Fluid Inclusions of Orogenic Gold Deposits in the Zhongchuan Area,
Western Qinling and Their Geological Significance

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Abstract  Orogenically-derived gold deposits of the Zhongchuan area in the western Qinling are distributed in the exo-
contact thermal metamorphic zone. The country rocks hosting the deposits are predominantly of Devonian age with low-
grade metamorphism and strong deformation with the ore deposits directly controlled by multi-level tectonic systems.
Three types of inclusions from these deposits have been recognized: CO₂-H₂O, CO₂-rich, and aqueous. The ore-forming
fluids were mainly CO₂-NaCl-H₂O type characterized by rich CO₂, low salinity, high temperature and immiscibility.
Incorporated with earlier isotopic data, the regional geological setting and features of diagenesis and metallogeny, it can be
concluded that the ore-forming fluids were derived from deep magma and mixed with meteoric and metamorphic water.
The deposits formed during an intra-continental collisional orogeny, and some of the materials derived from the deep might
have been involved in the ore-forming process.

Key words: fluid inclusion, orogenic gold deposit, Zhongchuan area, western Qinling

1 Introduction

Some large and medium scale gold deposits such as the Liba, Jinshan, and Maquan and many gold mineralizing
occurrences have been successively discovered in the Zhongchuan area as an important member of the large gold
Huang et al. (2000), Sun (2000) and Feng et al. (2003a) have done some preliminary research on three aspects of the
Liba and Maquan gold deposits: the geology, source of ore-forming materials and metallogeny. Chen (1993), Song
et al. (1997) and Cheng and Zhang (2001) have studied the features of the Zhongchuan intrusion and its relationship to
gold mineralization; Feng et al. (2002) have done research on the mineralization age and its significance for the Liba
gold deposit. In this paper we study the characteristics of fluid inclusions in the main gold deposits and try to ascertain the source of the ore-forming fluid, and ore-
forming process.

2 Regional Geology and Basic Features of the Gold Deposits

The western Qinling, intervening between the North China and Yangtze Craton, is located in the west of the Qinling orogenic belt and close to the Songpan-Garzê basin in the west. The region can be divided into three belts, northern, middle and southern, separated from north to
south by the regional deep Shangdan and Lixian-Shanyang faults. The Zhongchuan area is located in the middle belt of the western Qinling orogenic belt (Fig. 1). Several gold deposits including the Liba, Jinshan, Maquan, Sanrenyou and the Yawanli, as well as many gold mineralizing occurrences, have been discovered (Fig. 2). They occur in an exo-contact thermal metamorphic zone 1–5 km away from the Zhongchuan Indosinian-Yanshanian composite granitic intrusion, and are controlled by structural fractures and a joint-cleavage zone.

2.1 Regional geology

The stratigraphic sequence of the study area is mainly composed of Devonian to Permian with some scattered overlying Tertiary sandy-conglomerates and Quaternary sediments. The oldest stratigraphic unit is the middle Devonian Shujiaba Group, which is a marine turbidity, fine-grained clastic flysch-like formation with a low-grade metamorphism comprising metamorphic siltstones, spotted slates, quartz-biotite schists and marbles. Then there are Middle Carboniferous low-grade metamorphosed sedimentary rocks, which were formed on continental slope and submarine canyon, consisting of metaconglomerate quartz sandstones, phylite-like slates and siliceous rocks. Finally, the Permian beds consist of clasts and carbonates.

The major structural feature of the study area is the Luoba-Suolongkou and Taoping-Jiziba faults together with the Shijiaheba composite syncline, which constitute a fold-fault system. The general structure trend extends to the
southeast (110°–120°). The outcrops of the Zhongchuan intrusion and gold deposits of the area are mainly controlled by the deep Lixian-Shanyang fault, with subsidiary faults also well developed in varied directions. Among these faults, WNW-striking faults are the most pronounced. The fold also trends WNW, and the Shijiaba syncline comprises three secondary folds, the Mawu anticline in the north, the Shijiaba syncline in the middle, and the Zhangfengpo anticline in the southwest (Fig. 2).

Magmatism occurred very frequently in different periods with a major pulse in this area during the Indosinian period. The main Zhongchuan composite intrusion occurred as a batholith, which now crops out over a large area of ca. 700 km². The intrusion consists of three intrusive phases, i.e., the early stage (219 Ma) of medium-coarse grained porphyritic-like biotite monzonite and granodiorite; the middle stage (196 Ma) of coarse grained porphyritic crystal-bearing biotite monzonitic granite; and the late stage (181.5 Ma) of medium-fine grained biotite monzonite granite and two-mica monzonitic granite (Lu et al., 2001). From the early to late stages, the granitoid occurred as a concentric ring-like structure, but the medium-coarse grained porphyritic-like biotite monzonitic granite and the granodiorite of the Indosinian period are the most important. The granitoid shows an obvious intrusive contact with the country rocks. Plenty of xenoliths of country rocks appear in the endo-contact zone, the exo-contact obviously having suffered thermal metamorphism. The rocks display gray-white and pinkish colors with porphyritic-like and granitic texture and massive structure. The porphyritic crystals consist mainly of K-feldspar, plagioclase and quartz. The content of hornblende and biotite in the rock decreased from the early to late stage, while the content of quartz and plagioclase in the rock increased. The rock is rich in FeO, MgO, CaO, TiO₂, P₂O₅ and poor in SiO₂, Al₂O₃, Fe₂O₃, Na₂O and K₂O, and it is a typical calc-alkaline granitoid (Lu et al., 2001).

