The $\varepsilon_{\text{Hf}}(t)$ versus age diagrams (a, b) Hf model age histograms (c) of zircons from magmatic rocks in Guichi region. Data are from Hou and Yang (2009), Wong et al. (2009), Yang et al. (2016b), Yang and Zhang (2012), Wu et al. (2012), and Song et al. (2014).
compilation of Nd isotopic data from southeastern China has shown that the most important crustal formation events took place in the Proterozoic (Chen et al. 1991). Moreover, the Mesoproterozoic-Neoproterozoic rocks have εNd values similar to those of the Cretaceous granitic rocks (Chen et al. 1991).

High zircon saturation temperature (average ~760°C) of Guichi A-type granites indicates that the Guichi granites originated from partial melting under a relatively high-temperature environment (Figure 16(b)). The high and large ranges of Nb (25.5–68.7 ppm), Ta (2.2–6.75 ppm) contents, as well as low Y/Nb (0.5–1.7) ratios, indicate that they may be mixed with juvenile crust materials. Positive zircon εHf(t) values are frequently observed in Guichi A-type granites (Figure 11), such as Jiuhuashan alkali-feldspar granite (Wu et al. 2012), Dalishan granite (Chen 2014), Huayuangong granite (Liu et al. 2012), and Tanshan granite (Yang and Zhang 2012), implying a significant input of juvenile materials during magma generation.

The Guichi A-type granites show more significant negative Eu, Sr, Ba, P, and Ti anomalies in the spider diagrams and REE patterns (Figure 9), suggesting the fractionation of plagioclase, K-feldspar, apatite, and Fe–Ti oxides. The ‘V-shape’ REE patterns of the Guichi granites is considered to be a product of highly evolved granitic magma, suggesting the fractionation of plagioclase, monazite, thorianite (Xu et al. 2010). Furthermore, the V and Cr remain more or less constant rather than decreasing rapidly with increases in Rb (Figure 12), suggesting that fractional crystallization rather than partial melting played a major role in the chemical variations of the A-type rocks. The Guichi A-type granites show relatively high εNd(t) and zircon εHf(t) values; some εHf(t) values are >0 (Figure 9). They also exhibit higher zircon saturation temperatures than the first-stage rocks (Figure 16(b)). In the 207Pb/204Pb versus 206Pb/204Pb and 208Pb/204Pb versus 206Pb/204Pb diagrams (Figure 14), the initial Pb isotope of the A-type granites in Guichi region are plotted in the MORB and marine sediments area, indicating these A-type granites were derived from enriched lithospheric mantle.

These observations suggest that the formation of Guichi A-type granites involved addition of hot
asthenospheric mantle-derived magmas into the crustal magma chamber, followed by fractional crystallization. Similar granitic rocks with positive zircon $\varepsilon^{\text{Hf}}(t)$ values have also been reported in the LYRMB (Wong et al. 2009). Thus, mantle-derived magmas would provide not only sufficient heat energy for the melting of the crust by underplating into the crust–mantle interface (Zhou and Li 2000), but also some juvenile materials by upwelling along the Jiangnan Fault during the Cretaceous time. The upwelling of high-temperature mafic magma thus may lead to the long-term and extensive differentiation of felsic magmas (Zhou and Li 2000). All of these observations suggest that the investigated A-type granites were produced by the partial melting of Mesoproterozoic-Neoproterozoic crust, mixed with juvenile crust materials.

6.3. Tectonic evolution

The geochronology of Mesozoic intrusive-volcanic rocks of SE China shows that there was a ca. 25 Ma magmatic inactive period during Early Jurassic (205–180 Ma). This tectonic quiescence is regarded as the tectonic regime change from the influence of the Indosinian orogeny as part of the large-scale Tethyan tectonics to the influence of the late Mesozoic orogeny genetically associated with the western Palaeo-Pacific tectonics (Zhou et al. 2006). Therefore, the SCB became an active Jurassic-Cretaceous continental margin related to the subduction of the Palaeo-Pacific plate (Zhou and Li 2000; Zhou et al. 2006), and the margin was related to the subduction of the Palaeo-Pacific plate. The late Mesozoic intrusive-volcanic rocks resulted from the NW-WNW subduction of the Palaeo-Pacific plate beneath the eastern Asian continent. Therefore, the late Mesozoic magmatism in the SCB experienced three stages (Zhou et al. 2006): (1) intraplate magmatism including initial rift-type magmatism at the Middle-Late Jurassic period; (2) continental margin...
arc magmatism at the Early Cretaceous stage; and (3) tholeiitic basalt volcanism recorded in red beds of back-arc basins at the Late Cretaceous stage.

