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Puziwan Gold Deposit in Shanxi, China: A Special Linear Cryptoexplosive Breccia Type Gold Deposit

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Abstract The Puziwan gold deposit is a special linear cryptoexplosive breccia type deposit found in northeastern Shanxi, China, in recent years. The deposit is located in a secondary metallogenic belt of the most famous Au-Ag polymetallic metallogenic belt along the north margin of the North China platform. The secondary metallogenic belt is a synmagmatic tension-shear fault-fracture belt of ENE linear trend. The Indosinian cryptoexplosive breccia body, quartz monzonitic porphyry (beschtauite breccia), quartz monzonite (243.7 Ma, K-Ar), Yanshanian granite-porphyry (105±6 Ma, Rb-Sr) and orebodies mostly occur as dykes or veins and short lenses along the structural fracture belt. The orebodies are emplaced in the fractured cryptoexplosive breccia body in the tectonomagmatic belt and their attitude is consistent with that of the breccia body. The orebodies have two types: one is shallow-seated thick and big ones, which are short-lenticular in plan and wedge-shaped in cross section, shallow buried, large in size and high-grade; the other is lean orebodies, which occur as parallel veins at depths. The ores are mainly of Au-Ag polymetallic sulphide-rich breccia type. Pyrite (limonite) is the dominant metallic mineral, with subordinate chalcopyrite, galena, sphalerite, tenantite, native gold, electrum, native silver and argentite. The gangue minerals consist mainly of quartz and plagioclase, with subordinate carbonate minerals, alunite chalcedony and kaolin. Kaolinization is the characteristic alteration type. Sulphide minerals contain abundant trace minerals such as Cu, Pb, Ag, Sb and Hg, while in the ores Ag, Cu, Pb, Zn, As and Sb are the best indicator element assemblage of Au. The $\delta^{34}S$(‰) values of the ores range from −3.2‰ to 5.3‰, with average −0.102‰. The δO_{H_2O}(‰) and δD(‰) values are in the ranges from −3.1‰ to 7.73‰ and from −64‰ to −90‰ respectively. The Pb isotopic compositions of the rocks and ores in this region indicate that Pb comes from three tectonic sources—upper mantle, lower crust and orogenic belt. The inclusion homogenization temperature are in the ranges of 110 to 220℃ and 230 to 310℃, which suggests that the deposit formed under meso-epithermal conditions. The ore-forming pressures range from 6 to 32 MPa and the depths are 230 to 1200 m. In view of the above, the Puziwan gold deposit is genetically ascribed to a high-sulphur (alunite-kaolin) meso-epithermal gold deposit related to subvolcanic rocks. This gold deposit formed during the Indosinian stage (245.9±0.3 Ma) and then was influenced by a thermal event in the Yanshanian stage (142.9±0.5 Ma).

Key words: gold deposit, linear cryproexplosive breccia type, Shanxi

The Puziwan deposit in northern Shanxi is a new cryptoexplosive breccia type gold deposit, yielding also Ag, Cu, Pb and Zn. Compared with the Duguan Mn-Ag deposit in western Henan (Wei et al., 1999) and the Hongshan porphyry-crypto-explosive breccia type copper deposit in Huichang county, Jiangxi Province (Zhou et al., 1999), the mineralization related to magmatic crypto-explosion in the eastern Junggar orogenic-metallogenic belt, Xinjiang (Yu et al., 1999) and other gold mineralization related to magma crypto-explosion on the northern margin of the North China platform (Li et al., 1999), the Puziwan gold deposit is distinctive in respect to the geological environment of mineralization, geological features of orebodies and features of mineralization. The deposit is a special linear cryptoexplosive breccia type gold deposit.

1 Geological Environment of Mineralization

The gold district is situated along the northern margin of the North China platform, where Archaean metamorphic rocks are distributed extensively. The district mainly underwent Indosinian amalgamation between the Siberian plate and the North China plate, and Yanshanian subduction of the Pacific plate beneath the Eurasian plate. The plate amalgamation gave rise to an ENE-trending Au-Ag polymetallic metallogenic belt related to Indosinian granitoids and alkaline-subalkaline rocks. The metallogenic belt is a few thousand kilometres long and a few hundred kilometres wide. The Puziwan gold deposit is just located in a secondary metallogenic belt of the large-scale ENE-trending metallogenic belt. The Indosinian-Yanshanian tectonic and magmatic activities have close relationship with gold mineralization.

