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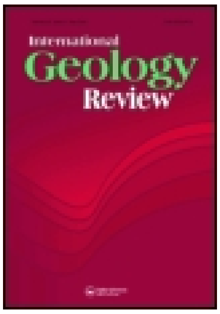

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Origin of Gold Metallogeny and Sources of Ore-Forming Fluids, Jiaodong Province, Eastern China

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Origin of Gold Metallogeny and Sources of Ore-Forming Fluids, Jiaodong Province, Eastern China

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Abstract

In this paper we use published isotopic ages for gold deposits and related rocks in the Jiaodong Peninsula (East Shandong Province) to investigate the origin of the large-scale gold metallogeny in the region, which contains world-class lode gold deposits. According to this database, metallogenic processes in this area occurred in the Mesozoic, with peak activities between 110 Ma and 130 Ma. In the Jiaodong gold province (JGP), the mineralizing events are coeval with or postdate Mesozoic granitoid intrusions. Both the Rb-Sr isochron ages and zircon SHRIMP age dating results suggest that Mesozoic granitoids were emplaced during several thermal events. The identification of inherited zircons coupled with I_{Sr} ratios (>0.709) indicate that these granitoids were mainly sourced from the continental crust, by remelting or partial melting. I_{Sr} values obtained from ores and fluid inclusions are generally higher than 0.709, and slightly higher than those for Mesozoic granitoids. This also indicates that both ore fluids and metals were mainly sourced from the crust. Synthesis of the available data suggests that collision between the South and North China continents was probably the dominant factor responsible for the gold metallogeny in the JGP. Granitoid emplacement and large-scale gold metallogenesis can be related to three important stages in the geodynamic evolution of a collisional orogen (compression–crustal thickening–uplift, lithospheric delamination and transition to extension, and a final extension phase). The most important metallogenic phase occurred at the transition from collisional compression to extension tectonics.

Introduction

THE JIAODONG GOLD PROVINCE (JGP) in the Jiaodong peninsula (Fig. 1), on the eastern margin of the North China Craton, is an important gold-producing region (Chen et al., 1998; Yang et al., 2003; X.-O. Zhang, 2002; Qiu et al., 2002; H.-M. Li et al., 2003), with several world-class gold deposits (> 100 t gold) accounting for about 25% of China's reserves (Zhou and Lü, 2000; Fan et al., 2003). The JGP is bounded by the Tan-Lu fault to west, the Qingdao-Rong fault to east, the Jiao-Lai basin to south, and the Longkou-Penglai fault and the Bohai Sea to the north (Fig. 1). The main lithological units in the JGP are rocks of the Late Archean Jiaodong Group, the Paleoproterozoic Jingshan Group, Yanshanian (Jurassic and Cretaceous) granitoids, and Cretaceous shoshonite-like volcanic rocks and ultra-high pressure metamorphic (UHPM) rocks. The UHPM rocks are intruded by the Yanshanian granitoids, and are present only east of the Wulian-Jimo fault. Cenozoic basalts outcrop on the northwest coast of the Jiaodong peninsula and are associated with the Longkou-Penglai fault (Fig. 1). The JGP was affected by two major tectono-thermal events, namely the collision between the Yangtze Craton and the North China Craton during the Indosinian (ca. 250–208 Ma), and the subduction of the Pacific plate beneath the Eurasian plate, with the formation of the Circum-Pacific magmatic arcs (Yanshanian Orogeny, 208–90 Ma) (Zhou and Lü, 2000; Zhou et al., 2002).

The gold deposits of the JGP are of the orogenic lode class as defined by Groves et al. (1998) and

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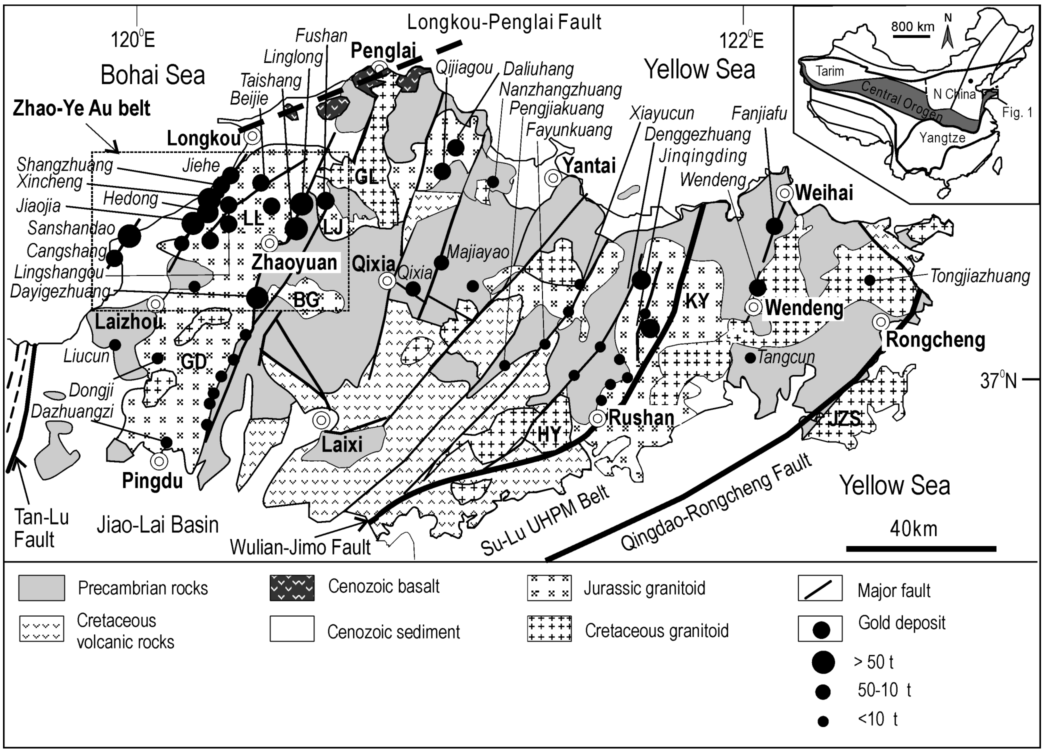

FIG. 1. Geology and distribution of gold deposits in the Jiaodong metallogenic province (data from Cun et al., 1992; Hu et al., 1997a; Ma, 2002; Fan et al., 2003). Abbreviations for granitoid intrusions: BG = Biguo; GD = Guojiadian; GL = Guojialing; HY = Haiyang; KY = Kunyushan; LJ = Luanjiahe; LL = Linglong.

Goldfarb et al. (2001). They are all controlled by NNE-trending fault zones (Fig. 1), possibly a subsidiary set to the major crustal structure of the Tan-Lu fault (H-M Li et al., 2003). The gold lodes are predominantly hosted in Mesozoic granitoids (metaluminous biotite-granite, hornblende-bearing granodiorite and lesser monzonite), intruded by numerous lamprophyre, basaltic, and felsic dikes (X.-O. Zhang, 2002; Li et al., 2003). The gold lodes are of two types: disseminated-and-stockwork type or massive-vein type (X.-O. Zhang, 2002). The origin of this gold mineralization, in terms of fluids, metal source(s), and tectonic setting, remains a contentious issue. Evidence from age dating has led most researchers to conclude that all the gold deposits were formed during the Yanshanian Orogeny, between 130 and 110 Ma (e.g., D.-Z. Wang et al., 1998; L.-G. Wang et al., 1998; Yang and Zhou, 2000, 2001; Qiu et al., 2002; Lian et al., 2004), although a few (e.g., Shen et al., 1994; Y.-W. Wang, 1996) emphasized the significance of Early Precambrian gold mineralization. Z.-H. Zhang et al. (1994) suggested two metallogenic events, one in the Early Jurassic and the other in the Early Cretaceous. More recently, Mao et al. (2003) proposed that three episodes of gold mineralization occurred in the time spans of 250–180 Ma, 170–140 Ma, and 130–100 Ma.

