High $^{3}$He/$^{4}$He ratios in the Wangu gold deposit, Hunan province, China: Implications for mantle fluids along the Tanlu deep fault zone

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(Received March 7, 2001; Accepted February 3, 2002)

The Wangu shear zone hosting gold deposit is located on splay faults of the regional scale Tanlu deep fault zone that extends to the MOHO and likely through the lithosphere. Fluid inclusions in pyrite from gold bearing veins have $^{3}$He/$^{4}$He (R/Ra) values of 3.5 to 9.8. Fluid inclusions in pyrite from barren vein have R/Ra values of 0.8, and 0.9. The projections of the analyses in $^{3}$He/$^{4}$He vs. $^{40}$Ar/$^{36}$Ar diagram can be separated obviously as two groups and display the variable degrees of mixing between mantle and crustal fluids. Fluid inclusion in quartz from auriferous veins are characterized by a higher temperature ($T_H = 207$ to $310^\circ C$), dilute, aqueous carbonic fluids, with $\delta D$ and $\delta ^{18}O$ values overlapping the magmatic fluids, whereas barren veins have low temperature ($T_H = 138$, $145^\circ C$), more saline, aqueous fluid with relatively low, light $\delta D$ and $\delta ^{18}O$ values, consistent with evolved meteoric water. Lithosphere extension accompanied with displacement of the Tanlu sinistral fault, with development of gas and oil-bearing sedimentary basins proximal to the fault. The $CO_2$-bearing fluids have high He contents of up to 0.1% He, $^{3}$He/$^{4}$He = (3~7.2)R/Ra, $^{40}$Ar/$^{36}$Ar = 573~7744, and $\delta ^{13}C_{CO_2} = –3.4$ to –16.9‰ (Xu et al., 1995; Tao et al., 1996). During the lithosphere extension and decompressional melting of asthenosphere, noble gases and $CO_2$ exsolved from basalt melts, advected up to the Tanlu fault zone into splay faults where gold mineralization developed, and through sedimentary basin. There was mixing with isotopically and compositionally evolved meteoric water.

INTRODUCTION

Helium isotopic composition is a useful tool for tracing mantle-derived fluids, given that depleted upper mantle $^{3}$He/$^{4}$He ratios of 7–9 Ra (for example, MORB: Zindler and Hart, 1986) and up to 30 Ra for some hot spots in continental province, which are thought to be derived from deeper mantle are distinct from both the atmospheric ratio and ratios of shallow crustal hydrothermal fluids (Rison and Craig, 1983; Mamyrin and Tolstikhin, 1984; Azbel and Tolstikhin, 1990; Marty et al., 1996; Graham et al., 1999; Orihashi et al., 2001). Several metallic deposits have been reported to involve mantle-derived fluids during mineralization, based on helium isotope studies (Simmons et al., 1987; Stuart et al., 1995; Hu et al., 1998; Burnard et al., 1999). All of the $^{3}$He/$^{4}$He ratios in these deposits are between two end members, implying variable degrees of mixing between mantle and crustal fluids.

To further address possible contributions of mantle fluids to gold metallogenesis, we have conducted a study of He and Ar isotopes and fluid inclusions in the Wangu gold deposit, Hunan province, China. This is one of several gold deposits distributed along the Tanlu deep fault system. High concentrations of mantle-derived helium and $CO_2$ have been reported in natural gases from several basins along the Tanlu fault zone (Xu et al., 1995;
Gold enrichments accompanied by mantle-derived CO\textsubscript{2} are also known in petroleum in the Shengli Oil Field, which is located proximal to the Tanlu deep fault zone (He \textit{et al}., 1998). In this work, we show that pyrite in the Wangu gold ores is characterized by variably high \(^3\text{He}/\text{He}^{\text{4}}\) ratios, which reflects mantle fluid involvement in the gold mineralization process.