2.2 Basic features of the gold deposits

Besides a few deposits such as the Maquan, most were hosted in the Devonian Shuijiaba Group silty slates and quartz sandstone with greenschist-facies metamorphism and strong deformation. The deposits were controlled by a multi-level structural system, i.e., the regional deep fault controlled the distribution, and the secondary fracture and shearing zone distributed in parallel with the regional deep fault controlled the occurrence of the deposits. Small-scale faults and folds are extensively developed in the mine area. The ore bodies occur mainly within the fractured and ductile-brittle shearing zones in vein, lens and tabular form. They also exhibit expansion (or contraction), branching (or composite) and thinning out (or re-emergence) features.

There are two types of ore, i.e. the alteration rock type and the quartz vein type. The former occurred as altered rocks subjected to pyritization-sericitization, showing obscure boundaries with the wall rocks, and the latter is auriferous quartz veins showing clear boundaries with the wall rocks. The ores mainly display anhedral, subhedral,
Fig. 2. Geological sketch map of the gold deposits in the Zhongchuan Area (modified from Liu, 1994b).

euhedral and idiomorphic granular textures; replacement residue, mortar and poikilitic textures can also be observed, as well as disseminated, banded, stockwork and spotted structures. The ores of these gold deposits show a complicated mineral assemblage. Besides native gold, pyrite, pyrrhotite and arsenopyrite there are also major gold-carrying minerals. The wall rocks are subjected to different types of alteration such as pyritization, sericitization, silicification, carbonization, occasionally albitization, tourmalinization and chloritization.

Although there is little difference in mineral association and occurrence of ore bodies in the various deposits, generally, the gold mineralization of the Zhongchuan area includes two epochs, i.e., hydrothermal and supergene epochs. According to the mineral assemblage and their various intercalated relations, three mineralization stages can be recognized in the hydrothermal epoch: (1) quartz veinlet stage that formed quartz veinlet and minor pyrite, arsenopyrite, galena with low grade of gold; (2) polymetallic sulfides stage that formed quartz, pyrite, pyrrhotite, arsenopyrite, chalcopyrite, sericite, and minor chlorite, the major mineralization stage that formed veinlet and disseminated ores; and (3) carbonate stage that formed calcite, chlorite, gypsum, barite and minor sulfides.
3 Fluid Inclusions

Considering the types of ores and the influence of supergene oxidation, we have collected samples of fluid inclusions for study from the localities as follows: (1) the 1690 m and 1730 m levels of No. 5 ore body, and the 1800 m level of No. 6 ore body in the Liba gold deposit; (2) the 1820 m and 1800 m levels of No. 5 ore body in the Jinshan gold deposit; and, (3) the 1660 m level of No. 2 mineralizing zone and the 1740 m level of No. 4 mineralizing zone in the Maquan gold deposit. Primary fluid inclusions of the quartz selected from the vein type ores, which formed during the polymetallic sulfides stage of these deposits have been selected for microthermometric measurements.

3.1 Characteristics of fluid inclusions

The fluid inclusions are rather common in both quartz and calcite, which were closely related to the mineralization of these gold deposits. The fluid inclusions vary from <2 μm to 30 μm, but mainly are about 2 to 15 μm.

![Image of fluid inclusions](image-url)

Fig. 3. Microphotographs of fluid inclusions.

a – three-phase CO₂-H₂O inclusion and aqueous inclusion with regular shapes; b – two-phase aqueous inclusion; c – directionally arranged CO₂-H₂O and CO₂-rich inclusions with negative crystal shapes; d – CO₂-H₂O inclusion and aqueous inclusion with irregular shapes; e and f – typical three-phase CO₂-H₂O inclusions.
(see Fig. 3), only those >6 μm could be used to do the micro-thermometric measurements. The fluid inclusions vary from ellipsoid, negative crystal, rhombic, triangular to rectangular.

On the basis of the characteristics and occurrence of fluid inclusions at room temperature, combining their cooling behavior (down to −40°C) and low temperature heating (up to 31°C), three major compositional types of fluid inclusions can be distinguished in decreasing order: the CO₂-H₂O, CO₂-rich, and aqueous type. The CO₂-rich fluid inclusions are defined by their lack of clathrate formation during the cooling.

