Genesis of the Bangbu Orogenic Gold Deposit, Tibet: Evidence from Fluid Inclusion, Stable Isotopes, and Ar-Ar Geochronology

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Abstract: The Bangbu gold deposit is a large orogenic gold deposit in Tibet formed during the Alpine-Himalayan collision. Ore bodies (auriferous quartz veins) are controlled by the E-W-trending Qusong-Cuogu-Zhemulang brittle-ductile shear zone. Quartz veins at the deposit can be divided into three types: pre-metamorphic hook-like quartz veins, metamorphic auriferous quartz veins, and post-metamorphic N-S quartz veins. Four stages of mineralization in the auriferous quartz veins have been identified: (1) Stage S1 quartz+coarse-grained sulfides, (2) Stage S2 gold+fine-grained sulfides, (3) Stage S3 quartz+carbonates, and (4) Stage S4 quartz+ greetite. Fluid inclusions indicate the ore-forming fluid was CO2-N2-CH4-rich with homogenization temperatures of 170–261°C, salinities 4.34–7.45 wt% NaCl equivalent. δ18Ofluid (3.98‰–7.18‰) and low δDsMOW (~90‰ to ~44‰) for auriferous quartz veins suggest ore-forming fluids were mainly metamorphic in origin, with some addition of organic matter. Quartz vein pyrite has δ34Sv,CDT values of 1.2‰–3.6‰ (an average of 2.2‰), whereas pyrite from phyllite has δ34Sv,CDT 5.7‰–9.9‰ (an average of 7.4‰). Quartz vein pyrites yield 206Pb/204Pb ratios of 18.662–18.764, 207Pb/204Pb 15.650–15.683, and 208Pb/204Pb 38.901–39.079. These isotopic data indicate Bangbu ore-forming materials were probably derived from the Langxi jue accretionary wedge. 40Ar/39Ar ages for sericite from auriferous sulfide-quartz veins yield a plateau age of 49.52 ± 0.52 Ma, an isochron age of 50.3 ± 0.31 Ma, suggesting that auriferous veins were formed during the main collisional period of the Tibet-Himalayan orogen (~65–41 Ma).

Key words: fluid inclusions, stable isotope, Ar-Ar dating, Bangbu deposit, orogenic gold deposit, Tibet-Himalayan orogen, southern Tibet

1 Introduction

Orogenic gold deposits are a distinctive class of mineral deposits that are characterized by (Bohlike, 1982; Groves et al., 1998; Goldfarb et al., 2001, 2014; Goldfarb, 2013): (1) deformed and metamorphosed host rocks; (2) low sulfide volumes; (3) carbonate-sulfide ± sericite ± chlorite alteration assemblages in greenschist-facies host rocks; (4) low salinity, CO2-rich ore-forming fluids with δ18Ofluid values of 5‰~10‰; (5) a spatial association with large-scale compressional to transpressional structures. There are lots of gold deposits in China, including orogenic gold deposits (Zhang and Mao, 2004; Chen et al., 2007; Sun et al., 2009; Liang et al., 2011; Shi et al., 2012; Niu et al., 2014; Song et al., 2014; Deng and Wang, 2015). Orogenic gold deposits have a unique temporal and spatial association with orogens, including accretionary and collisional orogens (Groves et al., 1998; Gordfarb et al., 2001). Although previous studies have suggested that internal collisional orogens, such as the Alpine-Himalayan Orogen, do not contain large lode gold provinces (Groves et al., 1998; Kerrich et al., 2000), some researchers think that collisional orogenic event and associated syn-peak metamorphism in Tibet may provide suitable conditions for formation of orogenic gold deposits (Hou et al., 2006; Hou and Cook, 2009; Jiang et al., 2009; Sun et al., 2016). Additionally, orogenic gold deposits, namely the Mayum (Wen et al., 2006; Jiang et al., 2009), Bangbu (Wei et al., 2010; Sun et al., 2010, 2016; Sun et al., 2012, 2013), and Zhemulang (Zhou et al., 2011) deposits, have been recently discovered in southern Tibet along the Indus-Yarlung Zangbo suture zone.
Discovered in 2003, the Bangbu gold deposit is located in Jiacha County in southern Tibet, China (Fig. 1a). Eleven lode gold ore bodies were identified with average Au grades ranging from 1.35 g/t to 9.36 g/t (Geological Survey of Tibet Bureau of Geology and Mineral Exploration and Development, 2008). Recent studies at Bangbu focused on the geochronology and the source of the ore-forming fluids have indicated that: (1) the Bangbu gold deposit was formed at around 44 Ma (Sun et al., 2016); (2) the ore-forming fluids, enriched in CO₂, were predominantly derived from metamorphic fluids with a small proportion of mantle-derived primary magmatic fluid (Wei et al., 2010; Sun et al., 2010, 2016). However, detailed information on the ore-forming fluids and sulfur and lead isotope geochemistry, which would provide a clearer understanding of this deposit, has seldom been reported.

For this paper, we carried out a detailed geological investigation of the Bangbu deposit. We present new Ar-Ar dating on sericite collected from auriferous sulfide-quartz veins of the No. 3 orebody, systematic microthermometric results for the different stages of mineralization, and H, O, S, and Pb stable isotopic data in order to improve our knowledge of this deposit. This study should prove useful in understanding orogenic gold deposits associated with the Alpine-Himalayan collisional orogenic system.

2 Geologic Setting

2.1 Regional geology

The Bangbu gold deposit is in the southern part of Jiacha County, southern Tibet, China. Tectonically, it is in the southeastern part of the Langjiexue accretionary wedge (Fig. 1b). The Indus-Yarlung Zangbo suture zone, lying between the Lhasa terrane and the Tethyan Himalaya, is bounded by the Dajiling-Angren-Renbu-Motuo fault to the north and Zhongba-Lazi-Qiongduojiang fault to the south (Fig. 1a, Pan et al., 2006, 2009). The Indus-Yarlung Zangbo suture zone can be divided into three subunits, namely the Yarlung Zangbo ophiolite mélangé zone, the Zhongba terrane, and the Langjiexue accretionary wedge. The Langjiexue accretionary wedge is bounded by the eastern part of the Yarlung Zangbo ophiolite zone to the north and the Qiongduojiang-Zhari fault to the south.