\section*{Fig. 1. Location of the Wangu gold deposit and the distribution of major gas fields, with mantle derived noble gases, and mantle-derived enclaves in volcanic rocks along the Tanlu fault zone system (modified from Tao \textit{et al}., 1996).}

\begin{itemize}
\item I. Tectonic-geophysical gradient belt along Daxing’ anling Mt, Taiheng Mt, and Wuling Mt, separates East-Middle uplift regions and East depression regions in China. It is also a geographic boundary between Inner Mongolia, Huangtu (Loess), and Yunnan-Guizhou plateaus in western side, and Northeast and North China basins and South China hilly land in eastern side; II. Tanlu fault zone system is about 4000 km long (in China part) by 300 km wide and 30–40 km, maximum 100 km deep, which penetrates to the Moho. ▲ Mantle-derived enclaves in volcanic rocks; ⊙ Gas fields with mantle derived noble gases and CO\textsubscript{2} resources: 1. Wanjinta; 2. Jie-3-jing; 3. Huanghua; 4. Ping14-3; 5. Minqiao; 6. Huangqian; 7. Sanshui; △ Shengli oil field. The averaging R/Ra and \(^{\delta^{13}}\text{C}\) values in figure took from Tao \textit{et al}.
\textit{(1996)} for Wanjinta, Jie-3-jing and Sashui; and from Xu \textit{et al}.
\textit{(1996b)} for Huanghua and Huangqian.
GEOLGY OF THE GOLD DEPOSIT

The Wangu gold deposit with 13 tonnes of gold reserve at an average grade of 6.5 g/t is located in the Jiangnan terrane at the south margin of the Yangtze Craton, which is one of the major gold provinces in South China (Fig. 1). The Wangu gold ore veins are hosted in a sequence of Mesoproterozoic siltstone, greywacke and slate metamorphosed to sub-greenschist facies (Fig. 2). Gold mineralization developed along a group of EW-trending shear and fracture zones, which link to the north northeastern-striking Tancheng-Lujiang (Tanlu) regional deep fault zone (Fig. 1). No intrusive rocks have been mapped at the surface, excepting minor small lamprophyre dikes in the mine. The nearest granite stock is about 10 km SW of the Wangu gold deposit (Mao et al., 1997).

There are three types of gold ore in the deposit: quartz veins, fractured slate, and tectonic breccia; the first type is predominant. The ores comprise mainly quartz, pyrite, minor arsenopyrite and sporadic clay minerals. Sericite and chlorite are more abundant in the auriferous slate type. Pyrite in the ores is fine grained (0.1~0.15 mm in diameter) with pentagonal, dodecahedron, or anhedral habits. Ore grade is generally proportional to the amount of pyrite. Barren white quartz veins are locally superimposed on the ore veins along the same NE-trending fractures. In barren quartz veins, pyrite is rare, and its crystal is cubic with dimensions of 5 to 8 mm diameters. The ore-forming element association in the deposit is Au-Sb (W). A Rb-Sr isochron age determined on fluid inclusions in quartz from the ore veins is 70.3 ± 8.6 Ma, signifying that gold mineralization formed in the Late Cretaceous (Mao et al., 1997; Mao and Li, 1997). The locations of samples analyzed are marked on Fig. 2.

Fig. 2. Map showing geology of the Wangu gold deposit and sampling locations. All gold ore veins are formed along a group of EW-striking faults, which are located several kilometers west to Tanlu fault zone system.
ANALYTICAL PROCEDURES

Eight pyrite separates were made from the auriferous quartz veins, and two from post-mineralization barren quartz veins (JT-4 and JT-5). The helium and argon isotope compositions were analyzed by in vacuo crushing. Crushing method in vacuo can reduce the effects of in situ produced radiogenic 4He and 40Ar and cosmogenic 3He, and the relatively low blank in comparison with fusion method. The pure pyrite samples with 0.2–0.8 mm diameter were first washed ultrasonically in distilled water, then in acetone, after then dried in oven. The on-line screw-type crushers were constructed from modified vacuo valves. Six samples were loaded into crushers in one time. Each sample was about 1 g in weight. The samples are baked on-line at 100–150°C for 24 hours to remove adsorbed atmospheric gases before crushing. Gases were extracted from the fluid inclusion by manual crushing in vacuum. The gases released by crushing were exposed to a titanium sponge pump at 780°C and a zircon-aluminum getter at 300°C for 20 minutes to remove the active gases such as H₂, N₂, O₂, CO₂, CH₄, H₂O and organic substance. Then the remained gases were exposed to a second cold zircon-aluminum pump for 10 minutes and Ar were then condensed onto liquid N₂-cooled charcoal for 10 minutes. Comparatively pure He was admitted to the analyzing system of mass spectrometer. Trace impure gases such as H₂ and Ar gotten into the analyzing system with He were re-purified and removed by a liquid N₂-cooled titanium sublimation pump, adjacent to the spectrometer ion source. The helium isotope compositions were measured on a MI-1201IG inert gas mass spectrometer made in Ukraine. 4He was measured by a Faraday cup and 3He by an electron multiplier with a resolving power of 1200. The peaks of 3He and HD + H3 can be completely separated from each other, needless to correct HD + H3. Ar was desorbed from the charcoal finger and separated from Xe at –78°C. 40Ar was measured by a Faraday cup, 36Ar and 38Ar by an electron multiplier. The standard gas for work was measured before analyzing the samples; the measurement results of samples were normalized to the standard gas for work, which was made by purifying the air and periodically examined by the air during using. All the analysis results are based on the atmosphere internationally generally used as standard, whose 3He/4He ratio is 1.40 × 10⁻⁶, and 40Ar/36Ar ratio is 295.5. All the results of helium were given in 3He/4He ratio and R/Ra ratio where R is the 3He/4He ratio of the sample and Ra is that of the air. The hot blank level of 4He was 2 × 10⁻¹¹ cm³ STP, for which 3He/4He ratio of 1 × 10⁻⁶ was assumed, whereas the blank level of 40Ar was