2 District Geology

The Jiuduigou-Puziwan-Qingjiapo ENE-trending large linear tectonomagmatic belt is 15 km long and 1000–1500 m wide. The Puzawan gold deposit occurs in the Puziwan-Dawuyao fractured cryptoexplosive breccia body in the central part of the tectonomagmatic belt. The country rocks are the Archaean Jining Group metamorphic rocks. The tectonomagmatic belt is composed of Mesozoic intermediate-acid magmatic-cryptoexplosive breccia, volcanic-subvolcanic breccia, subvolcanic rocks and small intrusions, which are arrayed linearly or as a string of beads. Along the tectonomagmatic belt, small nearly E-W-trending faults are developed. Geophysical and geochemical anomalies show a linear and beaded array.

The hosting Puziwan-Dawuyao fractured cryptoexplosive breccia occurs as a linear synmagmatic tension-shear fracture belt. The continual strong alteration and mineralization in the fracture belt are 1300 m long and 100–150 m wide. The Indosinian cryptoexplosive breccia body, beschtauite (beschtauite breccia) and quartz monzonite (243.7 Ma, K-Ar), Yanshanian granite-porphyry (105±6 Ma, Rb-Sr), and ore bodies and veins are mostly distributed as dykes or veins and short lenses along the structural fracture belt.

3 Deposit Geology

(1) The orebodies occur within a breccia body and are concordant with the latter. The orebodies have two types. One is thick and big orebodies occurring at shallow depths, which are short-lenticular in plan view and wedge-shaped in cross section, large in size, high-grade, easy to mine, and of great industrial value. They are the major type of gold orebodies to be looked for in the district and the whole metallogenic belt. The other type is parallel thin-vein orebodies, which occur at depths. The mining cost is high and the ore is difficult to utilize. There is a 50–100 m barren interval between the two types of orebody, which are not continuous vertically.

(2) The ores are mainly Au-Ag polymetallic sulphide-rich type, with a sulphide content above 10%. Pyrite (limonite) is dominant in the ore mineral assemblage, accounting for above 70% of the total ore minerals, and its formation has the polyphase and multi-stage features and went through the entire rock- and ore-forming processes. The subordinate metallic minerals include chalcopyrite, galena, sphalerite, tennantite, native gold, electrum, native silver and angentite. The Au-Ag series minerals account for about 10% of the total amount of the minerals, mostly represented by micron- and fine-sized gold, mainly occurring in the crystal interstices and subordinately in the crystal fissures. The dominant vein minerals are quartz and plagioclase, with subordinate carbonate minerals, alunite, chalcedony and kaolin. The main carrier mineral is pyrite, while galena and tennantite are subordinate. Vein quartz is also an important gold carrier mineral.

(3) The mineralization process can be divided into two periods and five stages.

① Hydrothermal period:

Ⅰ. gold-bearing quartz-pyrite-chalcopyrite stage

Ⅱ. quartz-sericite-Au-Ag polymetallic sulphide stage

Ⅲ. quartz-carbonate-Ag-Au polymetallic sulphur stage

Ⅳ. quartz-carbonate-sulphur stage

② Hypergenic period:

Ⅴ. quartz-limonite-kaolin stage

(4) Wall-rock alteration is well developed. The dominant alterations are pyritization, sericitization, silicification, kaolinization, carbonation and chloritization. Among them, pyritization, sericitization, silicification, kaolinization and carbonation are closely related to gold mineralization. In the hypergenic period kaolinization played an important part in secondary enrichment of gold. Alteration zones in the metallo-

-genic belt are (in descending order): kaolinization and illite-muscovitization–carbonation and silicification sericitization and silicifiation (carbonation)– silicification and sericitization. From country rocks to the ore belt are: potash alteration and silicification– chloritization, silicification and sericitization– sericitization and silicification (carbonation).