![Geological sketch map of tectonic outline of Tibet](image1.png)

![Geological map of the Bangbu ore district](image2.png)

Fig.1. (a), Geological sketch map of tectonic outline of Tibet; (b), Geological map of the Bangbu ore district (modified after Sun et al., 2015).
The regional strata are dominated by metasedimentary rocks of the Upper Triassic Langjiexue Group, including the Songre (T₃s), Jiangxiong (T₃j), and Zhangcun (T₃z) Formations. Most of these units are metamorphosed to lower greenschist facies. The Songre Formation mainly consists of grey to black phyllite, quartzose arkose, and greywacke; the Jiangxiong Formation mainly contains quartzose arkose, siltstone, and carbonaceous phyllite; the Zhangcun Formation is mainly composed of lithic quartz sandstone (Sun et al., 2013). The Bangbu gold deposit is controlled by the regional E-W-trending Qusong-Cuogu-Zhemulang brittle-ductile shear zone and the Jindi-Lunong synclinorium (Fig. 1b, Sun et al., 2010; Sun et al., 2013). The outcrop of the Jindi-Lunong synclinorium trends nearly E-W, but the axial surface strikes 210° (Sun et al., 2013). The main tectonic zones in this region are oriented nearly E-W but a series of secondary NNW and NE oriented faults have also been identified (Sun et al., 2010; Sun et al., 2013). Magmatism is extensive north of the Indus-Yarlung Zangbo suture but nearly absent in the Langjiaxue Group. In the Langjiexue Group, igneous rocks only occur as a few small granodiorite and diabase dikes intruded into the E-W faults.

2.2 District geology

Located in the central part of the Qusong-Cuogu-Zhemulang brittle-ductile shear zone, the Bangbu gold deposit is in the northern part of the Jindi-Lunong synclinorium (Fig. 2). The rocks in the Bangbu mining area are dominantly the Upper Triassic metasedimentary rocks described previously. The northwestern part of the deposit itself is hosted by the second and third members of the Songre Formation, T₃s² and T₃s³. Songre Formation T₃s² consists of carbonaceous phyllite and quartzose arkose and T₃s³ is carbonaceous phyllite, quartz sandstone, and siltstone. A diabase dyke is exposed in the northern part of the Bangbu deposit. The structure of the Bangbu gold deposit is dominated by a series of NE oriented thrust faults and NNW oriented strike-slip faults (Fig. 2, Geological Survey of Tibet Bureau of Geology and Mineral Exploration and Development, 2008). At Bangbu, the Qusong-Cuogu-Zhemulang Fault is a first-order structure, while the NE oriented thrust faults and NNW oriented strike-slip faults are the second-order structures.

2.3 Gold mineralization

The quartz veins at the Bangbu gold deposit can be divided into three types, namely, pre-metallogenic hook-like quartz veins (Fig. 3a), metallogenic auriferous quartz veins (Fig. 3b), and N-S post-metallogenic quartz veins (Fig. 3c). The hook-like quartz veins are mainly composed of white quartz with a small amount of euhedral pyrite. These veins occur in the bedding planes with shapes that are lenticular, hook-like, intestine-like, worm-like, and some are irregular and massive. The quartz veins in the hook-like class are several centimeters to tens of centimeters wide and tens of centimeters to more than ten meters long. Both the hook-like quartz veins and the wall rock are cut by the auriferous quartz veins and the N-S veins. This implies that the hook-like quartz veins are pre-
ore. The auriferous quartz veins are mainly white quartz plus small amounts of pyrite, galena, sphalerite, chalcopyrite, greigite, sericite, ankerite, and chlorite. The veins are several tens of centimeters to several meters in width and tens of meters to hundreds of meters in length. Most of these veins strike NNW–SSE (340°) or SW–NE.
The N–S quartz veins, small-scale and widespread, are composed almost solely of white quartz, strike 100°–160°. The N–S quartz veins cut the wall rock and the other types of veins indicating that the N–S quartz veins were probably quite late, no doubt post-metamorphic. The difference between the different types of quartz veins suggests that the hook-like quartz veins are controlled by ductile structures whereas the auriferous quartz veins were controlled by brittle-ductile structure. The N–S veins were controlled by brittle structures.

Most of the ore is in the auriferous quartz veins. These veins are hosted along the third-order faults associated with the NE oriented thrust faults and NWW oriented strike-slip faults, indicating that ore formation was probably related to activity along these secondary faults (Fig. 2). Eleven Au ore bodies have been identified with lengths of 66–584 m and thicknesses of 0.8–3.7 m. Average Au grades of eleven ore bodies range from 1.35 to 9.56 g/t. The No. 3 ore body is the largest in the deposit, 584 m in length and 25–158 m wide. It strikes 218°–255° and dips 26°–45° to the southwest with an average grade of 9.39 g/t Au and a reserve of 16.06 tonnes Au metal (Geological Survey of Tibet Bureau of Geology and Mineral Exploration and Development, 2008; Sun et al., 2016).

The main ore minerals in all of the known ore bodies are pyrite, galena, sphalerite, and chalcopyrite mostly occurring as aggregated clusters. The gangue minerals include quartz, sericite, epidote, and carbonates. The major alterations associated with the gold mineralization include sulfidation, carbonatization, silicification, and sericitization. Gold is concentrated in the quartz and sulfides (Fig. 3b). Preliminary studies have indicated that Au occurs predominantly as native metal with a fineness of 879 (Sun et al., 2012). Four stages of mineralization in the auriferous quartz veins have been identified. Stage S1 is quartz and coarse-grained sulfides (including coarse-grained pyrite and galena) (Fig. 3d), Stage S2 is gold and fine-grained sulfides (including fine-grained pyrite, galena, sphalerite, and chalcopyrite) (Fig. 3c), Stage S3 is quartz, carbonates (including calcite and ankerite) (Fig. 3f), and Stage S4 is quartz and greigite (Fig. 3g) (Sun et al., 2012, 2013). Gold was deposited in the first two stages, especially Stage S2.

3 Samples and Methods

3.1 ⁴⁰Ar/³⁹Ar dating

The sample used for ⁴⁰Ar/³⁹Ar dating, sample (BB09-4-1), was collected in the central part of the deposit from an auriferous sulfide-quartz vein in the No. 3 orebody. Under the microscope, the sericite used for dating appears undeformed. The sericite grains separated for analysis (0.08–0.15 mm in size) were purified using a magnetic separator and then cleaned by ultrasonic treatment under ethanol. The purity of these mineral separates was greater than 99%. The sample was irradiated for 3223 min in a nuclear reactor (The Swimming Pool Reactor) at the Chinese Institute of Atomic Energy, Beijing. ⁴⁰Ar/³⁹Ar dating was conducted using the MM-1200B Mass Spectrometer at the Key Laboratory of Isotopic Geology, Ministry of Land and Resources, Chinese Academy of Geological Science (CAGS), Beijing. Detailed analytical techniques are described in Chen et al. (2002). Measured isotopic ratios were corrected for mass discrimination, atmospheric Ar, blanks, and irradiation induced mass interference. The monitor used in this work was an internal standard: Fangshan biotite (ZBH-25; age 132.7±1.2 Ma and K₂O content 7.6%). The ⁴⁰Ar/³⁹Ar analytical data are given in Table 1. The ages and 2σ errors were plotted against the cumulative released ³⁹Ar fraction to establish the age spectra (Fig. 4a). The argon isotope ratios are presented graphically on classic isotope correlation plots (Fig. 4b) using ISOPLOT (version 3.0) (Ludwig, 2003).