<table>
<thead>
<tr>
<th>Sample</th>
<th>3He/4He (10⁻⁶)</th>
<th>40Ar/36Ar (10⁻⁶ cm³ STP/g)</th>
<th>3He (10⁻¹⁴ cm³ STP/g)</th>
<th>40Ar (10⁻⁶ cm³ STP/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-1-2</td>
<td>13.7 ± 1.0</td>
<td>3.50</td>
<td>47.79</td>
<td>2.1</td>
</tr>
<tr>
<td>I-1-3</td>
<td>10.3 ± 1.5</td>
<td>3.75</td>
<td>38.66</td>
<td>1.8</td>
</tr>
<tr>
<td>I-2-4</td>
<td>9.3 ± 0.9</td>
<td>3.10</td>
<td>28.72</td>
<td>1.4</td>
</tr>
<tr>
<td>I-2-11</td>
<td>7.7 ± 1.2</td>
<td>3.78</td>
<td>28.94</td>
<td>2.2</td>
</tr>
<tr>
<td>WG-T</td>
<td>6.9 ± 0.5</td>
<td>5.25</td>
<td>35.97</td>
<td>3.5</td>
</tr>
<tr>
<td>TSD-21</td>
<td>6.4 ± 0.8</td>
<td>2.87</td>
<td>18.36</td>
<td>1.6</td>
</tr>
<tr>
<td>V-1-6</td>
<td>6.8 ± 0.7</td>
<td>3.31</td>
<td>22.53</td>
<td>2.3</td>
</tr>
<tr>
<td>YJW-11</td>
<td>4.9 ± 0.5</td>
<td>9.94</td>
<td>48.19</td>
<td>2.7</td>
</tr>
<tr>
<td>JT-4</td>
<td>1.1 ± 0.2</td>
<td>12.09</td>
<td>12.94</td>
<td>0.8</td>
</tr>
<tr>
<td>JT-5</td>
<td>1.2 ± 0.5</td>
<td>10.10</td>
<td>12.12</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Table 1. Helium and Ar isotope values of fluid inclusions in pyrite from auriferous and barren quartz veins

Note: 2σ errors referred to the last digits are given for 3He/4He and 40Ar/36Ar.
High $^{3}$He/$^{4}$He ratios in the Wangu gold deposit, Hunan province, China

was $5 \times 10^{-9}$ cm$^{3}$STP. The effect of the blank on the measurement result was paltry and negligible. The analytical precision of standard gas was 1% and that of samples was included in Table 1.

We chose 14 quartz samples, in which 10 are corresponding to the analyzed pyrites from the auriferous and barren quartz veins, for oxygen and hydrogen isotopic measurement. For oxygen isotope analyses of silica and silicates, O$_{2}$ was prepared by the BrF$_{5}$ method described by Clayton and Mayeda (1963). For analysis of hydrogen isotope, the water in fluid inclusion was released by decrepitation method. Then the water was reacted with Zn at 400°C to produce H$_{2}$ (Coleman et al., 1982), which was collected in sample tube with activated charcoal at liquid N$_{2}$ temperature. Oxygen and hydrogen isotopes were analyzed in a Finningan MAT 251 mass spectrometer, at the Stable Isotope Laboratory of Institute of Mineral Resources, Chinese Academy of Geological Sciences. Analytical reproducibility in this study is ±0.2‰ for O isotopes, and ±2‰ for H isotopes.