(5) In this paper, vein quartz in polymetallic sulphide quartz veins formed during the stage II mineralization was selected for ^{39}Ar-^{40}Ar measurements of the ore-forming age. The Puziwan gold deposit formed during the Indosinian (245.9±0.3 Ma), and then was influenced by a thermal event during the Yanshanian (149.2±0.5 Ma).

4 Trace Element Geochemistry of Ores

(1) The purity of gold mineral in primary ore varies from 719 to 950 with an average of 819. The pyrite is iron-poor pyrite. The trace elements are Au, Ag, Cu, Pb, Zn, Co, Ni, As, Sb and Hg, with a Co content mostly above 100×10^{-6}, Co/Ni averaging 0.61 (40), (Pb+Zn)/(Co+Ni) averaging 4.95, Au less than Ag and Au/Ag averaging 0.03. The distinctive element assemblage in ore is Au-W-Cu-Hg-Ag-Bi-As-Co-Ni-Sb-Pb. Polymetallic sulphides, such as chalcopyrite, galena and sphalerite, contain abundant trace elements such as As, Sb and Hg. The grey quartz formed during the middle period also contains abundant trace elements such as Au, Co, Cu and As.

(2) The indicator trace elements in pyrite for determining the denudation degree of an orebody are: Ag, As, Hg and Ag/Au for the head halo; Au, Ag, As, Sb, Cu, W and As/(Co+Ni) for the halo in the middle-upper part; Au, Ag, Pb, Zn and (Pb+Zn)/(Co+Ni) for the halo in the middle-lower part; and Mn, V, Mo, Bi, Co and Ni for the rear halo.

(3) The trace elements in ores are Au, Ag, Bi, Pb, W, As, Zn, Cu, Sb, Mn, Hg, B and Mo. Among them, Ag, Cu, Pb, Zn, As and Sb are the best indicator element assemblage for indicating Au. The sequence of the indicator elements in an ideal vertical zoning is (in descending order) Hg→B→Sb→As→Ag→Pb→Cu→Au→Zn→Bi→Mo.

(4) The zoning of the characteristics element assemblages of the primary halo of the orebody is: (a) the abnormal elements Hg, B and Sb for the halo in the head and front; (b) the abnormal elements As, Ag and Au for the halo in the middle-upper part; (c) the abnormal elements Au, Cu, Pb and Zn for the halo I in the middle-upper part; (d) the abnormal elements W, Mo, Bi and Mn in the rear halo.

5 Stable Isotope Geochemistry of Ores

(1) The sulphur isotopic composition of ore is homogeneous. The $\delta^{34}S$ values of ores range from −3.2‰ to 5.3‰ (pyrite, 0.06‰ to 1.2‰; sphalerite, −1.3‰ to 0.9‰; chalcopyrite, −3.1‰ to 0.19‰; galena, −2.4‰ to 5.3‰), with an average of −0.102‰. The $\Delta^{34}S$ values of two paragenetic sulphide pairs exhibit good homogeneity, indicating that the $\delta^{34}S$ values of the hydrothermal ore fluids range from 0.1 to 1.4‰ and implying that the fluids were derived from the same source during mineralization, i.e. from the deep source.

(2) The $\delta^{18}O_{quartz}$ of the nonmetallic mineral quartz formed from mineralization stages I to IV range from 10.0‰ to 14.9‰ (Table 1). The $\delta^{18}O_{H_2O}$ values calculated according to the equation of Wenner (1971) are in the range from −3.1‰ to 7.73‰, which are deviated towards big positive values in the early stages and towards negative values in the last stages of mineralization. Correspondingly, the δD values of the fluid inclusions in quartz range from −64‰ to −90‰. The ore fluids were mainly magmatic water in the early stage, a mixture of magmatic water and meteoric water in the middle stage and mainly meteoric water in the late stage.