3.2 Fluid inclusion

Microthermometric analysis undertaken for this study used a Linkam THMSG-600 temperature controlled microscope stage at the CAGS, Beijing, China. The temperature of the stage can range between −200 and 600° C and be controlled to within 0.1°C. The ω(NaClω) calculated from the freezing temperature used the

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>⁴⁰Ar/³⁹Ar</th>
<th>⁴⁰Ar/³⁹Ar</th>
<th>⁴⁰Ar/³⁹Ar</th>
<th>⁴⁰Ar/³⁹Ar</th>
<th>⁴⁰Ar/³⁹Ar</th>
<th>⁴⁰Ar/³⁹Ar</th>
<th>⁴⁰Ar/³⁹Ar</th>
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</tr>
</tbody>
</table>

Abbreviation: ⁴⁰Ar/³⁹Ar, is the ratio of radiogenic Argon40 and Argon39.
formulas from Hall et al. (1988) and density for the inclusions were obtained from the formula in Bodnar (1993). Laser Raman component analysis of single inclusion in quartz veins were performed using a Renishaw System-2000 Laser Raman spectrometer in the Laser Raman Laboratory of the Institute of Mineral Resources, CAGS, Beijing. The laser wavelength is 514 nm, the laser power 20 mW, minimum laser beam diameter is 1 μm, and the spectral resolution is 1–2 cm⁻¹.

3.3 Stable isotopes

The H-O isotope analyses were carried out at the MLR Key Laboratory of Metallogeny and Mineral Assessment, CAGS, Beijing, using a MAT-251EM mass spectrometer. The accuracy of both the O isotope and H isotope was analyses were better than ± 0.2 ‰. The O isotope in water was calculated from the O isotope of the analyzed quartz using the fractionation equation 1000lnq_{water} = 3.38 × 10⁶T⁻²−3.40 (Clayton et al., 1972). The H isotope analysis was done directly on water as the test objects were fluid inclusions. To ensure accuracy of the isotopic test results, the fluid inclusions chosen for H isotope analysis were mainly primary rather than secondary inclusions as determined by inspection under the petrographic microscope.

The S isotope analyses were conducted with a MAT-251EM mass spectrometer at the MLR Key Laboratory of Metallogeny and Mineral Assessment, CAGS, Beijing. Routine analytical precision for standard material is ± 0.2 ‰.

The Pb isotope analysis was undertaken at the Institute of Geology, CAGS, Beijing. The analytical precision of the blank was 1 μg. Analytical errors for ²⁰⁸Pb/²⁰⁶Pb, ²⁰⁷Pb/²⁰⁶Pb and ²⁰⁶Pb/²⁰⁴Pb ratios are no more than 0.005 ‰.

4 Results

4.1 ⁴⁰Ar/³⁹Ar geochronological study of sericite

Previous study considered the possibility that the Bangbu gold deposit formed in the main Himalayan collision (Sun et al., 2016). However, the reported age (44.8 Ma, Sun et al., 2016) is inaccurate because the plateau age is incomplete. Only about 40% of the total ³⁹Ar was released. To define the mineralization age of the Bangbu gold deposit accurately, sericite associated with the gold mineralization was collected and analyzed.

The ⁴⁰Ar/³⁹Ar age analytical data, spectra, and isochron of the sericite from Stage S2 of the auriferous quartz veins in No. 3 ore body in the Bangbu gold deposit are listed in Table 1, and illustrated in Fig. 4. The total fusion age is 48.9 Ma. The weighted mean averages of the plateau-like steps, representing 73.9% of the total released ³⁹Ar, yield a plateau age of 49.52 ± 0.52 Ma (2σ) (Fig. 4a) and an isochron age of 50.3 ± 0.31 Ma (Fig. 4b). This age is interpreted as the minimum age for the formation of sericite alteration, and consequently it indicates that auriferous veins were formed at or earlier than about 49 Ma.

4.2 Fluid inclusions

4.2.1 Types and features

In this paper, only the primary fluid inclusions in the three types of quartz veins in the Bangbu deposit will be discussed: the primary gas-liquid two-phase inclusions and primary three-phase inclusions.

Gas-liquid two-phase inclusions from hook-like quartz veins are ellipsoid with major axes 5 to 15 μm long. They have V/(V+L) volume ratios of no more than 0.10 (Fig. 5a). Gas-liquid two-phase inclusions from auriferous quartz veins in Stage S1 and Stage S2 are ellipsoid or irregular with 5 to 20 μm long major axes and V/(V+L) ratios of 0.10 to 0.35 (Fig. 5b and c). Three-phase inclusions from Stage S1 and Stage S2 auriferous quartz veins are ellipsoid with 10 to 20 μm long major axes and V/(V+L) ratios of 0.05 to 0.25. Gas-liquid two-phase inclusions in Stage S3 auriferous quartz veins have major axes 5 to 10 μm long, V/(V+L) ratios 0.15 to 0.30 (Fig.
5d) whereas similar inclusions in Stage S4 are 5 to 20 μm long with V/(V+L) ratios of 0.05 to 0.25 (Fig. 5e). N-S quartz veins mainly contain gas–liquid two-phase inclusions that are spheroidal or ellipsoidal with diameters or major axes around 5 to 20 μm and V/(V+L) ratios of 0.10 to 0.30 (Fig. 5f).

The coexistence of fluid inclusions with varied V/(V+L) ratios in Stage S1 and Stage S2 auriferous quartz veins implies that fluid boiling may have played an important role in gold mineralization (Fig. 5b and c; Roedder and Ribbe, 1984).

4.2.2 Homogenization temperatures, salinities, and densities

A total of 66 gas–liquid two-phase inclusions in hook-like quartz veins underwent microthermometric analysis (Table 2). Homogenization temperatures (T_h,v) of fluid inclusions in these quartz veins range from 195.8 to 270.4°C with peak values of 225–235°C (Fig. 6a). Ice-melting temperatures (T_m,w) for these fluid inclusions range from −7.7 to −2.6°C, corresponding to equivalent salinities of 4.34 wt% to 11.34 wt% with peak values of 5.5–6.0 wt% (Fig. 6b). The obtained densities are in the range of 0.81–0.93 g/cm³ with peak values of 0.86–0.88 g/cm³ (Fig. 6c).