Doubly polished sections were prepared for fluid inclusion petrography and microthermometry. Microthermometric measurements were conducted on a calibrated Chaixmeca heating-freezing stage (+600/–180°C) and were

Fig. 3. Plot of $^{3}$He/$^{4}$He (R/Ra) vs. $^{40}$Ar/$^{36}$Ar ratios of the fluids in the pyrite from the Wangu gold deposit. The analyses of the fluids in the pyrite from auriferous and barren quartz veins are projected into two separated groups, which represent mantle-dominant derived and crust-dominant derived sources, respectively. Pure meteoric or marine fluids are characterized by atmospheric He and Ar isotope compositions, therefore $^{3}$He/$^{4}$He (R/Ra) = $1.4 \times 10^{-6}$ and $^{40}$Ar/$^{36}$Ar = 295.5 are used to represent the pure crustal fluids. The mantle fluid end member could be a varied area with high values of both $^{3}$He/$^{4}$He and $^{40}$Ar/$^{36}$Ar mentioned in the text.

Fig. 4. $^{40}$Ar/$^{36}$Ar and $^{3}$He/$^{36}$Ar of inclusion-trapped fluids. Filled circle symbols are auriferous quartz veins, whereas open circle symbols are barren quartz veins. Except for the two projected points, the others show a linear correlation between $^{40}$Ar/$^{36}$Ar and $^{3}$He/$^{36}$Ar. The samples of V-1-6 and YJW-II are away from the linear trend possibly due to the loss of $^{36}$Ar or input of $^{40}$Ar in the fluids. The high $^{40}$Ar/$^{36}$Ar and high $^{3}$He/$^{36}$Ar ratio are a mantle-derived component.
made on vapor-liquid inclusions that homogenized by disappearance of the vapor bubble. The stage was calibrated using synthetic fluid inclusions. Estimated accuracy was ±0.1°C at temperature of below 30°C and ±1°C at temperatures above 30°C. Freezing experiments were performed first on all section to avoid the decrepitation of inclusions. Resulting melting measurements of the final melting temperatures of ice were made to determine fluid salinities.

**RESULTS**

Helium isotopic compositions of fluid inclusions trapped in pyrite of the auriferous veins range from 3.5 to 9.8 Ra, whereas the ratios of the barren post-mineralization pyrite are much lower at 0.8–0.9 Ra, close to the atmospheric ratio of 1 Ra (Table 1). Two groups of the projections are obviously separated in Fig. 3. Pyrite from auriferous veins extends to high values of 3He/4He and 40Ar/36Ar, whereas pyrite from the barren veins has low values.

Fluid inclusion data support the presence of two distinct veins forming hydrothermal solutions (Table 2). Auriferous veins were precipitated from an auriferous fluid with higher temperature ranging from 207–310°C and low salinity varying from 3.0–4.5 wt% NaCl equiv., whereas barren veins from the fluids with low temperature of 138–145°C but higher salinity of 5.5–6.0 wt% NaCl equiv. (Table 2, Fig. 5).

Oxygen isotope compositions of quartz range are 17.8–19.6‰ for auriferous quartz veins and 17.7 and 22.0‰ for the barren quartz veins, respectively (Table 2). Both of them are strongly characterized by enrichment of 18O. Using the fractionation curve, 1000lnαquartz-water = 3.38 × 10^6T^−2 – 2.90 (Friedman and O’Neil, 1977) and corresponding homogenization temperature measurements of fluid inclusion in quartz (Th), the δ18O values of fluids are calculated and shown in Table 2. They are 7.4 to 10.9‰ for auriferous quartz veins, and 1.3 and 2.0‰ for barren quartz veins, respectively. It can be seen that the fluids from the auriferous and barren veins are distinct: the former plot almost overlapping the range of +5.5–+9.5‰ for magmatic water suggested by Ohmoto (1986) and Sheppard (1986), whereas the latter are shifted to the meteoric water line (Fig. 6).