The complexity and multiplicity of the metal source and ore fluids has been argued by most of the above-cited workers. Some of the more popular viewpoints include: (1) the crust (Z.-H. Zhang et al., 1994) or combination of granite-greenstone terranes and high-grade metasedimentary rocks rocks (Chen and Fu, 1992, Chen, 1994; Qiu et al., 2002); (2) the mantle (Sun et al., 1995; Yang et al., 2003); (3) Yanshanian granitoids (H.-Q. Li et al., 1993); (4) mixture of mantle and crust (Qiu et al., 1998, 2000; Zhou et al., 2003); and (5) lamprophyre dikes (Ji et al., 1992; Zhai et al., 1996; Sun et al., 2000; Li et al., 2003). Regarding the source of ore-forming fluids, key interpretations include: (1) mantle fluids

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(Sun et al., 1995;Yang et al., 2003; Du, 1996); (2) magmatic fluids (H.-Q. Li et al., 1993); (3) meteoric water (L.-G. Zhang, 1989); and (4) syncollisional metamorphic fluids (Chen, 1994; Lu et al., 1998; Fan et al., 2003).

The tectonic setting for gold mineralization in the JGP has been interpreted as: (1) transition from compression to extension during collision between the South and the North China plates (Chen and Fu, 1992; Chen, 1994; Chen et al., 1998; D.-Z. Wang et al., 1998; Hu et al., 1997a, 1997b; Zhai et al., 2001, 2002; Yang et al., 2003; Mao et al., 2003; Zhou and Lu, 2000; Zhou et al., 2002; Lian et al., 2004); (2) subduction of the paleo-Pacific oceanic plate (Sillitoe, 1989; Qiu et al., 2002); (3) mantle plume (L.-G. Wang et al., 1998); (4) multistage movements of the Tan-Lu fault (Xu et al., 1987; Du, 1996; H.-M. Li et al., 2003); and (5) Early Precambrian cratonization (Shen et al., 1994; Y.-W. Wang, 1996).

In this contribution we have compiled a list of isotopic ages of ores and host rocks published in the past decade. From this, we can establish that large-scale gold metallogenesis occurred in the period of 130–110 Ma. Then, we propose that the tectonic setting for this 130–110 Ma metallogeny is related to a tectonic regime of transition from collisional compression to extension. This was facilitated by the large-scale and far-field interactions between the Pacific and Eurasian plates (Ren et al., 2002), accompanied by lithospheric thinning and an overall regime of extensional stress in eastern China and adjacent regions (e.g., Mongolia; southern Siberia between the North China craton and the Siberian craton; Ren et al., 2002). This lithospheric thinning may have been caused by lithospheric delamination processes and associated mantle upwelling in eastern China. Finally, taking into account the strontium isotope ratios (I_{Sr}), we suggest that in the JGP the crust, thickened by continental collision, was the major source of both ore-forming fluids and metals.

Timing of Mineralization in the JGP

Isotopic ages for ore deposits and related rocks in the JGP are listed in Table 1. As shown in Figure 2, most isotopic ages fall between the Late Jurassic and Cretaceous, i.e., 190–65 Ma (Yanshanian), recording an important metallogenic event, consistent with previous observations (Hu, 1991; Zhai et al., 2001; Chen, 1994; Chen et al., 1998; H.-M. Li et al., 2003). More specifically, the timing of gold metallogeny in the JGP peaked in the period of 130–110 Ma (Cretaceous; Fig. 2).

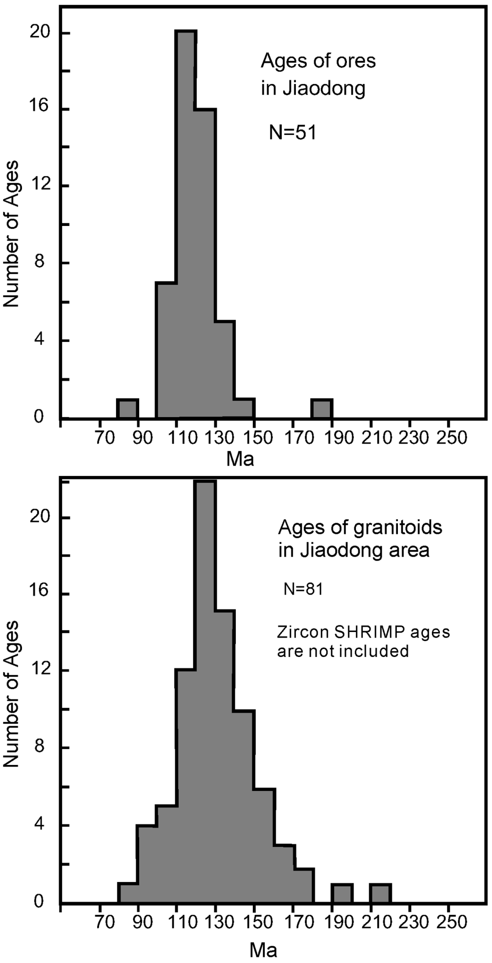

FIG. 2. Histograms of isotope ages for the Jiaodong gold province, and for granitoids in the region (data from Table 1).

Mesozoic granitoids are widespread in the JGP, and are spatially associated with the gold mineralization. Because of this, the isotopic dating (Table 1), geological, and geochemical characteristics of the granitoids have been well studied (Xu et al., 1989; Hu et al., 1997b; H.-N. Wang et al., 1992; D.-Z. Wang et al., 1998a; X.-O. Zhang, 2002; H.-M. Li et al., 2003), mainly in pursuit of a possible genetic link with the mineralization. A multistage evolution of granite complexes is revealed by zircon SHRIMP ages (Table 2). The Linglong and the Luanjiahe granitic intrusions (Fig. 1) formed at 150–170 Ma, while the Guojialing granite (Fig. 1)

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TABLE 1. List of Isotope Ages for Ore Deposits and Related Rocks in the Jiaodong Gold Province[1]

Mine/orefield	Rock type	Analyzed sample	Method	Ages (Ma) and I_{Sr}	Data sources
Dongji	Altered tectonite	K-feldspar of altered rocks	Ar/Ar	116.1±0.3 (P), 116.3±0.8 (I)	H.-M. Li et al., 2003
Dongji	Altered tectonite	Ore-bearing quartz vein	Ar/Ar	115.2±0.2 (P), 114.4±0.2 (I)	H.-M. Li et al., 2003
Zhao-Ye belt	Altered tectonite	Linglong granite	Rb-Sr	156 (I_{Sr} = 0.7095)	H.-Q. Li et al., 1993
Zhao-Ye belt	Altered tectonite	Linglong granite	K-Ar	153 (n = 14, I)	H.-Q. Li et al., 1993
Zhao-Ye belt	Altered tectonite	Linglong gneissic granite	Rb-Sr	161±1 (I_{Sr} = 0.7122)	H.-N. Wang et al., 1992
Zhao-Ye belt	Altered tectonite	Linglong gneissic granite	K-Ar	148, 144, 141, 141, 132, 131, 128, 127, 127, 121, 119, 112	H.-N. Wang et al., 1992
Zhao-Ye belt	Altered tectonite	Linglong granitic pegmatite	K-Ar	132, 124, 117, 102	H.-N. Wang et al., 1992
Zhao-Ye belt	Altered tectonite	Linglong granite	Ar/Ar	164±1 (P)	Qiu et al., 2002
Zhao-Ye belt	Altered tectonite	Guojialing granite	Rb-Sr	154 (I_{Sr} = 0.7103)	Li et al., 1993a
Zhao-Ye belt	Altered tectonite	Guojialing granite	K-Ar	150 (n = 12, I)	Li et al., 1993a
Zhao-Ye belt	Altered tectonite	Guojialing granite	K-Ar	165, 149, 135, 128, 118, 116	H.-N. Wang et al. 1992
Zhao-Ye belt	Altered tectonite	Guojialing granite	Ar/Ar	135±2(P)	Qiu et al. 2002
Zhao-Ye belt	Altered tectonite	Luanjiahe granite	Ar/Ar	155±2 (P)	Qiu et al., 2002
Zhao-Ye belt	Altered tectonite	Luanjiahe granite	Rb-Sr	152.47±7.15 (I_{Sr} = 0.7125)	H.-N. Wang et al., 1992
Zhao-Ye belt	Altered tectonite	Xiangkuang subvolcanic intrusion	K-Ar	128, 121	H.-N. Wang et al., 1992
Zhao-Ye belt	Altered tectonite	Granodiorite dike	K-Ar	101, 94, 82	H.-N. Wang et al., 1992
Zhao-Ye belt	Altered tectonite	Diorite dike	K-Ar	101, 100	H.-N. Wang et al., 1992
Zhao-Ye belt	Altered tectonite	Lamprophyre dike	K-Ar	122	H.-N. Wang et al., 1992
Zhao-Ye belt	Altered tectonite	K-feldspar dike	K-Ar	101	H.-N. Wang et al., 1992
Zhao-Ye belt	Altered tectonite	Aplite dike	K-Ar	110, 98	H.-N. Wang et al., 1992
Zhao-Ye belt	Altered tectonite	Dacite	K-Ar	123, 116	H.-N. Wang et al., 1992
Linglong	Quartz vein	Pyrite of ores	Rb-Sr	123±4, 123±3, 122±11	Yang and Zhou, 2001
Linglong	Quartz vein	Pyrite of ores (98JQ07)	Rb-Sr	121.6±8.1 (I_{Sr} = 0.7094±0.0019)	Yang and Zhou, 2000
Linglong	Quartz vein	Ore and its pyrite (98LL06)	Rb-Sr	121.8±3.5 (I_{Sr} = 0.7102±0.0001)	Yang and Zhou, 2000
Linglong	Quartz vein	Ore and its pyrite (98DK07)	Rb-Sr	120±29 (I_{Sr} = 0.7113±0.0048)	Yang and Zhou, 2000
Linglong	Quartz vein	5 samples of ores (JQ##)	Rb-Sr	110.6±2.4 (I_{Sr} = 0.7121±0.0002)	Yang and Zhou 2000
Xishan, Linglong	Quartz vein	Sericite of vein 108	Rb-Sr	101±4 (I_{Sr} = 0.7120±0.0002)	Z.-H. Zhang et al, 1994