**CO₂-H₂O inclusions**

CO₂-H₂O inclusions generally vary from 2 to 20 μm, maximum >30 μm, with most about 6 to 12 μm. They are the most abundant among the three types of inclusions, making up 80% of the inclusions. The inclusions occur as negative crystal or irregular shapes such as ellipsoid, rhombic, rectangular and sigmoid and consist of three phases (liquid H₂O + liquid CO₂ + vapor CO₂) or in a few, two phases (liquid H₂O+ liquid CO₂) at room temperature. During the freezing some bubbles in the central phase can be observed in the two-phase CO₂-H₂O inclusions. The volumetric proportion of CO₂ in the two-phase inclusions ranges from 5% to 45%, and mainly from 10% to 35%. That of three phases is in a range of 10%–90%, mainly less than 50%. The proportion of liquid CO₂ to vapor CO₂ in the CO₂ phase of inclusions is different. The volumetric proportion of vapor CO₂ in CO₂ phase varied in a wide range of from 30%–80%, a few closing to 100%, and some of the vapor CO₂ occurs as a moving round bubble. Most of the inclusions show a clear boundary between the different phases and a few of the inclusions are dark in color (brown or black) in the vapor phase.

**CO₂-rich inclusions**

The CO₂-rich inclusions are a little smaller than the CO₂-H₂O inclusions in size with a range of 2–20 μm, and most of them <10 μm. The CO₂-rich inclusions make up around 10%–15% of inclusions. They can have negative crystals or round and ellipsoid shapes. The CO₂-rich inclusions are distributed in a mode similar to the CO₂-H₂O inclusions, and most of them are of primary origin. The inclusions mainly show a single phase, only a few of them have two phases (liquid CO₂ + vapor rich in CO₂) at room temperature. The CO₂-rich inclusions generally co-exist with CO₂-H₂O inclusions and are transparent.

**Aqueous inclusions**

The long axis of aqueous inclusions is in a range of 2–15 μm with an average of 4–8 μm, the proportion of vapor phase to liquid phase in the inclusions is 5%–15%, a few of 30%. The amounts of this type of inclusion are less than that of the CO₂-H₂O and CO₂-rich inclusions and make up around 5%–10% totally. They consist of two phases of vapor and liquid at room temperature. Most of them show round, ellipsoid and irregular shapes, distributed along healed fractures, suggesting a secondary origin. However, part of this type of inclusion, which co-exist with CO₂-H₂O inclusions and are distributed as isolated occurrences, hint at a primary origin. This type of inclusion is transparent, occasionally displaying a dark brown color.

Quite a few inclusions with daughter minerals have also been observed. However, because of the small quantity and extremely fine nature, it is difficult at this stage to do any more detailed work with them.

### 3.2 Fluid inclusion microthermometry

Microthermometric analyses were carried out on a Linkam Thmsq 600 (−198°C to +600°C) heating–freezing stage; estimated accuracy is ±0.1°C at temperatures below 30°C and ±1°C at temperatures above 30°C. The salinity of the ore-forming fluids can be determined by measuring the ice-melting temperature (Tm_ice) in the H₂O-NaCl inclusions and the melting temperature of CO₂-clathrate in the CO₂-H₂O inclusions (Tm_clath). The purity of the CO₂ phase can be defined by measuring the melting temperature of the CO₂-solid phase (Tm_{CO₂}). The homogenization temperature of the vapor-liquid phases of CO₂ in the CO₂-H₂O inclusions (Th_{CO₂}) is also needed to determine the density of CO₂. Finally, the total homogenization temperatures of all phases in the inclusions (Th_{total}) were measured. The microthermometric results are shown in Table 1.

#### 3.2.1 Homogenization temperatures

The total homogenization temperatures in the CO₂-H₂O inclusions of the Liba gold deposit are in the range of 245–475°C, mainly ranging from 300 to 420°C with a peak value of 340°C. Most of the inclusions homogenized to liquid phase, a few of them homogenized to vapor phase. The homogenization temperatures of aqueous inclusions range from 208–475°C, mainly ranging from 300–420°C with a peak value of 340°C (Table 1, Fig. 4a), and the aqueous inclusions homogenized to liquid phase.

The total homogenization temperatures in the CO₂-H₂O inclusions of the Jinshan gold deposit range from 227 to 385°C, mainly ranging from 280 to 370°C with a peak value of 315°C, and most of the inclusions homogenized to liquid phase; the homogenization temperatures of the aqueous inclusions which are homogenized to a liquid phase are in the range of 239–332°C (Table 1, Fig. 4b). The total homogenization temperatures in the CO₂-H₂O inclusions of the Maquan gold deposit are in the range of 252–385°C, mainly ranging from 300 to 380°C with a peak value of 340°C; The total homogenization temperatures of the aqueous inclusions range from 295 to 332°C (Table 1, Fig. 4c), and both of the inclusion types homogenized to a
Table 1 Temperatures of different types of fluid inclusion of orogenic gold deposits in the Zhongchuan area