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**Table 2. Temperatures and salinity, and δD and δ18O_H2O values of fluids, measured on primary fluid inclusions in quartz veins**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temperature (°C)</th>
<th>NaCl (wt% equiv.)</th>
<th>δD_H2O (%)</th>
<th>δ18O (%)</th>
<th>δ18O_H2O* (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-1-2</td>
<td>207</td>
<td>3.4</td>
<td>−61</td>
<td>19.6</td>
<td>7.8</td>
</tr>
<tr>
<td>I-1-3</td>
<td>247</td>
<td>3.2</td>
<td>−59</td>
<td>19.5</td>
<td>9.9</td>
</tr>
<tr>
<td>I-2-4</td>
<td>295</td>
<td>4.5</td>
<td>−64</td>
<td>18.5</td>
<td>10.9</td>
</tr>
<tr>
<td>I-2-11</td>
<td>258</td>
<td>4.2</td>
<td>−60</td>
<td>18.7</td>
<td>9.6</td>
</tr>
<tr>
<td>WG-T</td>
<td>310</td>
<td>3.8</td>
<td>−64</td>
<td>17.8</td>
<td>10.8</td>
</tr>
<tr>
<td>TSD-21</td>
<td>276</td>
<td>3.8</td>
<td>−60</td>
<td>18.1</td>
<td>9.8</td>
</tr>
<tr>
<td>V-1-6</td>
<td>245</td>
<td>3.0</td>
<td>−56</td>
<td>17.9</td>
<td>8.2</td>
</tr>
<tr>
<td>YJW-11</td>
<td>216</td>
<td>3.6</td>
<td>−60</td>
<td>18.6</td>
<td>7.4</td>
</tr>
<tr>
<td>TS-1</td>
<td>265</td>
<td>4.0</td>
<td>−63</td>
<td>18.1</td>
<td>9.3</td>
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<tr>
<td>TS-2</td>
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<td>−59</td>
<td>18.5</td>
<td>10.1</td>
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<td>TS-3</td>
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<td>3.4</td>
<td>−56</td>
<td>19.1</td>
<td>10.1</td>
</tr>
<tr>
<td>TS-6</td>
<td>244</td>
<td>3.0</td>
<td>−61</td>
<td>18.8</td>
<td>9.1</td>
</tr>
<tr>
<td>JT-4</td>
<td>145</td>
<td>5.5</td>
<td>−92</td>
<td>17.7</td>
<td>1.3</td>
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<td>JT-5</td>
<td>138</td>
<td>6.0</td>
<td>−86</td>
<td>22.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

*Calculated based on Quartz - water fractionation: 1000lnα = 3.38 × 10^6T^−2 – 2.90 (Friedman and O’Neil, 1977) using filling temperatures of fluid inclusion in quartz (Th).
DISCUSSION

Pyrite is known to be a suitable trap for noble gases (Jean-Baptiste and Fouquet, 1996; Burnard et al., 1999; Stuart et al., 1994). The pyrites analyzed were well euhedral with no evidence of subsequent deformation, therefore, most of the fluid inclusions were probably related to mineralization. This is consistent with fluid inclusion trapped in the quartz, which is used to measure homogeneity temperature (Th) and salinity here.

Sano and Wakita (1988) and Rison and Craig (1983) have pointed out that measurement of helium isotopes may be affected by 10% if there is existence of a great amount of neon. Fortunately neon content is quite low compared to the high value of helium in the measured samples.