Zhou and Li (2000) pointed out that the late Mesozoic rocks in the NE Yangtze Block were related to the possible westward subduction of the Palaeo-Pacific oceanic plate. However, this model is inconsistent with a wide (>1000 km) magmatic belt and rock suites of A-type granites, bimodal volcanic rocks, and shoshonitic rocks (Wang et al. 2006; Wu et al. 2012). Moreover, as more high-precision zircon U–Pb ages have been accumulated (Liu et al. 2010a; Wu et al. 2012), the coastward young trend proposed by Zhou and Li (2000) has become much less obvious. Sun et al. (2007a) noted dramatic changes in the drift direction of the Palaeo-Pacific plate at ~125–122 Ma and correlated such changes with gold mineralization in eastern China. This model is reasonable since that the granites in Yangtze Block are controlled by the northwestward subduction of the Palaeo-Pacific plate, which can be further proven by the facts that 1) the Yangtze Block is NE-striking tectonically; 2) most of the granites in this region are elongated in a NE-SW orientation, similar to the distribution of regional Cretaceous granites in the coastal area. The tectonic discrimination diagrams (Figure 16(c,d)) also show that the adakitic rocks and A-type granites in the Guichi region plot in the compositional space straddling from volcanic arc granites to within-plate granites.

Integrating with the association of Cretaceous bimodal volcanic rocks, within-plate mafic rocks, rift basins, and metamorphic core complexes in the hinterland of southeastern China (Wang et al. 2006; Xie et al. 2012b), we suggest that the two episode magmatic rocks were most plausibly related to an extensional lithospheric setting. As discussed above, these adakitic rocks in Guichi region (150–132 Ma) are attributed to partial melting of subducted oceanic crust, assimilated with Yangtze lower crust and remelting Meso-Neoproterozoic crust/sediments. Whereas, these A-type granitic rocks (130–122 Ma) are likely to have formed at the last stage of continental arc formation, corresponding to the drift direction of the Palaeo-Pacific plate, probably at the beginning of the extension of back-arc or the rifting of continental arc. The underplating of mantle-derived magmas as a consequence of back-arc extension or intra-arc rift triggered the partial melting of Neoproterozoic crust, with input of the juvenile magma, and followed by fractional crystallization.

According the method of Ballard et al. (2002), the early-stage adakitic rocks (150–132 Ma) are copper-gold-related and characterized by high Ce\(^{4+}/\text{Ce}^{3+}\) ratios (32.29–3594, avg. 411), indicating an oxidized condition for their sources (Sun et al. 2012, 2013, 2015). However, the calculated Ce\(^{4+}/\text{Ce}^{3+}\) ratios of zircons from the late-stage A-type granites vary from 1.0 to 573.3 (avg. 95.0), which are systematically lower than the ratios of zircons from the earlier-stage adakitic rocks (Figure 16(a)). The systematic decreasing trend of zircon Ce\(^{4+}/\text{Ce}^{3+}\) ratios from the copper-gold-related adakitic rocks to the A-type granites indicates less oxidizing magma source conditions of felsic igneous rocks during the magmatic evolution in the Guichi area.