Table continues

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TABLE 1. *continued*

Mine/orefield	Rock type	Analyzed sample	Method	Ages (Ma) and I_{Sr}	Data sources
Dongshan, Linglong	Quartz vein	Sericite quartzite and its alteration minerals such as chlorite	Rb-Sr	111.4±2.8 (I_{Sr} = 0.7121±0.0001)	Z.-H. Zhang et al, 1994
Xishan, Linglong	Quartz vein	Fluid inclusions in quart	Rb-Sr	126.6±7.5 (I_{Sr} = 0.7111±0.0002)	H.-Q. Li et al., 1993
Xishan, Linglong	Quartz vein	Altered rocks	Rb-Sr	112±2 (I_{Sr} un-reported)	Luo and Wu, 1987
Xishan, Linglong	Quartz vein	Altered rocks	K-Ar	111±2	Luo and Wu, 1987
Jiehe, Jiao-Xin belt	Altered tectonite	Altered rocks, K-feldspar, clay mineral	Rb-Sr	46.5±2.3 (I_{Sr} = 0.7120±0.0001)	Z.-H. Zhang et al, 1994
Jiao-Xin belt	Altered tectonite	Shangzhuang granite	Rb-Sr	119.8±1.6 (I_{Sr} = 0.7116±0.0003)	Z.-H. Zhang et al, 1994
Jiaojia	Altered tectonite	Fluid inclusions in quartz	Rb-Sr	134±8 (I_{Sr} = 0.7104±0.0001)	H.-Q. Li et al., 1993
Jiaojia	Altered tectonite	L-stage sericite	Rb-Sr	88.1±0.1 (I_{Sr} = 0.71161±0.00018)	Luo and Wu, 1987
Jiao-Xin belt	Altered tectonite	Muscovite of altered rocks	Rb-Sr	105±7 (I_{Sr} un-reported)	Luo and Wu, 1987
Jiao-Xin belt	Altered tectonite	Muscovite of altered rocks	K-Ar	106±2	Luo and Wu, 1987
Cangshang	Altered tectonite	Fluid inclusions in quartz vein	Rb-Sr	113.5±0.6 (I_{Sr} un-reported)	Xu et al., 2002
Cangshang	Altered tectonite	Fluid inclusions in quartz vein	Ar/Ar	121.3±0.2 (P); 121.1±0.5 (I)	X.-O. Zhang et al., 2003
Lingshangou	Altered tectonite	K-feldspar, fuchsite in ores	Rb-Sr	188.9±4.2 (I_{Sr} = 0.7111)	Z.-H. Zhang et al, 1994
Lingshangou	Altered tectonite	Altered rock	Rb-Sr	115±5 (I_{Sr} un-reported)	Luo and Wu, 1987
Qixia	Quartz vein	Pyrite-sericite-quartz assemblage	Rb-Sr	125.8±1.7 (I_{Sr} = 0.7168±2)	Zhai et al., 1998
Majiayao	Quartz vein	Fluid inclusions in quartz	Rb-Sr	137.6±7.1 (I_{Sr} = 0.7163±0.0001)	H.-Q. Li et al., 1993
Majiayao	Quartz vein	Sericite of ores	Rb-Sr	135.1±5.2	H.-Q. Li et al., 1993
Majiayao	Quartz vein	chlorite, siderite, sericite quartzite	Rb-Sr	106±5 (I_{Sr} = 0.7152±0.0001)	Z.-H. Zhang et al., 1994
Majiayao	Quartz vein	Sericite	Rb-Sr	135.1±5.2 (I_{Sr} = 0.7215±0.0025)	Luo and Wu, 1987
Majiayao	Quartz vein	Sericite	K-Ar	120±2	Luo and Wu, 1987
Dayigezhuang	Altered tectonite	Ore-hosting granite	U-Pb	145±1 (single zircon grain)	H.-K. Li et al., 1998
Nanzhangzhuang	Altered tectonite	Altered quartz porphyry	Rb-Sr	113±7	Liu et al., 1998
Denggezhuang	Quartz vein	Sericite quartzite	Rb-Sr	118±9 (I_{Sr} = 0.71015±0.00019)	D.-Q. Zhang et al., 1995
Denggezhuang	Quartz vein	Biotite of ore-hosting granite (91-34-4)	Ar/Ar	129.01±0.58 (P), 130.68±2.73 (I)	D.-Q. Zhang et al., 1995
Denggezhuang	Quartz vein	Biotite of ore-hosting granite (91-34-4)	K-Ar	126.39	D.-Q. Zhang et al., 1995
Denggezhuang	Quartz vein	Biotite of E-stage altered Kunyushan granite	K-Ar	147.30±2.13, 135.17±3.48	D.-Q. Zhang et al., 1995
Denggezhuang	Quartz vein	Biotite of M-stage altered Kunyushan granite	K-Ar	131.03±2.42, 126.39±2.04	D.-Q. Zhang et al., 1995
Denggezhuang	Quartz vein	Biotite of L-stage altered Kunyushan granite	K-Ar	123.92±2.53, 120.03±1.77	D.-Q. Zhang et al., 1995