A total of 138 gas–liquid two-phase inclusions in auriferous quartz veins underwent microthermometric analysis (Table 2, Fig.6d, e and f). Thirty-five Stage I fluid inclusions have homogenization temperatures of 175.4 to 253.7°C, ice-melting temperatures of −5.3 to −2.9°C, salinities of 4.80 wt% to 6.30 wt%, and densities of 0.85–0.96 g/cm³. Fifty-two fluid inclusions from Stage S2 yielded homogenization temperatures of 170.0 to 261.3°C, ice-melting temperatures of −4.8 to −2.6°C, salinities of 4.34 wt% to 7.45 wt%, and densities of 0.84–0.95 g/cm³. Twenty-five fluid inclusions from Stage S3 have homogenization temperatures of 179.3 to 261.3°C, ice-melting temperatures of −6.1 to −2.8°C, salinities of 4.65 wt% to 9.34 wt%, and densities of 0.84–1.04 g/cm³. Twenty-six Stage 4 fluid inclusions yielded homogenization temperatures of 163.6 to 266.0°C, ice-melting temperatures of −5.3 to −3.0°C, salinities of 4.96 wt% to 8.28 wt%, and densities of 0.82–0.95 g/cm³.

A total of 55 gas–liquid two-phase inclusions in N-S quartz veins were also analyzed (Table 2). Homogenization temperatures for fluid inclusions from N-S veins are in the range of 214.0 to 259.6°C with peak values of 230–235°C (Fig. 6g). Ice-melting temperatures for these inclusions range from −6.2 to −3.1°C, corresponding to equivalent salinities of 5.11 wt% to 9.47 wt%, yielding densities of 0.83–0.94 g/cm³ with peak values of 6.0–6.5 wt% and 0.86–0.88 g/cm³ (Fig. 6h and i).

4.2.3 Laser Raman spectroscopy analysis

The vapor and liquid phases in the fluid inclusions in the different quartz veins were identified by Laser Raman analysis (Fig. 7). Fluid inclusions within hook-like quartz veins contain only liquid and vapor-phase H2O (Fig. 7a and b). Stage S1 inclusions and Stage S2 fluid inclusions within
Table 2 Results of microthermometric analysis of fluid inclusions formed at different stages in the Bangbu deposit

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Vein type</th>
<th>Stage</th>
<th>T_{min} (°C)</th>
<th>T_{max} (°C)</th>
<th>Salinity (wt% NaCl eq.)</th>
<th>Density (g/cm³)</th>
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<td>BB-4 (n=12)</td>
<td>hook-like quartz vein</td>
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<td>-7.7 to -2.6</td>
<td>208.0 to 230.0</td>
<td>4.34 to 11.34</td>
<td>0.87 to 0.93</td>
<td>Sun et al. (2013)</td>
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<td>BB-8 (n=11)</td>
<td>hook-like quartz vein</td>
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<td>-7.8 to -2.6</td>
<td>195.8 to 242.7</td>
<td>5.26 to 7.45</td>
<td>0.84 to 0.97</td>
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<td>-4.7 to -3.0</td>
<td>214.4 to 246.1</td>
<td>4.96 to 7.54</td>
<td>0.86 to 0.91</td>
<td>Sun et al. (2013)</td>
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<td>175.4 to 253.7</td>
<td>4.34 to 7.59</td>
<td>0.81 to 0.91</td>
<td>Sun et al. (2013)</td>
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<td>BB-10-37 (n=14)</td>
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<td>-4.7 to -3.0</td>
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<td>0.86 to 0.90</td>
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<td>215.1 to 247.6</td>
<td>5.40 to 8.28</td>
<td>0.86 to 0.94</td>
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<td>-3.6 to -2.9</td>
<td>159.2 to 219.5</td>
<td>5.11 to 6.16</td>
<td>0.88 to 0.96</td>
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<td>-3.8 to -3.1</td>
<td>201.9</td>
<td>6.20</td>
<td>0.92</td>
<td>this study</td>
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<td>-3.9 to -3.0</td>
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<td>175.4 to 236.8</td>
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<td>0.86 to 0.95</td>
<td>Sun et al. (2013)</td>
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<td>209.7 to 237.5</td>
<td>4.96 to 7.16</td>
<td>0.88 to 0.90</td>
<td>this study</td>
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<td>-3.4 to -3.0</td>
<td>170.0 to 203.0</td>
<td>4.96 to 7.56</td>
<td>0.90 to 0.94</td>
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<td>201.0 to 202.8</td>
<td>5.71 to 6.30</td>
<td>0.90 to 0.91</td>
<td>this study</td>
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<td></td>
<td>-6.1 to -2.8</td>
<td>179.3 to 261.3</td>
<td>4.65 to 9.34</td>
<td>0.86 to 0.92</td>
<td>Sun et al. (2013)</td>
</tr>
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<td>BB-10-31 (n=8)</td>
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<td></td>
<td>-4.3 to -3.0</td>
<td>179.6 to 220.0</td>
<td>4.96 to 6.88</td>
<td>0.89 to 0.93</td>
<td>this study</td>
</tr>
<tr>
<td>BB-11-16-2 (n=5)</td>
<td>auriferous quartz vein S3</td>
<td></td>
<td>-3.8 to -3.4</td>
<td>209.3 to 213.5</td>
<td>6.01 to 6.16</td>
<td>0.90 to 0.91</td>
<td>this study</td>
</tr>
<tr>
<td>BB-11-26-3 (n=1)</td>
<td>auriferous quartz vein S3</td>
<td></td>
<td>-4.0</td>
<td>188.2</td>
<td>5.56</td>
<td>1.04</td>
<td>this study</td>
</tr>
<tr>
<td>BB-10-4 (n=11)</td>
<td>auriferous quartz vein S4</td>
<td></td>
<td>-4.8 to -3.0</td>
<td>175.7 to 236.1</td>
<td>4.96 to 7.59</td>
<td>0.86 to 0.93</td>
<td>Sun et al. (2013)</td>
</tr>
<tr>
<td>BB-10-14 (n=12)</td>
<td>auriferous quartz vein S4</td>
<td></td>
<td>-5.3 to -3.4</td>
<td>163.6 to 259.6</td>
<td>5.56 to 8.28</td>
<td>0.83 to 0.95</td>
<td>Sun et al. (2013)</td>
</tr>
<tr>
<td>BB-11-26-4 (n=3)</td>
<td>auriferous quartz vein S4</td>
<td></td>
<td>-3.3 to -3.2</td>
<td>230.0 to 266.0</td>
<td>5.26 to 5.41</td>
<td>0.82 to 0.87</td>
<td>this study</td>
</tr>
<tr>
<td>BB-9 (n=11)</td>
<td>N-S quartz vein</td>
<td></td>
<td>-6.2 to -3.1</td>
<td>215.9 to 243.2</td>
<td>5.11 to 9.47</td>
<td>0.85 to 0.92</td>
<td>Sun et al. (2013)</td>
</tr>
<tr>
<td>BB-10-6 (n=14)</td>
<td>N-S quartz vein</td>
<td></td>
<td>-4.8 to -3.3</td>
<td>214.3 to 259.6</td>
<td>5.41 to 6.83</td>
<td>0.83 to 0.90</td>
<td>Sun et al. (2013)</td>
</tr>
<tr>
<td>BB-10-32 (n=13)</td>
<td>N-S quartz vein</td>
<td></td>
<td>-6.2 to -3.1</td>
<td>220.2 to 244.4</td>
<td>5.11 to 9.47</td>
<td>0.86 to 0.94</td>
<td>Sun et al. (2013)</td>
</tr>
<tr>
<td>BB-10-41 (n=9)</td>
<td>N-S quartz vein</td>
<td></td>
<td>-4.2 to -3.2</td>
<td>222.9 to 246.2</td>
<td>5.41 to 6.74</td>
<td>0.85 to 0.89</td>
<td>Sun et al. (2013)</td>
</tr>
<tr>
<td>BB-10-47 (n=8)</td>
<td>N-S quartz vein</td>
<td></td>
<td>-4.8 to -3.2</td>
<td>214.0 to 244.4</td>
<td>5.26 to 7.59</td>
<td>0.85 to 0.90</td>
<td>Sun et al. (2013)</td>
</tr>
</tbody>
</table>