Estimations of the zircon saturation temperatures for the adakitic rocks from Guichi region are lower than that of A-type granites (Figure 16(b)). Clearly, as the magma sources became shallower, the temperature of the magma increased, no matter whether the magma source was the mantle or crust. The systematic changes in magma P-T conditions are not only consistent with an increase in the intensity of extensional activity, but also imply that the early stages of mantle partial melting were under hydrous conditions, enabling magma generation under cooler conditions. In this regard, it is reasonable to assume that the tectonic setting for the adakitic magmatism is a continental arc, which was subsequently transformed to an extensional setting, and possibly a back-arc setting that formed as a result of drift of the subducted slab (Sun et al. 2007a; Wong et al. 2009), leading to A-type granitic magmatism in response to the drift of subduction direction of the Palaeo-Pacific plate (Sun et al. 2007a; Yang et al. 2011a; Yang and Lee 2011b; Deng et al. 2012; Duan et al. 2012; Li et al. 2012; Wu et al. 2012).

Integrating with previous regional studies, we propose a tectono-magmatic model for the Early Cretaceous intracontinental compressional-extensional transition in Guichi region in order to explain the generation of early adakitic rocks, and later A-type granites, as shown schematically in Figure 17.

(1) Before 148 Ma, the Palaeo-Pacific oceanic slab was subducted at low angles beneath the continental lithosphere in the Lower Yangtze River area (Li and Li 2007). Fluids from the dewatering of subducting sediments and basalts metasomatized the mantle wedge. Basaltic magmas formed by partial melting of the metasomatized mantle wedge intrude along the mantle–crust boundary, triggering melting of the Archaean LCC (Wu et al. 2012; Zhu et al. 2014; Yan et al. 2015) and eventually
leading to mixing of juvenile and evolved magmas and formation of a thickened juvenile LCC.

(2) From 148 to 135 Ma, the dip angle of subduction increased, possibly due to the eclogitization, which increased the density of the subducted slab (Zhou and Li 2000), thus producing even more intense dewatering and partial melting of the subducted sediments and basalts under relatively high P-T conditions. Meanwhile, the increased angle of subduction resulted in the tectonic setting to transform from one of a continental arc to one of extension, and the accompanying upwelling of hot asthenosphere triggered the partial melting of the thickened juvenile LCC to form the adakitic rocks (Figure 17(a)). Together with the high-K calc-alkaline magmatic rocks, adakitic rocks all display the geochemical characteristics of arc igneous rocks, representing the background of the continental margin, such as Anzishan quartz diorite porphyry, Matou granodiorite porphyry (Zhu et al. 2014), and Tongshan pluton (Zhang et al. 2011) (Figure 17(a)).

(3) Subsequently, the Pacific Plate subduction was rotated to become forward subduction, causing regional extension, which placed the Lower Yangtze River area in a back-arc setting. Ongoing lithospheric extension and crustal thinning induced more intensive underplating of the mantle-derived mafic magma. The extension enabled the fault planes of regional faults to propagate to greater depths and resulted in opening of the fault zones. Thus, the fault systems likely provided a suitable conduit for ascending mantle-derived melts, and resulted in the influx of heat into the middle-upper crust. In this scenario, the underplated magma migrated upward, crossing the fault and reaching the shallow part of crust. The ascent of mafic magma triggered decompression melting of the overlying Neoproterozoic rocks to produce the A-type parental magmas (Figure 17(b)).

6.4. Metallogenic model

Adakites from the circum-Pacific have strong association with Cu–Au deposits (Sajona and Maury 1998; Kay et al. 1999; Sun et al. 2011, 2012; Deng et al. 2016), and the close genetic association between porphyry Cu–Au deposits and adakites has been proposed for more than a decade (Thieblemont et al. 1997). In places where adakites coexist with non-adakitic igneous rocks, mineralization is usually associated with the adakites (Thieblemont et al. 1997). This model has gained wide support, and Sajona and Maury (1998) further proposed that most of the porphyry Cu and epithermal Au deposits are closely related to adakites in terms of age and space.