Table continues

TABLE 1. *continued*

Mine/orefield	Rock type	Analyzed sample	Method	Ages (Ma) and I_{Sr}	Data sources
Jinqingding	Quartz vein	K-feldspar of Kunyushan granite	Rb-Sr	145.5	Z.-H. Zhang et al., 1994
Jinqingding	Quartz vein	Ore-hosting unyushan granite	Rb-Sr	134.3 (I_{Sr} = 0.7096)	Zhai et al., 1996
Jinqingding	Quartz vein	Ore-forming Kunyushan granite	K-Ar	134.4±3.8	Yang, 1998
Jinqingding	Quartz vein	Biotite of Kunyushan granite	K-Ar	124.5~132.1 (N = ?)	Z.-H. Zhang et al., 1994
Jinqingding	Quartz vein	Biotite, or whole-rock of Kunyushan granite	K-Ar	157, 143±3, 126±3, 113±3, 217, 200, 180, 172, 134±4, 132, 132, 129, 125	Qiu et al., 2002
Jinqingding	Quartz vein	Ore-forming Kunyushan granite	Ar/Ar	(131) (P), 129 (P)	Qiu et al., 2002
Jinqingding	Quartz vein	K-feldspar and sericite of potash altered granite	Rb-Sr	121.3±0.6 (I_{Sr} = 0.7105±0.0001)	Z.-H. Zhang et al., 1994
Jinqingding	Quartz vein	Sericite quartzite	Rb-Sr	113.3±4.4 (I_{Sr} = 0.7103±0.0001)	Z.-H. Zhang et al., 1994
Jinqingding	Quartz vein	Alteration minerals and rocks	Rb-Sr	112.3±3.3 (I_{Sr} = 0.7105±0.0003)	Z.-H. Zhang et al., 1994
Jinqingding	Quartz vein	Pyrite-sericite-quartz assemblage	Rb-Sr	104.8±1.5 (I_{Sr} = 0.7131±0.0001)	Zhai et al., 1996
Jinqingding	Quartz vein	Alteration minerals and rocks	Rb-Sr	101.8±3.4 (I_{Sr} = 0.7106±0.0004)	Z.-H. Zhang et al, 1994
Xiayucun	Quartz vein	Sericite	K-Ar	124.6±2.5	Sun et al., 1995
Pengjiakuan	Altered tectonite	M-stage quartz (BP99-65)	Ar/Ar	118.42±0.25 (P), 117.03±0.13 (I)	L.-C. Zhang et al., 2002
Pengjiakuang	Altered tectonite	M-stage quartz (BP99-07)	Ar/Ar	120.53±0.49 (P), 117.33±0.15 (I)	L.-C. Zhang et al., 2002
Pengjiakuang	Altered tectonite	Biotite of footwall lamprophyre	Ar/Ar	117.49±0.25 (P), 116.83±0.36(I)	L.-C. Zhang et al., 2002
Pengjiakuang	Altered tectonite	Sericite of ore	K-Ar	100.59±1.96	Sun et al., 1995
Dazhuangzi	Altered tectonite	M-stage quartz (DZ004)	Ar/Ar	117.39±0.64 (P), 115.62±1.01(I)	L.-C. Zhang et al., 2002
Dazhuangzi	Altered tectonite	Three lamprophyre dikes	K-Ar	106±1 ~ 127±1 (n = ?)	L.-C. Zhang et al., 2002
Fayunkuang	Altered tectonite	Biotite of Early Cretaceous volcanic rocks	K-Ar	118.6 ~ 127.5 (n = ?)	S.-J. Li, 1998
Fayunkuang	Altered tectonite	Pyrite of ores	Rb-Sr	128.2±7.2 (I_{Sr} = 0.7128±0.0001)	L.-C. Zhang et al., 2002

[1] Sample numbers are in parentheses. I and P in parentheses represent isochron and plateau ages, respectively, and n in parentheses represents total number of data. Underlined data are used in histograms (Figs. 2 and 3).

was intruded during 126–130 Ma, and a postore granitic dike was emplaced at ~120 Ma. Recent ^{40}Ar/^{39}Ar dating of magmatic biotites from these granites (Linglong and Guojialing) yielded ages of ~124 Ma (H-M Li et al., 2003). The development of these granitoids is generally contemporaneous with or slightly predates the timing of gold mineralization (Fig. 2). It is important to note that all younger granites contain inherited zircon grains with similar ages to older granitoids, e.g. the Guojialing granite and the late dike contain inheritated zircon grains of 150-160 Ma; the majority of zircon grains from altered granitic breccias in the Cangshang gold mine have isotopic ages of 154 Ma, whereas zircon

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TABLE 2. SHRIMP U-Pb Zircon Results for Granitoid Samples from Jiaodong Peninsula[1]

Nos.	Lithology	Peak age (Ma)	Ages of zircon grains (Ma)
LD-20	Porphyric granodiorite, Linglong complex	153 ± 4 (19)	Inherited zircon: 206 ± 7 ~ 294 ± 9 (5); Pb-loss zircon: 131 ± 3 (2)
LX-13	Loushan garnet-bearing granite, Linglong complex	158 ± 4 (13)	175 ± 4 – 305 ± 9 (4); core of zircon: 3446 ± 2 (1), growth rim: 152 ± 2 (1); 2 grains with Pb-loss
JMS-1	Jiumoushan body, Linglong-like granite	160 ± 3 (23)	Zircon core: 658 ± 11 (1), rim: 154 ± 3 (1); core: 783 ± 13 (1), rim: 201 ± 3 (1), 165 ± 3 (1); core: 210 ± 4 (1), rim: 162 ± 3 (1)
MS-1	Moushan body, Linglong complex	158 ± 3 (7)	176 ± 4 –239 ± 7 (4); core: 226 ± 6 (1), edge: 146 ± 3 (1), for a grain without core-rim texture
GJD-1	Guojiadian coarse-grained granite, Luanjiahe complex	–	139 – 2875 (26), cluster at 200–300
LJH-1	Luanjiahe body, Luanjiahe complex	157 ± 5 (12) or 154 ± 4 (9)	181 ± 5 – 386 ± 9 (6)
BG-1	Biguo two-mica granite, Luanjiahe complex	152 ± 10 (5)	188 ± 5 – 224 ± 6 (9); core: 224 ± 6 (1), edge: 142 ± 4, for one grain without core-rim texture
SSD-15	Sanshandao, Guojialing porphyric granodiorite	128 ± 2 (19)	155 ± 3 (1); two grains yield concordant ages of 1934 ± 48 and 2708 ± 65, respectively
JH-8	Jiehe, Guojialing porphyric granodiorite	126 ± 2 (19)	Core: 2530 ± 11, edge: 2483 ± 21, for one idiomorphic grain; core: 225 ± 4, edge: 159 ± 3 for one idiomorphic grain with ring texture
TJ-1	Guojialing granite complex	130 ± 3 (14)	1860 ± 15 (1); 230 ± 5 (1)
MZS-1	Guojialing granite complex	129 ± 3 (5)	116 ± 3 (1); 155 ± 5 (1)
NM-1	Guojialing granite complex	128 ± 6 (9)	
LX-53	Linglong gold mine, postore K-feldspar porphyry dike	120 ± 2 (21)	Pb-loss: 110 (2); inherited zircon: 150-3100 (31), mostly cluster at 150–300, minor of 2300–3100
C1	Footwall granodiorite of the Cangshang gold deposit	166 ± 4 (10)	181 ± 5, 188 ± 4, 202 ± 4, 244 ± 11 (6) (232-254), 378-805 (4), 1800-2105 (10), 2542 ± 8
C3	Intensively altered granitic breccia within orebody, Cangshang gold mine	154 ± 5 (6)	291 ± 4, 598 ± 13, 771 ± 10, 2158 ± 61, 2292 ± 21, 2517 ± 8
C4	Plagioclase amphibolite of hanging wall, Cangshang gold mine	2530 ± 17 (7)	Metamorphic zircon: 2391-2482 (5), 2013-2321 (7), 1852 ± 37 (6), 1125 ± 809, 1336 ± 638

[1] Ages for inherited zircons represent either original ages for the zircons, ages for complete isotopic resetting, or Pb loss.; n = number of magmatic zircon analyses used to derive the pooled age. Samples C1, C2, and C3 are from X.-O. Zhang et al, 2003, with other data compiled from L.-G. Wang et al., 1998 and Qiu et al., 2002. Numbers in parentheses indicate number of analyzed zircon grains.

grains from the footwall granodiorite were dated at 166 Ma. SHRIMP ages of inherited zircons from Yanshanian granites cluster into two groups of 180–300 Ma and >1800 Ma, respectively, with some scatter within the span of 300–1800 Ma. These data suggest that multistage thermal events occurred in the Jiaodong metallogenic province before 180 Ma.