<table>
<thead>
<tr>
<th>Name of deposit</th>
<th>Mineral</th>
<th>Type of inclusion</th>
<th>$T_m$ (°C)</th>
<th>$T_m$ (°C)</th>
<th>$T_m$ (°C)</th>
<th>$T_m$ (°C)</th>
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<tr>
<td>Liba</td>
<td>quartz</td>
<td>CO$_2$-H$_2$O</td>
<td>6.8–8.5(4)</td>
<td>-57.1 to -61.1(37)</td>
<td>25.5–31.0(29)</td>
<td>245–475(81)</td>
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<tr>
<td></td>
<td></td>
<td>Aqueous</td>
<td>-4.5 to -12.3(40)</td>
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<tr>
<td></td>
<td></td>
<td>CO$_2$-rich</td>
<td></td>
<td>-57.6 to -59.8(7)</td>
<td>28.5–30.7(7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jinshan</td>
<td>quartz</td>
<td>CO$_2$-H$_2$O</td>
<td>7.5–9.3(7)</td>
<td>-56.6 to -59.3(30)</td>
<td>10.0–31.0(39)</td>
<td>227–385(65)</td>
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<tr>
<td></td>
<td></td>
<td>Aqueous</td>
<td>-3.2 to -7.3(9)</td>
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<tr>
<td></td>
<td></td>
<td>CO$_2$-rich</td>
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<tr>
<td>Maquan</td>
<td>quartz</td>
<td>CO$_2$-H$_2$O</td>
<td>6.5–9.5(6)</td>
<td>-56.8 to -59.4(15)</td>
<td>20.5–31.0(27)</td>
<td>252–385(51)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Aqueous</td>
<td>-5.7 to -8.4(5)</td>
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Note: The numbers in brackets mean the quantity of the measured fluid inclusions.

3.2.2 Homogenization temperatures of CO$_2$

The homogenization temperatures of CO$_2$ in the CO$_2$-H$_2$O inclusions of the Liba gold deposit are in a range of 25.5–31.0°C, mainly around 30°C, and that of CO$_2$ in the CO$_2$-rich inclusions are in a range of 28.5–30.7°C (Table 1, Fig. 5a). The $T_{m}$ CO$_2$ in the CO$_2$-H$_2$O inclusions ranges from 10 to 31°C, mainly ranging from 20 to 28°C with a peak value of 26°C; and that of CO$_2$ in the CO$_2$-rich inclusions...
range from 20.1 to 26.0°C (Table 1, Fig. 5b) in the Jinshan gold deposit. The \( T_{CO_2} \), of CO\(_2\) in the CO\(_2\)-H\(_2\)O inclusions in the Maquan gold deposit are in a range of 20.5–31.0°C with a peak value of 26°C (Table 1, Fig. 5c).

The results reveal that the homogenization temperatures of CO\(_2\) in the CO\(_2\)-rich inclusions are located in the range of those of the three phase CO\(_2\) inclusions. The Liba gold deposit has a relatively high peak value of homogenization temperature. However, the Jinshan and Maquan gold deposits show the same peak value. This reflects the fact that the inclusions from these deposits might have had similar pressure-temperature \((P-T)\) conditions.

### 3.2.3 Melting temperatures of CO\(_2\) solid phase

The melting temperatures of the CO\(_2\) solid phase \((Tm_{CO_2})\) of 37 CO\(_2\)-H\(_2\)O inclusions and 7 CO\(_2\)-rich inclusions from the Liba gold deposit range from −51.1 to −61.1°C and from −57.6 to −59.8°C, respectively, and the general range is from −57.5 to −59°C with a peak value of −58.5°C. The \( Tm_{CO_2} \), of 30 CO\(_2\)-H\(_2\)O inclusions from the Jinshan gold deposit range from −56.6 to −59.3°C with most around −57°C. The \( Tm_{CO_2} \), of 15 CO\(_2\)-H\(_2\)O inclusions from the Maquan gold deposit range from −56.8 to 59.4°C with a mean of ca. −58.5°C (Table 1).

There is a wide range of \( Tm_{CO_2} \), in the inclusions from these gold deposits as described above. However, all of them are lower than that of the pure CO\(_2\) solid phase (−56.6°C). This suggests that the ore-forming fluid was not very homogeneous when the inclusions were entraped, and the CO\(_2\) was mixed with CH\(_4\) or N\(_2\) to some degree.