Notes: Numbers in parentheses refer to numbers of fluid inclusions analyzed, T_{min} = ice-melting temperature, and T_{max} = homogenization temperature.

Fig. 6. Histograms showing fluid inclusion microthermometry for the Bangbu deposit. (a), (d), and (g), homogenization temperatures; (b), (e), and (h), salinities; and (c), (f), and (i), density.
auriferous quartz veins have a vapor phase containing CO₂, N₂, and CH₄ (Fig. 7d and f), whereas CO₂ was the only vapor phase identified in Stage S3 and S4 fluid inclusions (Fig. 7h and j). Fluid inclusions in N–S quartz veins contain liquid and vapor-phase CO₂ (Fig. 7k and l).

These data suggest that: (1) the fluid inclusions from hook-like quartz veins were formed in an H₂O-NaCl system; (2) the fluid inclusions from auriferous quartz veins were in a CO₂–N₂–CH₄ system; and (3) the fluid inclusions from the N–S quartz veins were in a CO₂-NaCl system (Fig. 7).

4.3 Stable isotopes

4.3.1 H-O isotopes

A systematic analysis of the H-O isotopes in the three types of quartz veins from the Bangbu deposit have been previously reported by Sun et al. (2013). The results of H and O isotope compositions are given in Table 3. All of the analyses plot on one side of the meteoric water line in a δDSMOW–δ¹⁸Ofluid diagram (Fig. 8).

In hook-like quartz veins, these analyses yielded δD of SMOW values of −84‰ to −45‰, δ¹⁸O of SMOW values of 13.9‰ to 16.2‰, and δ¹⁸Ofluid values of 4.00‰ to 6.30‰. In auriferous quartz veins, the analyses gave δD of SMOW values of −90‰ to −44‰, δ¹⁸O of SMOW values of 15.0‰ to 18.2‰, and δ¹⁸Ofluid values of 3.98‰ to 7.18‰. In N–S quartz veins, the results were δD of SMOW values of −74‰ to −52‰, δ¹⁸O of SMOW values of 14.4‰ to 15.2‰, and δ¹⁸Ofluid values of 4.12‰ to 4.92‰.

4.3.2 S isotopes

The S isotope compositions of pyrite from the Bangbu deposit are shown in Table 4 and Fig. 9a. A total of 18 samples were analyzed for this study. The 13 pyrite samples from auriferous quartz veins have δ³⁴S values of 1.2‰ to 3.6‰ (an average of 2.2‰), whereas the five pyrite samples from phyllite have δ³⁴S values of 5.7‰ to 9.9‰ (an average of 7.4‰).

4.3.3 Pb isotopes

The Pb isotope compositions of pyrite from the Bangbu deposit are shown in Table 4. A total of 18 samples were analyzed. The 13 pyrite samples from auriferous quartz veins yield ²⁰⁶Pb/²⁰⁴Pb values of 18.662 to 18.764, ²⁰⁷Pb/²⁰⁴Pb values of 15.650 to 15.683, and ²⁰⁸Pb/²⁰⁴Pb ratios of 38.901 to 39.079, with average values of 18.683, 15.659, and 38.952, respectively. The five pyrite samples from phyllite yield ²⁰⁶Pb/²⁰⁴Pb values of 18.672 to 18.898, ²⁰⁷Pb/²⁰⁴Pb values of 15.660 to 15.712, and ²⁰⁸Pb/²⁰⁴Pb ratios of 38.882 to 39.282, with average values of 18.736, 15.668, and 38.978, respectively.

5 Discussion

5.1 Nature of and relationships among fluids associated with the three types of quartz veins

The hook-like quartz veins are associated with low to moderate temperature (195.8–270.4°C), moderate salinity (4.34–11.34 wt% NaCl equivalent), and low density (0.81–0.93 g/cm³) fluids (Fig. 6a, b, and c). The fluids involved in precipitating the quartz in the N–S quartz veins had a narrow range of temperatures (214.0–259.6°C), salinities (5.11–9.47 wt% NaCl equivalent), and densities (0.83–0.94 g/cm³) (Fig. 6g, h, and i). In contrast,
Fig. 7. Laser Raman spectra of liquid and vapor phases within fluid inclusions from the Bangbu gold deposit.
(a), the liquid phase in fluid inclusions from hook-like quartz veins; (b), the vapor phase in fluid inclusions from hook-like quartz veins; (c), the liquid phase in Stage S1 fluid inclusions from auriferous quartz veins; (d), the vapor phase in Stage S1 fluid inclusions from auriferous quartz veins; (e), the liquid phase in Stage S2 fluid inclusions from auriferous quartz veins; (f), the vapor phase in Stage S2 fluid inclusions from auriferous quartz veins; (g), the liquid phase in Stage S3 fluid inclusions from auriferous quartz veins; (h), the vapor phase in Stage S3 fluid inclusions from auriferous quartz veins; (i), the liquid phase in Stage S4 fluid inclusions from auriferous quartz veins; (j), the vapor phase in Stage S4 fluid inclusions from auriferous quartz veins; (k), the liquid phase in fluid inclusions from N-S quartz veins; (l) the vapor phase in fluid inclusions from N-S quartz veins.
the fluids in the auriferous quartz veins had slightly lower temperatures (163.6–266.0°C) and salinities (4.34–9.34 wt% NaCl equivalent) but higher density (0.82–1.04 g/cm³) (Fig. 6d, e, and f) than those in the hook-like quartz veins and the N–S quartz veins. These factors indicate that fluid boiling, caused by declining pressure, could have been responsible for formation of the auriferous quartz veins.