The 180–300 Ma magmatic events can be interpreted as being related to the northward subduction of the Qinling–Dabie–Su Lu oceanic plate and the subsequent collision between the South and North China continents, which formed the Central Orogen (or Qinling Orogen) (see inset of Fig. 1). The 2000–1800 Ma granitic episode is coeval with amalgamation or collision between different blocks or terranes that formed the North China craton (Chen and Fu, 1992; Zhao et al., 1998, 2002; X.-O. Zhang et al., 2003). The granitic magmatism in the span of

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TABLE 3. Initial Strontium Isotope Ratios (I_{Sr}) Used in Various Classifications of Granitoids[1]

Authors	Xu et al., 1982		Chappell and White, 1984		Barbarin, 1999		Chen et al., 2000	
Classification	S	I	S (sedimentary)	I (igneous)	MPG, CPG	KCG, ACG	Collisional hypobatholith	Collisional hypabyssal
I_{Sr}	0.709–0.741	0.705–0.710	0.709–0.718	0.704–0.712	0.706–0.760	0.706–0.712	0.705–0.710	0.705–0.714
Typical area	Mesozoic granitoids in South China		Paleozoic granitoids in Lachlan fold belt		Worldwide, mainly in Hercynides		Mesozoic granitoids in Qinling Mountains	

[1] Abbreviations: MPG = muscovite-bearing peraluminous granitoids; CPG = cordierite-bearing lperaluminous granitoids; KCG = K-rich and K-feldspar porphyritic calc-alkaline granitoids; ACG = amphibole-rich calc-alkaline granitoids.

1800–180 Ma may be interpreted as a series of accretion and rifting episodes at the southern margin of the North China craton (Chen et al., 2003; Kusky and Li, 2003; Lu et al., 2002).

Source of Granitoid Rocks in Jiaodong Province

Preservation of inherited zircons in young granitoids shows that earlier granite or crust were involved in the later thermal events that produced granitic magmatism. This means that these later granitic magmas formed by partial melting of crustal materials and/or remelting of earlier granitoids (Xu et al., 1989; Tu and Zhao, 1992; H.-N. Wang et al., 1992; D.-Z. Wang et al., 1998), or that these late granitic magmas were strongly contaminated by older granitoids or crust. We conclude that the Yanshanian granitoids in the Jiaodong area could not have evolved from juvenile mantle magma, nor could they have been sourced from partial melting of subducted slabs or an enriched mantle wedge; rather they must have been produced from the crust by partial melting or remelting.

Strontium isotope ratios (I_{Sr}) are good indicators of source materials. In general, igneous lithologies with $I_{Sr}<0.705$ are inferred to have been sourced from the mantle; I_{Sr} >0.709 values are indicative of crustal sources, and those between 0.705 and 0.709 probably indicate mixtures of the mantle and crustal sources (Xu et al., 1982; Chappell and White, 1984; Faure, 1986; Barbarin, 1999; D.-Z. Wang and Zhou, 2002; Table 3). However, igneous lithologies of the same type may have different I_{Sr} values due to their contrasting ages, source regions of different compositions, and/or regionally geochemical inhomogeneity. For example, in the North China craton, granitoids derived from continental crust commonly have I_{Sr} values lower than 0.710 (Hu et al., 1988, 1997b; Chen et al., 2000). Hence the I_{Sr} criteria need to be used with some caution to distinguish the genetic types of geological bodies from different regions.

In the Jiaodong area, all the Yanshanian granitoids have I_{Sr} > 0.7095, whereas I_{Sr} > 0.710 are obtained from the ores, altered rocks, mineral separates from the ores, and from fluid inclusions and are slightly higher than the associated Yanshanian granitoids (Table 1 and Fig. 3). These I_{Sr} values are higher than those of the Mesozoic collision-type or S-type granitoids in the southern margin of the North China craton (Hu et al., 1988; Chen et al., 2000), confirming that the granitoids in the Jiaodong area were sourced from the crust. This conclusion was also reached by several other workers (e.g., Xu et al., 1989; H.-N. Wang et al., 1992; Hu et al., 1997b; Zhou and Lu, 2000; Qiu et al., 2002; Lian et al., 2004) and is supported by Sr-Nd-Pb isotope sytematics (Fig. 4; Yang et al., 2003). We conclude that the ore fluids and metals must have been dominantly derived from the crust. Their I_{Sr} values (Fig. 3), suggest that their protoliths might be more evolved than the coeval granitoids. We suggest that the Archean rocks in the region were likely the main source by partial melting for the Yanshanian granitoids.

Gold Metallogeny and Its Constraints

Large-scale Yanshanian gold metallogenesis is believed to have taken place during or following the

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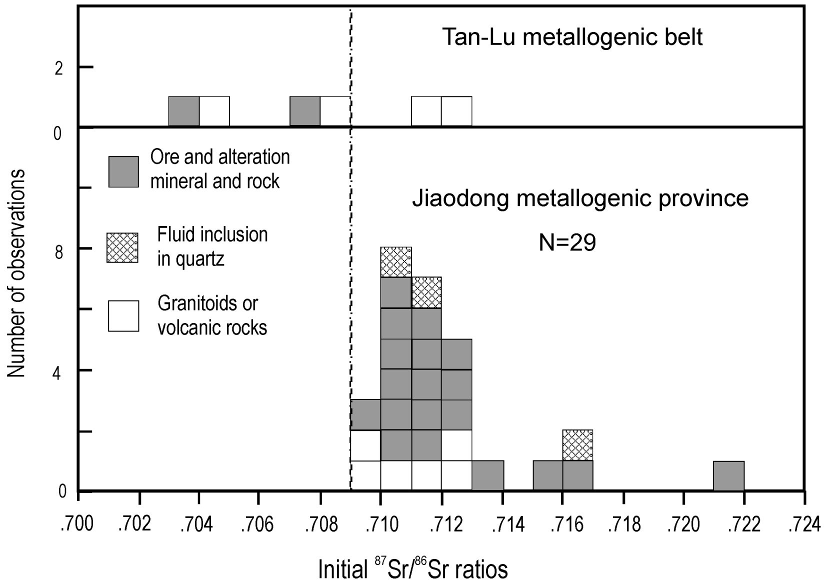

FIG. 3. Histograms showing the distribution of I_{Sr} values for ore deposits and granitoids in the Jiaodong gold province and the Tan-Lu metallogenic belt (data from Tables 1 and 4).

transition regime from compression to extension (Chen and Fu, 1992; Hu et al., 1997b; Chen et al., 1998; D.-Z. Wang et al., 1998; L.-G. Wang et al., 1998; Zhai et al., 1999, 2001, 2002; Deng et al., 1999; Kerrich et al., 2000; Zhou and Lu, 2000; Zhou et al., 2002; Qiu et al., 2002; Mao et al., 2003; Yang et al., 2003). However, disagreement exists as to what caused this transition from a tectonic regime of compression to one of extension.

Four end member views were proposed: (1) tectonism along the Tan-Lu fault; (2) mantle plume activity; (3) subduction of the Pacific plate; and (4) collisional tectonics and lithospheric delamination. These viewpoints are discussed below.

Role of the Tan-Lu fault

The Tan-Lu fault, with a total displacement estimated at about 500 km, is a major strike-slip crustal structure, with a complex history of both sinistral and dextral movements between the Late Jurassic and Early Cretaceous (Xu and Zhu, 1994; Ren et al., 2002).