Each of the ore-forming and barren vein fluids has distinct, but relatively uniform homogenization temperature, salinity, and $\delta^{18}$O and $\delta$D values. The ore-forming fluids possess a large range of high $^3$He/$^4$He and high $^{40}$Ar/$^{36}$Ar ratios (Fig.
Although ore-forming fluids have higher $^{3}$He/$^{4}$He values than the barren vein fluids, both of them reflect the mixed fluids. The previous study (Turner et al., 1993) has explained that there are several possible distinct noble gas sources for a hydrothermal fluid, i.e., air, air-saturated meteoric water, mantle noble gases, and noble gases produced in the crust. Due to low content of helium in the air it can not give an obvious affect to the hydrothermal fluids (Stuart et al., 1994; Marty et al., 1989). Crustal production of $^{3}$He is dominated by the reaction: $^6$Li$(n, \alpha)^3$H$(\beta)^3$He (Clarke et al., 1969), but Li-bearing minerals are not known in the study area. Due to the samples from underground the affect of cosmogenic $^3$He can be ruled out. Therefore, the mantle and air-saturated water are main sources for $^3$He. $^3$He are not produced in significant quantities in the Earth. The main terrestrial $^3$He reservoir is the mantle (Burnard et al., 1999). Most mantle-derived rocks have a well-defined $^3$He/$^4$He ratio of 1.0–1.3 $\times$ 10$^{-5}$ (7–9 Ra, Zindler and Hart, 1986). Pure meteoric or marine fluids are characterized by atmospheric He and Ar isotope compositions. However, radiogenic $^4$He produced by decay of U and Th in the crustal rocks will diffuse into grounder water, hydrothermal fluids and gas and oil wells with 0.01–0.1 Ra (Aldrich and Nier, 1948; Andrews and Lee, 1979; Torgersen and Jenkins, 1982; Torgersen and Clarke, 1985; Eliot et al., 1993; Ballentine et al., 1994). As a result, most geological fluids of meteoric or marine origin have $^3$He/$^4$He ratios lower than the atmospheric values and $^4$He concentrations greater than air-saturated water. Therefore, the analyzed results in the Wangu gold deposit (Fig. 3) indicate that the helium in fluid inclusions associated with gold mineralization has a dominant mantle-derived component, whereas the He isotope signature of hydrothermal fluids precipitating barren quartz veins is dominated by meteoric water. In addition, a correlation between $^{40}$Ar/$^{36}$Ar and $^{3}$He/$^{36}$Ar (Fig. 4) also demonstrates that the fluids responsible for the auriferous quartz veins and barren quartz veins can be considered as a combination of mantle and crustal components in different percentages.

The percentage of the mantle-derived He can be calculated according to the crust-mantle mixing model, which is expressed as:

$$\text{He}_{\text{mantle}}(\%) = \frac{(\text{He}_{\text{sample}}^{3}/\text{He}_{\text{sample}}^{4}) - (\text{He}_{\text{crust}}^{3}/\text{He}_{\text{crust}}^{4})}{(\text{He}_{\text{mantle}}^{3}/\text{He}_{\text{mantle}}^{4}) - (\text{He}_{\text{crust}}^{3}/\text{He}_{\text{crust}}^{4})} \times 100$$

where the $^3$He/$^4$He of crust end member is 2 $\times$ 10$^{-8}$, and the $^3$He/$^4$He of mantle end member is 1.1 $\times$ 10$^{-5}$ (Stuart et al., 1995). The calculated results show that the percentages of the mantle-derived He in the pyrite in auriferous quartz veins range from 45.2–95.7% (Table 1), averaging 69.1%; only one sample labeled No. I-1-2 has 100% value because its Ra value measured is higher than the proposed mantle value. In fact, $^3$He/$^4$He values in vesicles and fluid inclusions of the tholeiite, alkali basalt and transitional basalt from Loihi, Hawaii could be 20–30 Ra (Rison and Craig, 1983). Even those of geothermal well waters from Iceland range from 7.9 Ra to 12.7 Ra (Torgersen and Jenkins, 1982). Compared with the fluids in the areas of the mantle plume and hot spot, the fluids of the No. I-1-2 sample are quite close to the mantle fluids but still mixed with some crustal component. Because the projecting point of the No. I-1-2 sample is quite close to the correlation line in the $^{40}$Ar/$^{36}$Ar and $^3$He/$^36$Ar (Fig. 4), it seems a signature of the primordial fluids. Whereas pyrite in the barren quartz veins has 10.2–11.5% of the mantle component, reflecting more crustal substances evolving in the hydrothermal fluid system, which is consistent with the indications of $^{40}$Ar/$^{36}$Ar, $\delta$D, $\delta^{18}$O values (Figs. 4 and 6).

Studies of the fluid inclusion in the Wangu gold deposit indicate that fluid inclusions in auriferous veins are characterized by low salinity and high content of CO$_2$, belonging to CO$_2$-NaCl-H$_2$O system (Mao et al., 1997). In contrast, fluids related to barren quartz veins are NaCl-H$_2$O system (Mao et al., 1997). The CO$_2$-rich fluid in the mesothermal or orogenic gold deposit as recently defined by Groves et al. (1998) and Goldfarb et al. (1998) is genetically related to deep lithosphere process (Groves et al., 1988; Kerrich, 1990).
IMPLICATIONS FOR THE MINERALIZATION PROCESS