The fluids involved in the four stages of auriferous quartz veins have similar homogenization temperatures, salinities, and densities (Fig. 6d, e, and f) but different chemistries (Fig. 7). Stage S1 and Stage S2 fluids commonly contain CO₂, N₂, and CH₄ (Fig. 7d and f), whereas Stage S3 and Stage S4 fluids contain very low concentrations of CO₂ (Fig. 7h and j), suggesting that Stage S1 and Stage S2 fluids could be considered mineralization-related fluids. Homogenization temperatures of Stage S1 fluids are in the range of 175.4 to 253.7°C with peak values of 200–205°C and 220–225°C, whereas Stage S2 fluids yield similar homogenization temperatures.

Table 4 Sulfur and lead isotope compositions of pyrites from Bangbu gold deposit

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Occurrence</th>
<th>δ³⁴S_o.CO₂(‰)</th>
<th>δ¹⁸⁷Pb/²⁰⁶Pb</th>
<th>δ¹⁸⁷Pb/²⁰⁴Pb</th>
<th>δ¹³⁸Pb/²⁰⁶Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>BB-2</td>
<td>Auriferous quartz vein</td>
<td>2.2</td>
<td>38.947</td>
<td>15.658</td>
<td>18.672</td>
</tr>
<tr>
<td>BB-5</td>
<td>Auriferous quartz vein</td>
<td>3.6</td>
<td>39.079</td>
<td>15.683</td>
<td>18.715</td>
</tr>
<tr>
<td>BB-6</td>
<td>Auriferous quartz vein</td>
<td>1.9</td>
<td>39.072</td>
<td>15.677</td>
<td>18.764</td>
</tr>
<tr>
<td>BB-11</td>
<td>Auriferous quartz vein</td>
<td>2.5</td>
<td>38.948</td>
<td>15.662</td>
<td>18.664</td>
</tr>
<tr>
<td>BB-12</td>
<td>Auriferous quartz vein</td>
<td>1.7</td>
<td>38.952</td>
<td>15.659</td>
<td>18.673</td>
</tr>
<tr>
<td>BB-14</td>
<td>Auriferous quartz vein</td>
<td>2.5</td>
<td>38.937</td>
<td>15.657</td>
<td>18.674</td>
</tr>
<tr>
<td>BB-15</td>
<td>Auriferous quartz vein</td>
<td>1.6</td>
<td>38.917</td>
<td>15.654</td>
<td>18.678</td>
</tr>
<tr>
<td>BB-16</td>
<td>Auriferous quartz vein</td>
<td>1.2</td>
<td>38.901</td>
<td>15.650</td>
<td>18.676</td>
</tr>
<tr>
<td>BB-17</td>
<td>Auriferous quartz vein</td>
<td>2.4</td>
<td>38.916</td>
<td>15.654</td>
<td>18.679</td>
</tr>
<tr>
<td>BB-18</td>
<td>Auriferous quartz vein</td>
<td>2.0</td>
<td>38.929</td>
<td>15.655</td>
<td>18.676</td>
</tr>
<tr>
<td>BB-9-3-8</td>
<td>Auriferous quartz vein</td>
<td>2.0</td>
<td>38.923</td>
<td>15.654</td>
<td>18.676</td>
</tr>
<tr>
<td>BB-9-3-2</td>
<td>Auriferous quartz vein</td>
<td>2.6</td>
<td>38.924</td>
<td>15.654</td>
<td>18.673</td>
</tr>
<tr>
<td>BB-9-4-2</td>
<td>Auriferous quartz vein</td>
<td>2.4</td>
<td>38.925</td>
<td>15.654</td>
<td>18.662</td>
</tr>
<tr>
<td>BB-10</td>
<td>Wall rock</td>
<td>8.0</td>
<td>39.282</td>
<td>15.712</td>
<td>18.898</td>
</tr>
<tr>
<td>BB-19</td>
<td>Wall rock</td>
<td>6.9</td>
<td>38.847</td>
<td>15.641</td>
<td>18.731</td>
</tr>
<tr>
<td>BB-9-1-4</td>
<td>Wall rock</td>
<td>5.7</td>
<td>38.989</td>
<td>15.678</td>
<td>18.682</td>
</tr>
<tr>
<td>BB-9-2-1</td>
<td>Wall rock</td>
<td>6.5</td>
<td>38.882</td>
<td>15.660</td>
<td>18.672</td>
</tr>
<tr>
<td>BB-9-2-1</td>
<td>Wall rock</td>
<td>9.9</td>
<td>38.891</td>
<td>15.651</td>
<td>18.696</td>
</tr>
</tbody>
</table>
of 170.0 to 261.3°C with slightly lower peak values of 195–200°C (Fig. 6d). Peak salinities in Stage S1 and Stage S2 fluid inclusions are similar (5.5–6.0 wt%, Fig. 6e). The temperatures and salinities of the ore-forming fluids that formed the Bangbu gold deposit are similar to those associated with typical orogenic gold deposits (220–500°C, 3.0–6.0 wt%; Groves et al., 1998; Kerrich et al., 2000).

5.2 Origin of the ore-forming fluids

On a $\delta^{18}$O$_{fluid}$--$\delta^{18}$O$_{SMOW}$ diagram, most of the calculated $\delta^{18}$O$_{fluid}$ and $\delta^{18}$O$_{SMOW}$ data for the three types of quartz veins at Bangbu plot within the fields of metamorphic or primary magmatic water (Fig. 8), approaching the field of most orogenic gold deposits (Kerrich et al., 2000; Goldfarb et al., 2004). This suggests that the fluids involved in the Bangbu quartz veins were mainly dominated by metamorphic water.