On the basis of ^{40}Ar/^{39}Ar data, H-M Li et al. (2003) envisaged that gold mineralization and mafic magmatism (e.g., lamprophyre dikes and volcanism) were controlled by transtensional movements along the Tan-Lu fault during 132–120 Ma. However, if the Tan-Lu fault is the structure that channeled fluids that formed gold deposits in the JGP, then (1) the lode gold deposits and Yanshanian granitoids should concentrate along the Tan-Lu fault, with their abundance decreasing away from the fault. This is not observed. Instead gold deposits and Yanshanian granitoids cluster on the eastern side of the fault, namely the Jiaodong area. (2) Metallogeny and magmatism in the Jiaodong area should be comparable with those in the Tan-Lu fault belt, but this is not supported by I_{Sr} values of igneous rocks and ore deposits (Table 4 and Fig. 3). A small number of I_{Sr} values for the Tan-Lu fault belt shows a wide variation from <0.705 to >0.710, implying a great complexity of the ore- and the rock-forming materials, including mantle, crust, and mantle-crust mixtures. This variability promoted a metallogenic diversity in the Tan-Lu belt, characterized by the presence of orogenic gold lodes, skarns, and porphyry/breccia–type gold-copper/iron deposits (Table 4). This variability clearly contrasts with the singularity of orogenic-type gold lodes (gold-only province) in the JGP, thereby indicating a different type of control and tectonic setting. (3) The magmatism and metallogenesis in the Jiaodong metallogenic province should also occur on both sides of, as well as along, the Tan-Lu fault, but so far, except for the Tan-Lu fault-controlled magmatic belt (Chen et al., 2004), no gold deposit and few of granitic

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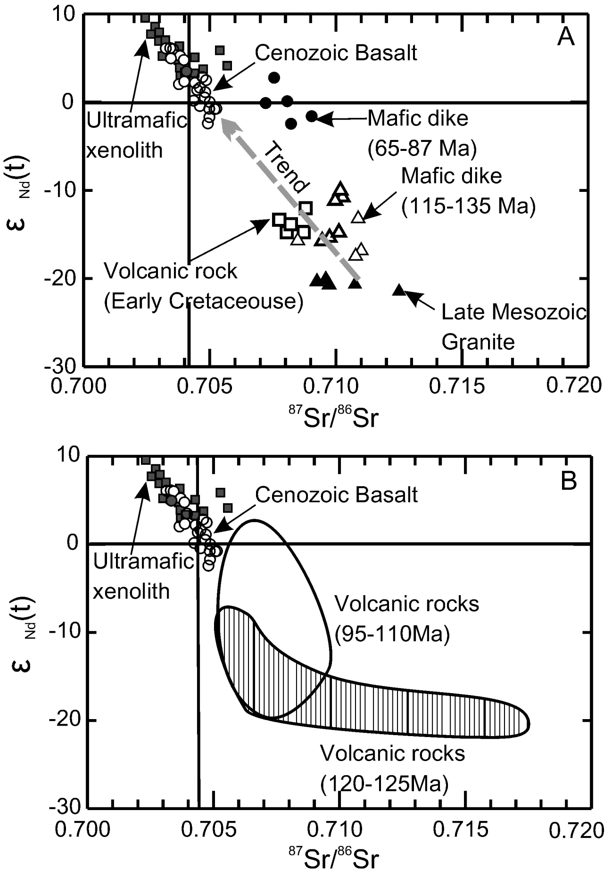

FIG. 4. Temporal variation of Sr-Nd isotope systematics of igneous rocks from the North China craton, including the Jiaodong gold province (from Yang et al., 2003).

intrusions have been found in the northern Jiangsu, southern and western Shandong, northern Anhui, and southern Hebei (Fig. 5).

Therefore, we conclude that the Tan-Lu fault was not a dominant factor for the gold metallogenesis in the JGP, although we acknowledge that it remains the main controlling structure for the granitic magmatism and gold mineralization within and along the fault belt.

Mantle plume activity

The metallogenic significance of mantle plumes has been discussed by Pirajno (2000). Some authors have argued that the Jiaodong metallogenic province is the result of mantle plume activity (L.-G. Wang et al., 1998; Niu et al., 2001). However, surface manifestations indicative of mantle plume activity, such as continental flood basalts, are lacking (Ernst and Buchan, 2001). Plume-related basalts are sourced from the mantle by decompression melting and in the Jiaodong area, parts of northeastern China, and Mongolia, vast amounts of basalts present in rift-basins that might reflect mantle plume activity were emplaced in the Cenozoic (Ren et al., 2002; Barry et al., 2003) (Fig. 1). This suggests that a mantle plume was active in the Cenozoic, but not in Mesozoic (L.-G. Wang et al., 1998; Niu et al., 2001). In addition, except for gold placers, gold mineralization is absent from Cenozoic rocks; instead it is essentially confined to the 130–110 Ma period.

Pacific plate subduction

Metallogenesis in the Circum-Pacific Rim has been linked to the subduction of the Pacific oceanic plate (e.g., Sillitoe, 1972, 1989). East China is

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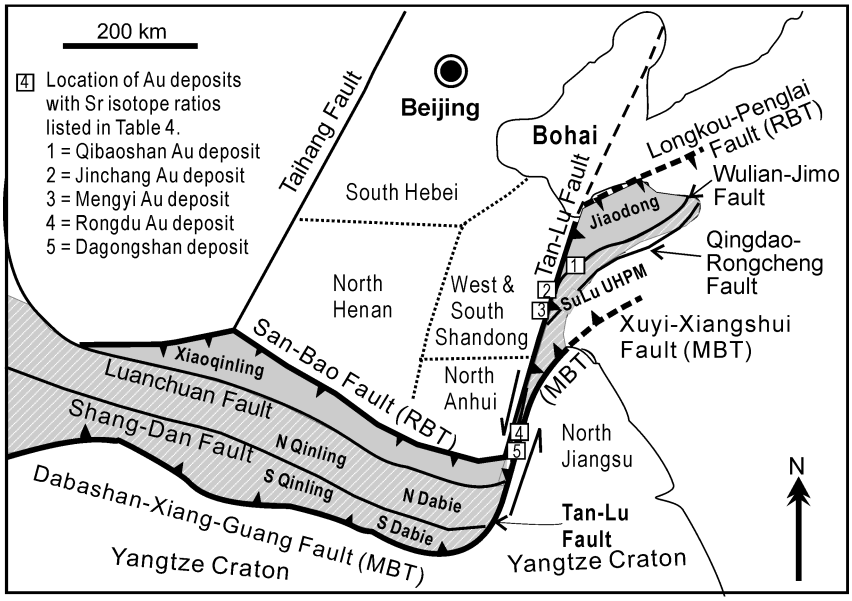

FIG. 5. Simplified tectonic map showing position of the Jiaodong gold province in relation to major tectonic units in the region. MBT and RBT are main boundary thrust and reverse boundary thrust, respectively (data from Hu et al., 1997a; Ma, 2002; Chen et al., 1998, 2004).

TABLE 4. List of Initial Strontium Isotope Ratios (I_{Sr}) for the Granitoids and Au Deposits in the Tan Lu Fault Belt

Name	Mineralization style	Location	Analyzed sample	Age (Ma)	I_{Sr}	Data sources
Qibaoshan	Breccia-type Au	Wulian, Shandong	Volcanic rocks in the Jiao-Lai basin	111.4 ± 2.1	0.70842 ± 4	Qiu et al., 2000
Jinchang	Skarn-type Au	Yinan, Shandong	Felsite porphyry	154.8 ± 0.3	0.7112 ± 1	Qiu et al., 2000
Jinchang	Skarn-type Au	Yinan, Shandong	Amphibole monzonitic porphyry	126.6 ± 0.3	0.7049	Zhao et al., 1992
Mengyi	Breccia-type Au	Mengyi, Shandong	Shoshonite volcanic rocks	119.6 ± 3.7	0.71245 ± 7	Qiu et al., 2000
Dagongshan	Orogenic-type Au	Wuhe, Anhui	Alteration minerals, e.g. sericite, chlorite	154 ± 11	0.7037 ± 2	Dong et al., 1995
Rongdu	Orogenic-type Au	Wuhe, Anhui	Alteration minerals	109 ± 4.4	0.7077 ± 1	Dong et al., 1995

adjacent to the Circum-Pacific Rim, and mainly for this reason, the Yanshanian metallogenesis in East China, including the JGP, has been interpreted as the result of Pacific plate subduction. A number of researchers (e.g., Hu et al., 1997b, 1998; Chen et al., 1998; D.-Z. Wang et al., 1998; Pirajno and Bagas, 2002; Mao et al., 2003; Yang et al., 2003) proposed far-field effects from the Pacific oceanic subduction beneath the Eurasia continent, as the main controlling mechanism for the tectonics,

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metallogenesis, and magmatism in East China. However, models advocating Pacific plate subduction cannot explain: (1) why I_{Sr} values for granitoids and ore fluids in the Jiaodong metallogenic province are higher than those in the Tan-Lu metallogenic belt, opposite of what would be expected across a magmatic arc; (2) the trend of metallogenic belts in East China is perpendicular and not parallel, to the subduction system; (3) many of the gold deposits are in the Jiaodong area, whereas none are present in northern Jiangsu (Fig. 5); (4) gold metallogenesis occurred in the Jurassic and Cretaceous in East China including the Jiaodong area, whereas the age of gold metallogeny in other areas of the Circum-Pacific Rim is Cenozoic; (5) granitoids associated with the Yanshanian metallogeny in East China show characteristics dominantly of S-type, whereas the granitoids associated with Cenozoic metallogeny in the other areas of the Circum-Pacific appear to be dominantly I-type granitoids.