### 3.2.4 Correlated parameters of fluid inclusions

The salinity and the relevant density of the H\(_2\)O-NaCl inclusions could be estimated by measuring the ice melting temperatures from the form of the NaCl-H\(_2\)O system (Bodnar, 1992). It might be possible to determine if there were some other volatile components in the CO\(_2\)-H\(_2\)O inclusions using the melting temperatures of the CO\(_2\) solid phase (Liu and Shen, 2002). The salinity of the aqueous component in the CO\(_2\)-H\(_2\)O inclusions was calculated using \( Tm_{\text{clath}} \) by the equation based on temperature and salinity (Collins, 1979). On the basis of total homogenization temperatures and salinities of aqueous solution of the CO\(_2\) inclusions, the density of the aqueous solution in relevant inclusions \((\rho_{\text{H}_2\text{O}})\) can be estimated from the parameter form of the NaCl-H\(_2\)O system. The density of the CO\(_2\) phase can be obtained using the homogenization temperatures of CO\(_2\) from the temperature-density form. The total fluid density was calculated using the equation \( \rho_{\text{total}} = \rho_{\text{CO}_2} \cdot \rho_{\text{CO}_2} + \phi_{\text{H}_2\text{O}} \cdot \rho_{\text{H}_2\text{O}} \) (Liu and Shen, 1999), in which \( \phi_{\text{CO}_2} \) and \( \phi_{\text{H}_2\text{O}} \) represent the volumetric proportions of the CO\(_2\) phase and the H\(_2\)O phase (the sum equal to 1) at the \( Tm_{CO_2} \), respectively. The mole fraction of CO\(_2\) \((x_{\text{CO}_2})\), H\(_2\)O \((x_{\text{H}_2\text{O}})\) and NaCl \((x_{\text{NaCl}})\) can also be obtained. The \( x_{\text{CO}_2} \), can be obtained by the intercalating method from the correlation diagram of \( x_{\text{CO}_2} \), \( \phi_{\text{CO}_2} \), \( Tm \) and \( \rho_{\text{CO}_2} \), in the NaCl-CO\(_2\)-H\(_2\)O inclusions with a certain salinity (Schwartz, 1989). Using the salinity \((\omega)\) of the CO\(_2\)-H\(_2\)O inclusions in the equation \( x_{\text{NaCl}} = \frac{18.0152\omega}{\left[18.0152\omega + 58.4428 \left(100-\omega\right)\right]} \), and then use the equation \( x_{\text{NaCl}} = x_{\text{NaCl}} - x_{\text{CO}_2} \). The \( x_{\text{H}_2\text{O}} \) was calculated by the equation \( x_{\text{H}_2\text{O}} = 1 - x_{\text{NaCl}} - x_{\text{CO}_2} \). Using the correlation diagram of \( x_{\text{CO}_2} \), \( \phi_{\text{CO}_2} \), and \( Tm \) in the NaCl-CO\(_2\)-H\(_2\)O inclusions of Schwartz (1989), incorporating the relevant parameters as described above, the pressure of the CO\(_2\) inclusions at total homogenized temperature can be obtained by intercalation method.

On the basis of calculation method for salinity mentioned above, a histogram of salinity obtained in this way from the Liba, Maquan and Jinshan gold deposits can be made (Fig. 6). Generally, the \( Tm_{\text{clath}} \) cannot be observed during homogenization measurements of the CO\(_2\)-H\(_2\)O inclusions, whereas they are constrained by the size of the inclusions.

![Fig. 6. Histograms showing the salinity of fluid inclusions of the gold deposits.](image-url)

* a – Liba deposit; b – Jinshan deposit; c – Maquan deposit.
and the proportion of vapor CO$_2$. The $T_{m_{\text{eq}}}$ of 40 aqueous inclusions for the Liba gold deposit is in a range of $-4.5$ to $-12.3^\circ\text{C}$, the relevant salinity ($\text{wt}\%\text{(NaCl)}_{\text{eq}}$) ranges from $7.17\%$ to $16.24\%$. The $T_{m_{\text{eq}}}$ of 4 CO$_2$-H$_2$O inclusions range from 6.8$^\circ\text{C}$ to 8.5$^\circ\text{C}$, and the relevant salinity ($\text{wt}\%\text{(NaCl)}_{\text{eq}}$) ranges from 3.00 to $6.12\%$. The salinity shows a peak value of 10% (Fig. 6a).

The $T_{m_{\text{eq}}}$ of 7 CO$_2$-H$_2$O inclusions for the Jinshan gold ($\phi_{\text{CO}_2}$) is in the range of 0.630–0.696 g/cm$^3$. The density of the aqueous solution in the inclusions is in the range of 0.620–0.778 g/cm$^3$. The total density of fluid ranges from 0.626 to 0.737 g/cm$^3$. The mole fraction of CO$_2$ ($\phi_{\text{CO}_2}$) is in the range of 0.17–0.24; the mole fraction of NaCl in the aqueous solution ($\phi_{\text{NaCl}_{\text{aq}}}$) ranges from 0.009 to 0.020; the total mole fraction of NaCl ($\phi_{\text{NaCl}}$) in the CO$_2$-H$_2$O inclusions with three phases is in the range of 0.008–0.015.