We have proposed the Guichi adakitic rocks were formed through partial melting of subducted oceanic slab, thus favourable for Cu mineralization, given that the oceanic crust has higher initial Cu contents than the continental crust and mantle (Sun et al. 2004, 2011). Slab-derived melts/fluids, which have high oxygen fugacity, are generally considered to favour Cu–Au mineralization (Oyarzun et al. 2001; Ballard et al. 2002; Mungall 2002; Kelley and Cottrell 2009; Sun et al. 2011; Wang et al. 2013; Zhang et al. 2013). High oxygen fugacity may remove sulphide in the source region and make the melt sulphide under-saturated, thereby promoting porphyry copper mineralization (Sun et al. 2012, 2013, 2015, 2017). The zircon Ce⁴⁺/Ce³⁺ and Eu/Eu* ratios of ore-bearing adakitic rocks from Cu–Au deposits show that this ore-bearing adakitic rocks were formed at high oxygen fugacity (Figure 16(a)). High oxygen fugacity can extract additional sulphur in the form of sulphate during partial melting, liberating more chalcophile elements, which are consequently scavenged by magmatic fluids when the oxygen fugacity is reduced (Sun et al. 2007b; Zhang et al. 2017b). Therefore, high oxygen fugacity can transform more sulphur to sulphate, which induces sulphur-undersaturated magmas and consequently allows assimilation of more sulphide (Sun et al. 2013, 2015; Zhang et al. 2017c). Copper is incompatible in sulphur-undersaturated magmas; when initial concentration of copper is high in oxidized magmas (Sun et al. 2004, 2017; Zhang et al. 2017b), conditions are favourable for copper mineralization. Therefore, the large-scale Cu–Au metallogenesis in the Guichi and LYRMB is closely related to partial melting of oceanic slab subduction, whereas adakite can be an important indicator for Cu–Au deposit exploration.

The chalcophile elements (e.g. Cu and Au) are highly compatible in magmatic sulphide phases, and incompatible in silicate and oxide minerals (Ballard et al. 2002). Sulphur isotopes can be used to determine sulphur source and regarded as a main tool to judge the source of ore-forming fluids. It is well-known that sulphur has three different storage (Rollison 1993), that is, mantle source with δ³⁴S value of ca. 0 ± 3‰ (Chaussidon and Lorand 1990), the sea-water with δ³⁴S value of approximately +20‰, deposition of sulphur with very negative
δ³⁴S values and strong reduction. Chang et al. (1991) summarized more than 40 groups of sulphur isotope data of metal deposit, showing that 45.2% of δ³⁴S values ranging from 0‰ to 5‰ and 38.6% ranging from 5‰ to 15‰, suggesting that most sulphur isotope of the LYRMB was characterized by mantle source (magmatic sulphur). Zhou and Li (2000) suggested that the sulphur of porphyry deposits and contact-metasomatic ore deposits related to the Late Jurassic-Early Cretaceous intermediate-acid intrusive rocks in LYRMB was mainly derived from magmatic hydrothermal, and some other from the strata. The δ³⁴S values of sulphides in porphyry and skarn ore bodies of individual deposits exhibit a considerable range of variation, mostly from −2.52‰ to 8.59‰ (Figure 15, Supplementary Table 5), which fall inside the magmatic fluid and LYRMB sedimentary sulphide fields. These δ³⁴S values correspond closely to those of sulphides in their host magmatic rocks, supporting magmatic sulphur as a major component for the formation of these ore bodies (Ohmoto 1986; Ohmoto and Goldhaber 1997), with host sedimentary strata contamination.

Summarizing the discussion above, we propose a metallogenic model for the formation of the Cu–Au–Mo deposits of the Guichi region (Figure 18). The Late Jurassic-Early Cretaceous magmatism in Guichi region is dominated by intrusive rocks and controlled by regional structure. The ore-bearing intrusive rocks are distributed in the both sides of the Gaotan Fault and Jiangnan Fold and thrust belt. The main mineralization related to the Late Jurassic-Early Cretaceous magmatic activity in the area can be divided into two episodes: one is the Cu–Au polymetallic mineralization related to the early adakitic rocks; the other is epithermal Mo–Cu mineralization associated with late A-type granites. In the early stage, the mineralization types include skarn type, porphyry type, hydrothermal type, and weathering-infiltration type. In the late stage, the epithermal mineralization is caused by the late magma overlapped with early mineralization. In the north belt of main thrust belonging to the LYRMB, the mineralization is mainly related to the Late Jurassic-Early Cretaceous basic-medium high-K calc-alkaline magma, in where the metallogenesis and occurrence regularity of ore body is similar to the Tongling area (Figure 18). Along the Dunshang-Zhangxi Fault, the mineralization is associated with the Late Jurassic-Early Cretaceous medium-basic and medium-acid high-K alkaline magma, but also affected by the early acid and alkaline magma (Figure 18).