For the reasons given above, we do not accept the subduction of the Pacific plate model for the Yanshanian gold metallogeny in the Jiaodong area. As pointed out by D.-Z. Wang et al. (1998), Yanshanian magmatism and metallogeny in East China cannot be interpreted merely by subduction of the Pacific plate; however, they may have resulted from a combination of the Mesozoic collision between the North China and the Yangtze cratons, and interaction between the paleo-Pacific plate with Eurasia.

Intercontinental collision and lithospheric delamination

Having excluded the above three possibilities, we are led to conclude that continental collision and subsequent extensional collapse are left as the dominant cause of the Yanshanian gold metallogenesis in the JGP. We argue that the Mesozoic collision between the South and North China continents (Figs. 5 and 6) was perhaps the principal cause for the development of the Yanshanian gold metallogenesis in the JGP as well as in other tectonic provinces of China (e.g. Qinling orogen; Chen et al., in press[a]). The major continent-continent collision between the Yangtze craton and the North China craton was associated with deep subduction (A type) of the Yangtze crust beneath the North China craton, which began in the Triassic (Indosinian Orogeny) (S.-G. Li et al., 1993). We propose that a model in which large-scale fluid flow and metallogeny resulted in the formation of orogenic style gold deposits (CMF model of Chen and Fu, 1992; Chen, 1998, Chen et al., 2003), linked to this collision and the extensional tectonics that followed. This is discussed below.

A Model for Gold Metallogeny in the JGP

As mentioned previously, there is no consensus regarding the origin and tectonic setting of gold mineralization in the JGP. A close temporal and spatial association with lamprophyre dikes and granitic rocks in the region demands that some connecting factor(s), not necessarily genetic, must be operative. Many authors have suggested that the granitic rocks acted as a heat source for the circulation of ore-forming fluids (e.g., Xu et al., 1989), whereas others saw a direct link of the mineralizing fluids from the granitoids (e.g., Lü and Kong, 1993). The role of the lamprophyre dikes, if any, is even more uncertain, but perhaps they could have provided favorable channelways for the mineralizing fluids and/or dikes and fluids could have originated from the same source (L.-G. Wang et al., 1998).

Here we propose a model, schematically illustrated in Figure 6 and explained more fully later, which combines the generation of fluids and magmas in an evolving geodynamic setting. This is a model of continental collision, metallogeny, and fluid flow (CMF), first promulgated by Chen (1998) and Chen et al. (1990, 2003). We begin with a collision event, which by its very nature implies a compressional regime, followed by a phase of extensional tectonics. The latter is perhaps a more complex situation in that this is the time when fluid flow was at its peak, and this is also the time when melts could easily intrude into fractures and faults. We look at the transition to and the final extensional setting of an evolving orogen, in terms of P-T-t paths (Jamieson, 1991). A complete collisional-extensional process can be divided into three stages (snapshots in time), with P_{max} and T_{max} as the main criteria, i.e., an early stage of compression with P and T increasing, a middle transition stage from compression to extension with P decreasing and T increasing, and a late extension stage with P and T decreasing. In the transition stage, both P decrease and T increase engender partial melting and fluid generation, which results in granitic magmatism and metallogeny.

S.-G. Li et al. (1993) and Yuan (1996) concluded that the present-day Qinling–Dabie–Su Lu orogen is an Indosinian-Yanshanian orogenic belt formed in the period from Late Triassic to Early Cretaceous.

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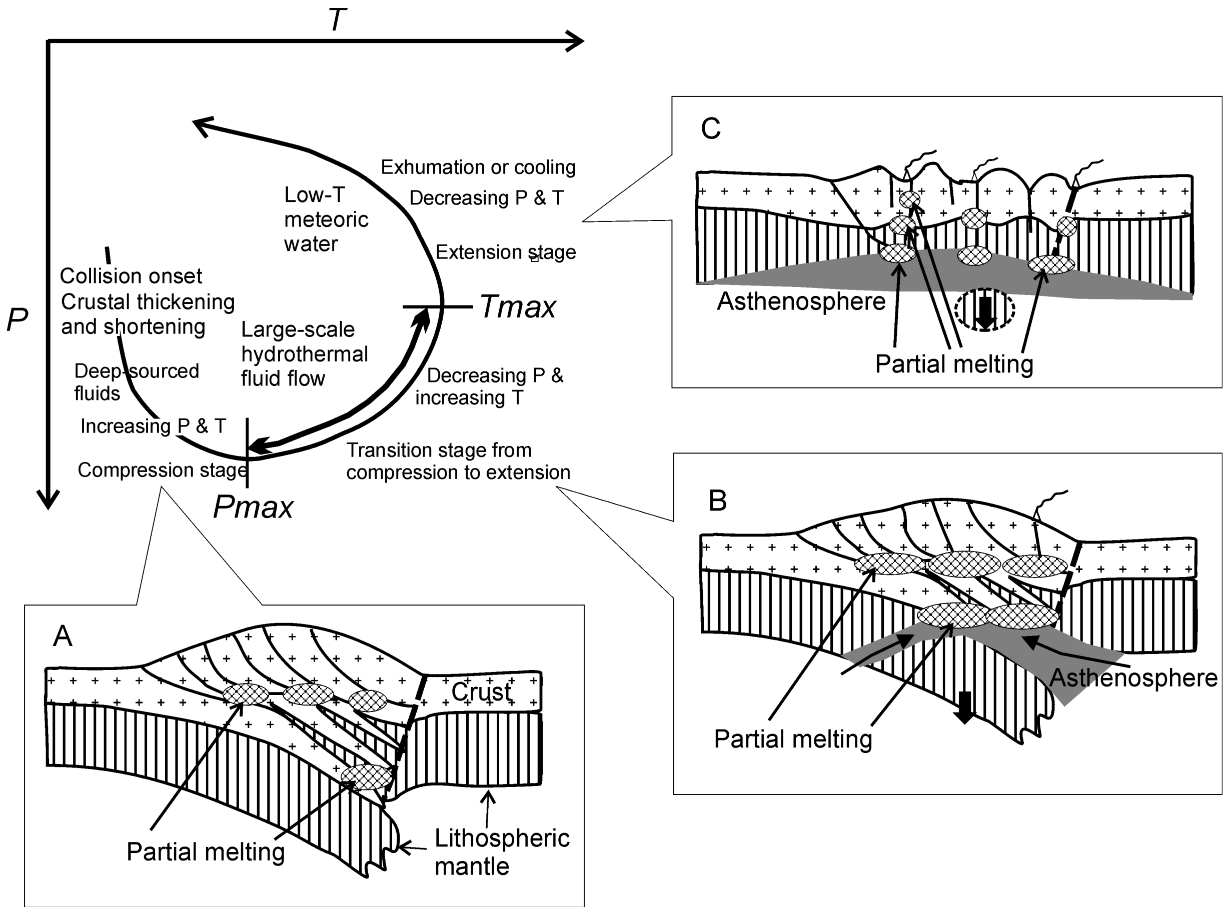

FIG. 6. Model showing relationship of *P-T-t* clockwise path, generation of fluids, magmas, large-scale hydrothermal fluid flow, and related tectonic settings. See text for details.