### Table 2 Temperatures of calculated parameters of CO$_2$-H$_2$O fluid inclusion of orogen gold deposits in Zhongchuan area

<table>
<thead>
<tr>
<th>Name of deposit</th>
<th>$\phi_{\text{CO}_2}$ (%)</th>
<th>$T_{\text{HCO}_2}$($^\circ\text{C}$)</th>
<th>$T_{\text{H}}$($^\circ\text{C}$)</th>
<th>$T_{m_{\text{eq}}}$($^\circ\text{C}$)</th>
<th>Salinity (% NaCl$_{\text{eq}}$)</th>
<th>$\rho_{\text{HCO}_2}$</th>
<th>$\rho_{\text{CO}_2}$</th>
<th>$\rho_{\text{H}}$</th>
<th>$\rho_{\text{sol}}$</th>
<th>$x_{\text{CO}_2}$</th>
<th>$x_{\text{H}_{\text{H,O}}}$</th>
<th>$x_{\text{H}}$</th>
<th>$x_{\text{NaCl}}$</th>
<th>$x_{\text{NaCl}_{\text{aq}}}$</th>
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<tbody>
<tr>
<td>Liba 50</td>
<td>25.5</td>
<td>2.90</td>
<td>6.8</td>
<td>6.12</td>
<td>0.778</td>
<td>0.696</td>
<td>0.737</td>
<td>0.24</td>
<td>0.745</td>
<td>0.015</td>
<td>0.020</td>
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<tr>
<td>Liba 65</td>
<td>27.9</td>
<td>410</td>
<td>7.3</td>
<td>5.23</td>
<td>0.670</td>
<td>0.655</td>
<td>0.660</td>
<td>0.33</td>
<td>0.659</td>
<td>0.011</td>
<td>0.017</td>
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<tr>
<td>Liba 60</td>
<td>29.0</td>
<td>392</td>
<td>7.8</td>
<td>4.32</td>
<td>0.620</td>
<td>0.630</td>
<td>0.626</td>
<td>0.28</td>
<td>0.710</td>
<td>0.010</td>
<td>0.014</td>
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<tr>
<td>Liba 40</td>
<td>29.0</td>
<td>300</td>
<td>8.5</td>
<td>3.00</td>
<td>0.745</td>
<td>0.630</td>
<td>0.699</td>
<td>0.17</td>
<td>0.822</td>
<td>0.008</td>
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<td></td>
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<tr>
<td>Jinshan 25</td>
<td>19.5</td>
<td>227</td>
<td>7.8</td>
<td>4.32</td>
<td>0.864</td>
<td>0.771</td>
<td>0.780</td>
<td>0.25</td>
<td>0.740</td>
<td>0.010</td>
<td>0.014</td>
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<td>315</td>
<td>8.5</td>
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<td>0.703</td>
<td>0.755</td>
<td>0.724</td>
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The mole fraction of H$_2$O ($\phi_{\text{H}_2\text{O}}$) in the CO$_2$-H$_2$O inclusions with three phases was estimated and the values range from 0.659 to 0.822 (Table 2).

The density of the aqueous inclusions of the Jinshan gold deposit range from 0.76 to 0.88 g/cm$^3$, and the pressure of the aqueous inclusions mainly ranges from 32 to 81 MPa. The $\rho_{\text{CO}_2}$, is in the range of 0.688–0.775 g/cm$^3$, the density of the aqueous solution in the inclusions ranges from 0.659–0.864 g/cm$^3$, and the total density of the fluid is in the range of 0.690–0.780 g/cm$^3$. The $\phi_{\text{CO}_2}$, is in the range of 0.12–0.68; the mole fraction of NaCl in the aqueous solution ranges from 0.005 to 0.016; the $\phi_{\text{NaCl}}$ is in the range of 0.004–0.014. The estimated $\phi_{\text{H}_2\text{O}}$ is in the range of 0.316–0.866 (Table 2).

The density of aqueous inclusions for the Maquan gold deposit is in the range of 0.78–0.92 g/cm$^3$. The correlated pressure ranges from 71 to 122 MPa. The $\rho_{\text{CO}_2}$, is in the range of 0.667–0.751 g/cm$^3$, the and density of the aqueous solution in the inclusions ranges from 0.703 to 0.839 g/cm$^3$. The total density of the fluid is in the range of 0.708–0.817 g/cm$^3$. The $\phi_{\text{CO}_2}$, ranges from 0.11 to 0.18; the $\phi_{\text{NaCl}}$ is in the range of 0.002–0.021; The $\phi_{\text{NaCl}}$ ranges from 0.002 to 0.018. The $\phi_{\text{H}_2\text{O}}$ in the three phase CO$_2$ inclusions is in the
range 0.803–0.873 (Table 2).