The transport of mantle volatiles through the crust is closely linked to tectonic setting; mantle $^3\text{He}$ in groundwater is typically found in regions of crustal extension, which is thought to be released during intrusion of subsurface melts (interplating) associated with extension (Oxburgh et al., 1986). Why do the hydrothermal ore fluids of the Wangu gold deposit have a significant component of mantle-derived helium, and what is the tectonic environment? Since the Late Mesozoic, East China located east of the tectonic-geophysical gradient belt along Daxing’anling Mt, Taiheng Mt, and Wuling Mt from north to south (Fig. 1) got lithospheric extension and thinning, with asthenospheric upwelling (Deng et al., 1999), which was possibly driven by plume (Niu et al., 2001). The Tanlu strike-slip fault zone is several thousands kilometers long (about 4000 km long in China) by 300 km wide, extending from the South China Sea through the Chinese mainland to the Sikhote—Alin area in the Russian Far East (Xu et al., 1990; Xu and Zhu, 1994). It accommodates about one hundred kilometers of sinistral displacement. The crustal thickness within the fault zone is 29–33 km and becomes 43 km thick westward immediately (Liu, 1985). Geophysical studies demonstrate that this fault zone penetrates to the Moho (IGSSB, 1987; Yuan, 1983). A series of fault basins developed in a NNE-striking orientation are accompanied by extensive basalt and andesite eruption with enclaves of olivine-rich basalt, basanite and nephelinolite proximal the Tanlu fault (Tao et al., 1996; Tao et al., 1999).

Over the past ten years, several natural gas fields, that include major CO$_2$ and 0.05–0.1% of helium, were discovered along the Tanlu fault zone, and which constitute an industrial helium resource (Xu et al., 1990; Xu and Zhu, 1994). Geophysical studies demonstrated that this fault zone penetrates to the Moho (IGSSB, 1987; Yuan, 1983). A series of fault basins developed in a NNE-striking orientation are accompanied by extensive basalt and andesite eruption with enclaves of olivine-rich basalt, basanite and nephelinolite proximal the Tanlu fault (Tao et al., 1996; Tao et al., 1999).

The helium and argon isotope compositions of fluid inclusions hosted in the pyrites from Machangqing alkali-porphyrty copper deposit (Hu et al., 1998) and Ailaoshan gold deposits (Burnard et al., 1999) in southwest China, Casapalca Ag-Pb-Zn-Cu and Pasto Bueno W-base metal deposits in Peru (Simmons et al., 1987), and Dae Hwa W-Mo deposit in Korea (Stuart et al., 1995) were reported before. $^3\text{He}/^4\text{He}$ values in the hydrothermal fluids of those deposits range from 0.1 Ra to 2.7 Ra. Helium and argon systematics define the mixtures between magmatic and crustal components in the hydrothermal fluids (Stuart et al., 1995; Hu et al., 1998) or the paleofluids were mixtures between a mantle-derived, magmatic fluid and two different low temperature fluids similar to modern groundwater (Burnard et al., 1999). The helium-argon system in the Wangu gold deposit is significantly different from the others. Especially, it is strongly characterized by high $^3\text{He}/^4\text{He}$ values for the auriferous quartz veins. This obvious difference can be possibly ascribed to the tectonic setting of strong extension and volcanic activities during late Cretaceous and Cenozoic ages in east China continent. He, Ar, and CO$_2$ probably exsolved from basalt melts.
that formed during lithospheric extension, and decompressional melting of the upper mantle (Oxburgh et al., 1986; Matthews et al., 1987). The gases emitted along the Tanlu fault zone, which penetrates to the Moho, providing conduits for mantle-derived melts as well as mantle-derived fluids. The mantle derived fluids, carrying noble gases and CO₂, were involved in the process at shallower crustal levels, including the formation of gold deposits, and advected into natural gas and oil fields. Because of the benefit conditions for mantle fluid moving and kept in the Tanlu fault zone, typical mantle-derived character without apparent admixing of meteoric water is locally shown. Barren veins formed from meteoric water that evolved compositionally and isotopically in the crust, and locally advected into Tanlu fault system.

Acknowledgments—We appreciate P. G. Burnard, K. Nagao, and Wang Yitian for their constructive suggestions on an earlier manuscript. We thank Yuji Orihashi and an anonymous reviewer of Geochemical Journal for their thoughtful reviews. This work was funded by Major State Basic Research Program of People’s Republic of China (No. G1999043211), the National Natural Science Foundation of China (No. 49825103), and the Geological Professional Fund (No. 9617).

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