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Detailed studies in geotectonics (G.-W. Zhang et al., 1996; Meng and Zhang, 1999), stratigraphy and paleontology (F.-X. Zhang et al., 1997), regional geochemistry (B.-R. Zhang et al., 2002), granite petrology (Hu et al., 1988; J. Zhang et al., 2002; Sun et al., 2002; C. Li et al., 2001), metamorphic geology (Liou et al., 1996; Hacker et al., 1996), structural geology (Xu et al., 1986), geochronology (S.-G. Li et al., 1993; Z.-Q. Zhang et al., 2002), basin analysis (Chen and Fu, 1992), paleomagnetism (Zhu et al., 1998), and reflection seismology (Yuan, 1996) support the view that the collision between the South and North China continents began at the end of Triassic (C.-Y. Li et al., 1978)—i.e., ca. 210–220 Ma (Yin and Nie, 1996; Sun et al., 2002; Chen, 2002). Crustal and lithospheric compression, underthrusting, shortening, thickening, and uplift reached a peak in the Jurassic, whereas extension and thinning of the lithosphere occurred most intensively in the Early Cretaceous (Yanshanian orogeny) and continued through to the Cenozoic. From the Late Cretaceous, magmatism is dominated by the development of A-type granitoids, followed by Cenozoic basalts (Tu et al., 1982; Chen and Fu, 1992; Z.-J. Zhang et al., 2003). Therefore, it can be surmised that the transition from compression to extensional tectonism occurred between the end of Jurassic and Early Cretaceous time (about 130–110 Ma).

In our model and taking into consideration the architecture of collisional orogens (Sengör, 1990), granitoids and hydrothermal deposits tend to concentrate in the overriding slab between the reverse boundary thrust (RBT) and the main boundary thrust (MBT). In this scenario, the JGP, China's largest gold province, is in the overriding slab, whereas the western and southern areas of Shandong, northern Anhui, northern Jiangsu, and southeastern Shandong below the MBT or RBT are poorly endowed with granitoids and hydrothermal deposits. Northern Jiangsu is south of the Xuyi-Xiangshui fault, the MBT of the Su Lu orogen (Fig. 5), and therefore is outboard from the collision orogen. Northern Anhui is located north of the RBT (San-Bao fault) and away from the Dabie collisional orogen (Fig. 5). Considering the strike-slip movements along the Tan-Lu fault (Xu et al., 1987; Zhu et al., 2004), the western Shandong and southern Hebei areas are also outboard from the collision orogen. Therefore, the Yanshanian metallogeny is very weak in northern Jiangsu, western Shandong, southern Hebei, and northern Anhui (Fig. 5). The above scenario is supported by the fact that the Xiaoqinling Au province, China's second-largest gold producer (Chen et al., 1998; Yang et al., 2003), is also located in the overriding slab (Fig. 5; Chen et al., 2003; 2004; in prep.).

Studies in the Qinling Mountains and northern Xinjiang show that fluids, and associated mineral deposits, were mainly sourced from crustal materials (Chen and Fu, 1992; Chen, 1997; Gu et al., 1999, 2001; Chen et al., 2000; C. Li et al., 2001; J. Zhang et al., 2002; Z.-J. Zhang et al., 2003). In these regions, granitic magmas were derived from partial melting or remelting of continental crust (Hu et al., 1998). The nature of granitoids in collisional orogens generally reflect changes from crustal to mantle-derived, which in turn reflect changes in the evolutionary geodynamics (Barbarin, 1999). The granite typology associated with collisional tectonic settings changes from syn-collisional peraluminous granitoids (two-mica granitoids of crustal origin), through potassium-rich calc-alkaline KCG, mixed crustal and mantle contribution (as defined by Barbarin, 1999), and finally to A-type granitoids (dominantly mantle source; Deng et al., 1994; Chen et al., 2000; Z.-J. Zhang et al., 2003). A-type granitoids are commonly followed by alkaline basalts, and develop in rifting or extensional settings (Tu et al., 1982), which indicates an important change in the final stages of the geodynamic evolution of a collisional orogen.

Table 1 and Figure 3 show that I_{Sr} values of granitoids and ore fluids in the JGP are greater than 0.709, indicating that ore metals and associated granitiods were sourced from the crust. The temporal evolution of Sr-Nd isotope systematics in granitoids in the Jiaodong area (Fig. 4; Yang et al., 2003) demonstrates that these granites evolved from early-collisional crust-sourced, through late-collisional mantle-crust–sourced, to post-collisional and mantle-derived.

Based on our study, we envisage that the geodynamic evolution of a collisional orogen, from compression through to extension, creates a favorable environment for the development of hydrothermal fluids, granitic magmas, and the development of lode style gold deposits (Qiu and Groves, 1999; Chen et al. 2003, in press[a], in press[b]). The model, as shown in Figure 6, purports three main stages, each being the end member of a time-continuum.

In the first stage (Fig. 6A) crustal shortening-thickening develops from continent-to-continent collision with subduction of a continental slab (A-type

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subduction). During this phase, a largely compressive regime results in increasing *P* and *T*, which induce prograde metamorphism and the generation of deep-sourced fluids. Also, at this point, heating of the crust would produce S-type granitic melts, represented by muscovite-bearing peraluminous granitoids, defined as MPG by Barbarin (1999).

In the second stage (Fig. 6B) the lithospheric root and the continental subducting slab tend to sink, allowing upwelling of asthenospheric mantle to replace space created by this delamination (Platt and England, 1993). The upwelling asthenospheric mantle will produce a large thermal anomaly, and the beginning of uplift and extension, which in turn promotes a giant circulation system of hydrothermal fluids (Fig. 6B), in agreement with the delamination model of Qiu and Groves (1999). This is a transition stage from compression to a predominantly extensional physical regime. During this transition stage, P-T conditions (from P_{max} to T_{max}, i.e. decompression–rising geotherms; Fig. 6B) result in decompression melting in the deep levels, providing energy, fluids, and melts for metallogenesis. These melts result in the emplacement of granitoids represented by K-rich and K-feldspar porphyritic calc-alkaline granitoids (KCG), and ACG (amphibole-rich calc-alkaline granitoids), reflecting increasing levels of mantle contribution (Barbarin, 1999). Structures would dilate due to regional (terrane- or orogen-scale) decompression and uplift, providing good conduits for fluid circulation. These upward-flowing, deeply sourced, fluids would progressively mix with downward-flowing, shallow-sourced fluids in fractures and other favorable loci. Upon mixing, the upward-flowing, deep-sourced fluids and the downward-flowing, shallow-sourced fluids change their physicochemical character, depositing ore-forming elements rapidly, resulting in the most intensive mineralization.

Figure 6C shows the last "snapshot" in which extension is now fully established, a regime characterized by exhumation, cooling, and retrograde metamorphism. At this stage, low-T meteoric fluids percolate downward and continue mixing with the deep-sourced fluids. Retrograde metamorphism is concentrated along shear zones, crustal structures, and faults. In this final stage, post-collision shoshonitic magmatism occurs (Turner et al., 1996), particularly along deep faults (e.g., Tan-Lu fault) and/or in extensional or pull-apart basins, as for example the Cretaceous shoshonitic rocks in the Jiao-Lai basin (Fig. 1). During this late extensional stage and thermal relaxation (after T_{max}C), heat energy and the mobilized ore components decrease and the deep-sourced fluids become negligible, with only the shallow-sourced fluid-systems acting weakly and already restrictedly. Therefore, this latest stage is characterized by low-temperature, shallow-sourced fluids, which may have contributed little to Au mineralization.

This model is supported by detailed studies conducted in orogenic Au lodes in the Xiong'er terrane in the Qinling orogen (e.g., Shanggong and Tieluping; Chen et al., in press[a], in press[b]), where the same sequence of geodynamic events can be reconstructed from collision, and the transition to extension can be followed by examination of isotopic and field data.

Concluding Remarks

Large-scale gold metallogeny in the Jiaodong area occurred in the period 130–110 Ma, and was accompanied by widespread granitic magmatism. The main phases of Yanshanian metallogeny and granitic magmatism occurred during the transition from compression to extension tectonics in the Mesozoic continental collision between the North China and South China plates. This Mesozoic intercontinental collision is one of the dominant factors that caused the Yanshanian large-scale gold metallogeny in the Jiaodong gold province. The ore-forming fluids and associated granitic magmas for Jiaodong Province were derived mainly from the crust.

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