4 Discussion

4.1 Fluid immiscibility

As described above, the primary CO₂-H₂O inclusions, CO₂-rich and aqueous inclusions coexist in a given inclusion cluster. The end members of the CO₂-rich and aqueous solution inclusions are generally considered to be the results of selective entrapment of unmixed aqueous and CO₂ composition from a homogeneous, one-phase CO₂-H₂O fluid. The mixing of end members of the CO₂ and aqueous solutions might cause the variation in CO₂ contents in the CO₂-H₂O inclusions. Therefore, the inclusions with different volumetric proportions of CO₂ and NaCl-H₂O display a consistent origin; the volumetric proportions of CO₂ and NaCl-H₂O constitute a successive variation series. The immiscible fluid inclusions indicate that the CO₂-H₂O inclusions have a similar range of homogenization temperature, the CO₂ in both of the CO₂-rich and CO₂-H₂O inclusions should display similar homogenization and total homogenization temperatures (although it is difficult to observe the water in the CO₂-rich inclusions, there can be around 15% of water (bulk percent) occurring as the thin film adhered on the wall of inclusions, which creates the difficulty because of the internal reflection on the inclusion margin) (Ramboz et al., 1982; Olsen 1988; Hollister, 1990); and the different types of inclusions show a similar salinity range. Therefore, fluid immiscibility is a more likely explanation for the variety of fluid inclusions in the gold deposits.

As described above, the volumetric proportions of CO₂ in the numerous CO₂-H₂O inclusions of orogenic gold deposits in the western Qinling range from 10% to 90%. Some of them are H₂O-rich three-phase inclusions with the volumetric proportion of CO₂ being 10%, and some are CO₂-rich three-phase inclusions with the volumetric proportion of CO₂ up to 70%. In addition, some one- or two-phase CO₂-rich inclusions can also be observed. All these types of inclusions show a primary origin. The CO₂-rich inclusions homogenized to the CO₂ phase and the aqueous rich inclusion homogenized to the aqueous phase. No matter whether these inclusions homogenized to vapor or liquid phase, they show roughly the same range of homogenization temperature (at a peak ranges from 320 to 340°C). Furthermore, the homogenization temperatures of the NaCl-H₂O type inclusions range from 280 to 320°C. Generally the homogenization temperature of the CO₂-H₂O inclusions is higher than that of aqueous inclusions. This is consistent with fluid immiscibility, because the CO₂-H₂O inclusions represent a mixing product of two end members. These characteristics suggest that during the ore-forming process there was an immiscible action between CO₂ and NaCl-H₂O, CO₂. This was separate from that of the saline solution being an independent fluid phase that coexisted with the saline solution, and made the ore-forming fluid change from a homogeneous to an inhomogeneous phase. The salinity measurements suggest that there is a wide range of salinity (wt% (NaCl)₀) in the ore-forming fluids. However, it belongs to the CO₂-H₂O system with an intermediate-low salinity (Fig. 6). The salinity of the CO₂-H₂O inclusions have a similar feature with a low-salinity

![Diagram](image_url)

**Fig. 7.** Influence of pressure on the CO₂-rich and H₂O-rich two-phase immiscible areas in the NaCl-CO₂-H₂O system with salinity (wt% (NaCl)₀) being 6% (after Bowers and Helgeson, 1983).

CO₂-H₂O system, and a salinity (wt% (NaCl)₀) of 1.03%–6.63%, which falls completely into the immiscible field between CO₂ and H₂O-NaCl (Fig. 7).

4.2 Ore-forming P-T conditions

As described above, the CO₂-rich and aqueous solution inclusions in the gold deposits of this area represent an immiscible association between CO₂ and NaCl-H₂O inclusions, and the homogenization temperature and pressure correlate with the those of the inclusions when they were entrapped, namely the ore-forming temperature and pressure. The ore-forming temperatures of the orogenic gold deposits of the area show a wide range, mainly ranging from 260 to 400°C with a peak value of 320–340°C. The ore-forming temperature of the Liba gold deposit is in the range of 208–475°C, mainly ranging from 300 to 420°C.
with a peak value of 340°C; that of the Jinshan gold deposit is in the range of 227–385°C, mainly ranging from 280°C to 370°C with a peak value of 315°C; and that of the Maquan gold deposit is in the range of 252–383°C, mainly ranging from 300 to 385 °C with a peak value of 340°C (Fig. 4). The ore-forming pressures of the gold deposits were estimated using the microthermometric data of the inclusions, and are in the range of 85–150 MPa for Liba, 32–81 MPa for the Jinshan, and 71–122 MPa for the Maquan gold deposits.

4.3 Fluid composition

The fluid composition can be estimated using the melting temperature of the solid phase in the CO₂-bearing inclusions, and the initial melting temperature of CO₂-H₂O inclusions of the gold deposits is in the range of ~56.6 to ~60.5°C. Therefore, besides CO₂, there might be CH₄ and some other volatiles, probably such as N₂ and CO occurring to some degree in the inclusions. In addition, the melting temperature of CO₂ clathrate is generally lower than the homogenization temperature of CO₂ suggesting that the content of CH₄ in the inclusions is relatively low. The salinity of the fluid (wt% (NaCl)) is low with a peak value of 8.00%–10.00% or slightly lower. The fluid thus belongs to the H₂O-CO₂ system with low salinity. The relative mole percent of CO₂ in the fluid is in the range of 10%–68%, the relative mole percent of H₂O in the fluid ranges from 31.6% to 89.4%, and the relative mole percent of NaCl in fluid is in the range of 0.2%–1.6%. The total density of the fluid is in the range of 0.626–0.817 g/cm³.