Furthermore, these data generally plot with $\delta^{18}$O$_{SMOW}$ values as low as $-90\%o$, values indicative of an influx of either exchanged meteoric water or a fluid containing organically derived hydrogen (Goldfarb et al., 2004). However, the narrow range of $\delta^{18}$O$_{fluid}$ data (3.98% to 7.18%, Fig. 8) for these samples, defining a nearly parallel trend along the $\delta^{18}$O$_{SMOW}$ axis, excludes the possibility of an influx of meteoric water. In view of the abundance of organic matter-bearing sedimentary units in the Bangbu district that would generate a significant methane component in any fluid produced during devolatilization (Sheppard, 1986). The fluid inclusions in the hook-like quartz veins and the N–S quartz veins associated with regional metamorphism do not contain CH$_4$, indicating that the CH$_4$ in the auriferous quartz veins is best interpreted as being the product of water-rock reactions between organic matter-bearing sedimentary units and the ore-forming fluids.

A recent study analyzed noble gases such as He and Ar trapped in fluid inclusions in pyrites separated from the auriferous quartz veins and wall rocks (Sun et al., 2016). This study suggests that the ore-forming fluids in the Bangbu gold deposit were predominantly of metamorphic origin with the addition of a small proportion of mantle-derived primary magmatic fluid. However, mantle-derived water identified in Bangbu was probably associated with magmatic rocks in the Langjiexue accretionary wedge rather than having been derived directly from the mantle.

In conclusion, the fluid inclusion and H-O isotope data from this study indicate that the ore-forming fluids that formed the Bangbu gold deposit were mainly metamorphic in origin with some addition of organic matter.

5.3 Source of ore-forming materials

Sulfur isotope compositions of S-bearing hydrothermal minerals are controlled by the total S isotope composition of the fluids, temperature, oxygen fugacity, and pH at the site of mineralization (Ohimoto, 1986; Ohimoto and Goldhaber, 1997). The first parameter can be regarded as a source characteristic but the latter three relate to the environment of deposition. Under reducing conditions, where H$_2$S is the dominant aqueous sulfur species, the sulfides precipitated will have $\delta^{34}$S values very similar to the sulfur in the ore fluid (Hodkiewicz et al., 2009). The ore-forming fluid at Bangbu was in a CO$_2$ + N$_2$+ CH$_4$ system, implying that sulfides at Bangbu were the product of precipitation from a reduced fluid. Hence, the $\delta^{34}$S$_{V-CDT}$ values for pyrites in the Bangbu deposit could be used to trace the source of the ore-forming materials.

However, sulfides in orogenic gold deposits have a wide range of sulfur isotopic compositions ($\delta^{34}$S$_{V-CDT}$), and a definitive source for the gold-transporting sulfur ligands within the ore-forming fluids is equivocal (McCuaig and Kerrich, 1998; Goldfarb et al., 2005). For example, $\delta^{34}$S$_{V-CDT}$ values for sulfides in Archean orogenic gold deposits range from about 0% to 9% (Kerrich, 1987; Golding et al., 1990; McCuaig and Kerrich, 1998), whereas $\delta^{34}$S$_{V-CDT}$ values for sulfides in Phanerozoic orogenic gold deposits are in the range of $-20\%$ to $25\%$ (Peters and Golding, 1989; Kontak et al., 1990). The $\delta^{34}$S$_{V-CDT}$ values of sulfides from the Bangbu auriferous quartz veins span a narrow range, from 1.2% to 3.6% (an average of 2.2%), suggesting that the sulfur was derived from a single source. In contrast, the sulfur isotopes in sulfides from the wall rocks range from 5.7% to 9.9% (an average of 7.4%). This sulfur could be derived either directly from magmas, indirectly by dissolution and/or desulfidation of primary magmatic sulfides, or provided from average crustal sulfur sources (Kerrich, 1987; Ho et al., 1992). However, the near absence of magmatic rocks in the Langjiexue Group indicates that sulfur probably was not derived from magmas. Overall, the gold-transporting sulfur ligands at Bangbu were probably sourced from deep metamorphic fluids.

The average growth curves of Pb from different source regions compiled by Zartman and Haines (1988) were used to determine the likely sources for Pb in the Bangbu gold deposit. The majority of the Bangbu samples plot above the upper crustal evolution line in $^{206}$Pb/$^{208}$Pb–$^{208}$Pb/$^{204}$Pb space and are very close to Zartman and Haines’ “orogen” field (Fig. 10a). In addition, most of the samples plot near the orogen and orogenic evolution lines in a $^{207}$Pb/$^{206}$Pb–$^{208}$Pb/$^{204}$Pb diagram (Fig. 10b). However, some samples of Bangbu pyrite in auriferous quartz veins have Pb isotope compositions similar to those of the wall rocks, suggesting that the lead of these samples may have been derived from the wall rocks. As discussed above, there is one probable source for the lead in the Bangbu gold deposit, namely the Langjiexue accretionary wedge.
In short, the sulfur and lead isotope data imply that the ore-forming materials were probably sourced in the Langjiexue accretionary wedge.

5.4 Structural controls on ore formation

The Tethyan Himalayan thrust belt, located between the South Tibet Detachment and Indus-Yarlung Zangbo suture, probably accommodated 130–140 km of shortening during the Indo-Asia collision (Ratschbacher et al., 1994). The collisional orogenic event and associated syn-peak metamorphism in Tibet provided suitable conditions for formation of orogenic gold deposits along the Indus-Yarlung Zangbo suture (Hou and Cook, 2009). Translithospheric structures marked by the Indus-Yarlung Zangbo suture provide conduits for large-scale ore-forming fluid flow and the second- or third-order structures (such as ductile-brittle shear zones and thrust faults probably associated with the first-order structures) can provide a locus for gold precipitation.

The regional Quonsung-Cuogu-Zhemulang brittle-dextral shear zone was probably the ore-transmitting structure for the Bangbu gold deposit. The ore-forming fluids could flow along NE oriented thrust faults and NNW oriented strike-slip faults and precipitate gold in the third-order faults. However, the Jindi-Lunong synclinorium, located to the south of the Bangbu ore district, and numerous faults therein played essentially no role in the precipitation of the gold.

5.5 A genetic model for the Bangbu gold deposit

The framework for Tibetan metallogenic systems includes three principal metallogenic epochs in the Tibetan orogen. Metallogenesis took place in: (1) a main-collisional convergent setting (~65–41 Ma); (2) a late-collisional transform structural setting (~40–26 Ma); and (3) a post-collisional crustal extension setting (~25–0 Ma) (Hou and Cook, 2009). The main collisional metallogenesis took place in a convergent setting characterized by collision-related crustal shortening and thickening associated with syn-peak metamorphism (Hou and Cook, 2009).