The Guichi region as an important ore-cluster district in LYRMB crosses different tectonic divisions and two metallogenic belts, with different basement

![Figure 15. Sulphur isotope of sulphides from the deposits in the Guichi region (after Wang et al. 2015). Data and data sources are given in Supplementary Table 5.](image-url)
and sedimentary cover. The Late Jurassic-Early Cretaceous petrogenetic-mineralization is mainly controlled by the Yangtze Fault and the Gaotan Fault, forming a unique double petrogenesis-mineralization centre, while other regional fracture like a network control the distribution of metallogenic district and metallogenic section. Different deposits types and mineral associations are formed in different tectonic area, with different petrogenesis-metallogenic characteristics. Therefore, the metallogenic regularity is characterized by endogenetie mineral deposits with multi-source demutation, multi-type symbiotic metallogenic series assembles, multi-mineral composition, multi-stage mineralization. Meanwhile, the depression cross to the uplift zone of the Jiangnan Ancient Continent forms a gradually transition relation, and the hydrothermal mineralization composite with two stages have certain characteristics along the regional fault (Gaotan Fault), so the regional metallogenic model has been put forward to guide the mine exploration.

7. Conclusions

(1) Two episodes of magmatism in the Guichi ore-cluster district are identified, the early episode (150–132 Ma) yielded high-K calc-alkaline intrusions is generally associated with Cu–Au deposits, the late episode (130–125 Ma) produced granite-syenite series characterized by shoshonite is related to Mo–Cu mineralization.

(2) The first stage of magmatic rocks characterized by adakitic rocks is suggested to be formed by partial melting of subducted Palaeo-Pacific Plate, assimilated with Yangtze lower crust and remelting Meso-Neooproterozoic crust/sediments. The second stage of magmatism similar to A-type granites is originated from partial melting of Mesoproterozoic-Neooproterozoic crust, mixed with juvenile crust materials.

(3) The best model accounting for the petrogenesis of the two stages of magmatism in the Guichi
ore-cluster district is subduction of the Palaeo-Pacific plate, following by the drift of subduction direction of the Palaeo-Pacific plate.

(4) The Late Jurassic-Early Cretaceous petrogenetic-mineralization of Guichi ore-cluster district is mainly controlled by the Yangtze Fault and the Gaotan Fault characterized by multi-type symbiotic metallogenic series assembles, multi-mineral composition, multi-stage mineralization.

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Highlights

- Two episodes of intrusions have been identified in the Guichi ore-cluster district.
- The 150–132 Ma high-K calc-alkaline intrusions are associated with Cu–Au polymetallic ore deposits.
- The 130–125 Ma shoshonite series intrusions are related to Mo–Cu mineralization.
- Guichi ore-cluster district has occurred tectonic transition from subduction of Palaeo-Pacific Plate to within-plate extensional setting.

Figure 17. A schematic illustration of the subduction model for the petrogenesis of the late Mesozoic magmatic rocks in the LYRMB, also showing the movement history of the Paleo-Pacific Plate in the Cretaceous (after Koppers et al. 2001; Sun et al. 2007a). (a) Formation of adakitic intrusions in the Guichi region (150–132 Ma); (b) formation of A-type granites and potassic volcanic rocks in the Guichi region (130–125 Ma). See detailed discussion in the text. Main fault: CJF-Yangtze Fault; JNF-Jiangnan Fault.

Figure 18. Metallogenic model of the Guichi region. Main fault: CJF-Yangtze Fault; MTF-Maotan Fault; GTF-Gaotan Fault; JNF-Jiangnan Fault; ZJF-Zhaojialing Fault; DSF-Dunshang Fault.
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