3.4 Source of ore-forming fluids

The ore-forming fluids characterized by CO₂-rich and low salinity are very common in many typical gold deposits (Bohlke and Kistler, 1986; Robert and Kelly, 1987; Kerrich, 1989). However, there exists a diversity of views on the source of the ore-forming fluids, such as magmatic (Burrows and Spooner, 1987; Jiang et al., 1999; Mao et al., 2003a), metamorphic (Kerrich and Fyfe, 1981; Goldfarb et al., 1988; Colvine, 1989; Cameron, 1989; Kerrich, 1989) and mantle degasification source or the ore-forming fluids involved with some fluids from the mantle (Newton et al., 1980; Groves et al., 1998; He et al., 2003).

The δ¹³C of calcite from the Liba, Jinshan and Sanrengou gold deposits ranges from ~4.10‰ to ~6.43‰ (Wang, 1999), which is similar to that of some carbonates derived from the mantle (~5.1‰±1.4‰), kimberlite (~4.7‰±1.2‰) and the initial mantle reservoir (~6‰±2‰). This suggests that the CO₂-rich fluids of the mining area of the gold deposits might be derived from a deep source, namely the lower crust or the mantle. The δD of quartz of the Liba gold deposit ranges from ~63‰ to ~92‰, the δ¹⁸O of the water ranges from 4.9‰ to 9.5‰, almost the same as that of magmatic water (+5.5‰ to 9.5‰) (Ohmoto, 1986; Sheppard, 1986). This suggests that the ore-forming fluids are mainly derived from the magma but mixed with some meteoric water. The features of isotopic composition for these gold deposits are consistent with some typical gold deposits such as Baguamiao, Shuangwang and Ma’anqia, which are located in the eastern part of the same tectonic metallogenic belt as those in the Zhongchuan area, suggesting that the carbon from these deposits was mainly derived from the lower crust or mantle and that the ore-forming fluid mainly consisted of water derived from magma but mixed with some meteoric or metamorphic water (Gu and Dai, 1983; Shi et al., 1993; Zheng et al., 1994; Zhong and Zhang, 1997; Liu et al., 1999; Sun, 2000; Zhu et al., 2000; Guo et al., 2000; Li et al., 2001; Feng et al., 2003b).

Several tens of orogenic gold deposits have been proved in the western Qinling region (Mao et al., 2002). Most of the gold deposits occur within the ductile-brittle shearing zones and are hosted in Devonian turbidites with strong deformation and greenschist-facies metamorphism. Furthermore, Indosinian-Yanshanian granitic bodies and stocks are developed in most of the mining area. The mineralization age of the gold deposits obtained by different methods in this belt vary from 131 to 232 Ma (Feng et al., 2002), with a pulse of 161 Ma to 197 Ma (Shi et al., 1993; Liu M., 1994a; Fan and Jin, 1994; Shao and Wang, 2001). The gold mineralization related to the granites shows an age range of 148–244 Ma (Yan, 1985; Zhang, 1988; Shi et al., 1993; Fan and Jia, 1994; Lu et al., 2001). The ore-forming age of the gold deposits of the area is fully consistent with a period of 160–200 Ma, which was the main metallogenic epoch in the North China Craton and its adjacent region, corresponding to a geodynamic setting of continent-continent collisional orogenic processes (Mao et al., 2003b).

After a long period of strong collision between the Yangtze, Qinling Micro-plate and North China Plate, the Qinling subduction-collision orogenic belt was created during an intracontinent collision orogeny in the Indosinian-Yanshanian (Zhang, 1988). The Indosinian-Yanshanian movement led to multi-stage activity of deep faults in the western Qinling belt. During the process a large amount of syntaxis or re-melting granitic magmas were produced and intruded upward. Corresponding to the structural setting mentioned above, a series of ore-forming systems related to the large scale of gold deposits were formed. At the same time deep-derived fluids migrated upward and joined with the fluid originated from other sources, finally leading to the formation of the orogenic gold deposits along the strike-slip shearing zone.
5 Conclusions

(1) Three types of inclusions can be distinguished in the orogenic gold deposits of the Zhongchuan area in the western Qinling, i.e., CO₂-H₂O, CO₂-rich and aqueous, which are characterized by CO₂-rich, low salinity and immiscibility.

(2) The ore-forming fluid is mainly of the CO₂-NaCl-H₂O type mixed with some volatiles including CH₄, N₂ and CO of varying contents.

(3) The ore-forming fluid mainly derived from deep magma and mixed with some meteoric and metamorphic water.

(4) The metallogeny of the ore-forming fluids of the research area is closely related to the Indo-Australian-Yanshanian synxectis or re-melting granitic magmas and their intrusion. The gold deposits were formed during a process of intracontinental collisional orogeny, when some deep-derived substances ascended and were involved in the ore formation.

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