At approximately 50 Ma, CO2-dominated metamorphic fluids were generated by the syn-peak metamorphism caused by continental impact during the main-collisional metallogenesis of the Tibet-Himalayan orogen. These fluids were transported along the regional Quonsung-Cuogu-Zhemulang brittle-dextral shear zone at depths of 500 to 2000 m. Under low oxidation conditions, the ore-forming materials were probably extracted from the deep metamorphic rocks of the Langjiexue accretionary wedge when the CO2-rich metamorphic fluids migrated upward. Sulfur-bearing fluids were capable of transporting a significant amount of gold when they migrated through a complex fracture network. Gold migrated in the form of Au(HS)2 when the fluid’s oxygen fugacity was low. The second- or third-order structures at Bangbu, such as NE oriented thrust faults and NNW oriented strike-slip faults, provided suitable foci for gold precipitation. When the ore-forming fluids migrated into the second- or third-order structures, the pressure of the fluids dropped rapidly resulting in fluid boiling. During fluid boiling, reducing species such as CO2 and CH4 entered into the gas phase and this raised the SO2/H2S ratio (Hodkiewitz et al., 2009). The escaping H2S decreased total sulfur in the fluids and then increasing oxygen fugacity destroyed the stability of the Au(HS)2 complexes. That precipitated gold efficiently. Fluid boiling, caused by declining pressure, was probably responsible for gold deposition at Bangbu. A sketch of the genetic model for the Bangbu gold deposit is shown in Fig. 11. Comparisons of geological characteristics of Bangbu and typical orogenic gold deposits are shown in Table 5.

5.6 Comparison of the Bangbu deposit with the Mayum deposit

In addition to the Bangbu gold deposit, other orogenic
gold deposits, such as the Mayum (Wen et al., 2006; Jiang et al., 2009) and the Zhemulang (Zhou et al., 2011) deposits, have been discovered in Tibet along the Indus-Yarlung Zangbo suture zone. There are both similarities and differences between the Bangbu deposit and the Mayum deposit. (1) $^{40}$Ar/$^{39}$Ar radiometric dating of the Bangbu gold deposit gives an accurate age for gold mineralization (49.52 Ma), which is completely consistent with the reported ages (44–59 Ma) of the Mayum gold deposit (Wen et al., 2004; Jiang et al., 2009). (2) The ore-forming fluids in the Bangbu gold deposit were mainly metamorphic in origin (with some additions from organic matter) however the ore-forming fluid at Mayum may have been derived from metamorphic deep-crustal fluids (Fig. 8, Jiang et al., 2009). (3) The ore-forming materials at Bangbu were probably derived from the Langjiexue accretionary wedge. However, the $\delta^{34}$S$_{VDGT}$ values of sulfides from the Mayum quartz veins show a large range from $-15.9\%$ to $16.8\%$ (Wen et al., 2006; Jiang et al., 2009), and most samples in the total population range between $-0.2\%$ and $5.9\%$, indicating that the ore-forming materials for the Mayum deposit were possibly sourced from the wall rocks (Fig. 9, Jiang et al., 2009).

Internal collisional orogens, such as the Alpine-Himalayan Orogen, do not host large lode gold provinces because the relatively small scale and shallow vertical fracture systems and poor interconnectivity of these fractures in the collisional orogens are not conducive to the migration of ore-forming fluids (Groves et al., 1998; Kerrich et al., 2000). Nevertheless, the existence of the Mayum, Bangbu, Zhemulang, and Nianzha gold deposits along the Indus-Yarlung Zangbo suture is indicative of the zone’s great potential to generate additional orogenic gold deposits associated with the Indo-Asian collision.

### 6 Conclusions

(1) The Bangbu gold deposit, a large Cenozoic syn-collision orogenic gold deposit in southern Tibet, is hosted in Upper Triassic metasedimentary rocks with its location controlled by the NE-trending Quonsong-Cuogu-Zhemulang brittle-ductile shear zone. $^{40}$Ar/$^{39}$Ar age data for sericite

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![Diagram](image-url)

**Fig. 11. A sketch genetic model for the Bangbu gold deposit.**

<table>
<thead>
<tr>
<th>Geological features</th>
<th>Bangbu gold deposit</th>
<th>Typical orogenic gold deposits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tectonic background</td>
<td>Collisional orogen</td>
<td>Accretionary orogens</td>
</tr>
<tr>
<td>Ore-controlling structures</td>
<td>Second- or third-order structures of Quonsong-Cuogu-Zhemulang brittle-ductile shear zone</td>
<td>Second- or third-order structures of brittle-ductile shear zone</td>
</tr>
<tr>
<td>Host rocks</td>
<td>Upper Triassic metasedimentary rocks</td>
<td>Mafic and ultramafic volcanic rocks, intrusive rocks, BIF-chert, and greywacke</td>
</tr>
<tr>
<td>Mineralization style</td>
<td>Quartz veins</td>
<td>Carbonatization, sulfidation, chloritization, etc</td>
</tr>
<tr>
<td>Hydrothermal alteration</td>
<td>sulfidation, carbonatization, silicification, and sericitization</td>
<td></td>
</tr>
<tr>
<td>ore-forming fluid</td>
<td>4.34 to 7.45 eq. wt% NaCl; CO$_2$-riching, CO$_2$H$_2$O-NaCl-CH$_4$</td>
<td>3 to 10 eq. wt% NaCl; CO$_2$-riching, CO$_2$H$_2$O-NaCl-CH$_4$</td>
</tr>
<tr>
<td>Temperature conditions</td>
<td>170 to 261°C</td>
<td>220 to 500 °C</td>
</tr>
<tr>
<td>isotopes (water)</td>
<td>$d^{18}O = -9%$ to $-44%$; $\delta^{18}O = 4%$ to $7%$ this study</td>
<td>$d^{18}O = -80%$ to $-20%$; $\delta^{18}O = 6%$ to $10%$</td>
</tr>
</tbody>
</table>
collected from auriferous sulfide-quartz veins of the No. 3 orebody in the deposit gives a plateau age of 49.52 ± 0.52 Ma. The orebody was formed during the main collisional event (~65–41 Ma) of the Tibet-Himalayan orogen created by Indo-Asian collision.

(2) Fluid inclusions indicate that the ore-forming fluid at Bangbu was part of a CO₂ + N₂ + CH₄ system and the fluid was one of moderate temperatures and medium to low salinity. The H₂O isotopic data indicate that the ore-forming fluids in the Bangbu deposit were mainly metamorphic in origin with the addition of organic matter. Studies of S and Pb isotopes suggest that the ore-forming materials at Bangbu were probably derived from the Langjixue accretionary wedge.

(3) The geology and geochemistry of Bangbu are quite consistent with those of most typical orogenic gold deposits. Additionally, the existence of the Bangbu and Mayum gold deposits indicates that the Indus-Yarlung Zangbo suture zone has great potential to generate more orogenic gold deposits.

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