Table 1 Hydrogen and oxygen isotopic compositions in the Puziwan gold deposit

Sample No.	Analyzed mineral	$\delta^{18}O_{quartz}$ (‰)	δD (‰)	Homogenization temperature (℃)
T133-1	Quartz	13.0	−64	163
T9207	Quartz	12.9	−90	230
T132-1	Quartz	10.0	−66	307
T152-2	Quartz	14.9	−73	328

(3) The comparison in lead isotopic composition between galena, pyrite and sphalerite in ores and granitoids in the Baoziwan gold district is shown in Table 2. Lead in ores and rocks of the district is almost

Table 2 Comparison in Pb isotopic ratios between rocks and ores in the Puziwan gold deposit

	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Galena in ore (3)	16.630	15.388	36.619
Pyrite in ore (3)	16.667	15.360	36.665
Sphalerite in ore (1)	16.474	15.232	36.251
Indosinian quartz monzonitic porphyry (4)	16.782–17.546 (17.152)	15.384–15.487 (15.418)	36.808–37.602 (37.169)
Indosinian quartz monzonite (1)	16.833	15.602	37.338
Yanshanian granite porphyry (whole rock) (1)	18.153	16.646	36.408

Note: Figures in the brackets denote the numbers of samples.

all common lead, and the radiogenic lead content is low. The narrow range of lead isotopic ratios and high degree of homogenization of seven ore samples, combined with the monotonous source, indicate that the ore lead was derived from three tectonic source regions: the upper mantle, low crust and orogenic belt. The lead isotopic composition of ores is essentially consistent with that of the Indosinian quartz monzonitic porphyry and quartz monzonite. The lead isotopic compositions of ores and Indosinian magmatic rocks are close to those of the upper mantle and lower crust, whereas that of the Yanshanian granite-porphyry is relatively close to that of the orogenic belt.

6 Mineral Inclusion Studies

(1) Inclusion studies of 15 representative samples were performed. According to the genesis, inclusions are divided into two types. The primary inclusions, which are rounded and distributed sporadically and randomly, are abundant. The secondary inclusions, which are mostly oriented as bands, are scanty. Liquid phase inclusions are dominant, with subordinate vapour phase inclusions and minor amounts of CO_2 inclusions and multi-phase inclusions with daughter crystals. The inclusions are mostly 5 to 15 μm in size, and in a few cases 20 μm; in poorly mineralized rock bodies, inclusions are smaller and less, mostly less than 5 μm in size. The vapour to liquid ratio is 5 to 20%.

(2) The homogenization temperatures of inclusions range from 108 to 380℃ and the main mineralization temperatures range from 110 to 220℃ and from 230 to 310℃, which reveals that the deposit is a meso- and epithermal deposit. The mineralization pressures fall in a range between 6 and 32 MPa, and the depths range from 230 to 1200 m. The salinities of the inclusions vary from 9.2 to 13.2 wt% NaCl equiv.

(3) The results of analyses of the inclusion composition (Table 3) shows that the vapour phase is dominated by H_2O, and CO_2 with minor H_2, N_2, CH_4, and CO and no O_2. The various inclusion assemblages have similar characteristics and the same fluid source. The mole ratios of CO_2/H_2O are low, being 0.027–0.049. The $(CH_4+H_2+CO)/CO_2$ ratios are 0.045–0.132, with an average of 0.08. Cations of the liquid-phase components are mainly Na^+, K^+ and Ca^{2+}, while Mg^{2+} was not detected; anions are mainly SO_4^{2-} and Cl^- with minor F^-, The liquid belongs to Na^+- K^+-SO_4^{2-}- Cl^- type liquid, which suggests the characteristics of postmagmatic hydrothermal fluids.

(4) Through calculation, the ore-forming fluids, with pH= 4.2–4.91, Eh=0.045–0.132 and the reduction index R=0.045–0.132, belong to the subalkaline and weak reducing conditions.

7 Genetic Analysis of the Deposit

The main mineralization geological factor of the Puziwan gold deposit is tectonomagmatism. The source of ore materials has close relationship with magmatic hydrothermal fluids. The rock bodies directly

Table 3 Inclusion composition of quartz in the Puziwan gold deposit

Sample No.	Vapour phase (μg/g)						
	CO_2	H_2O	H_2	O_2	N_2	CH_4	CO
T9207	66.35	820.48	0.11		1.45	0.29	0.32
T133-1	23.98	365.06	0.09		0.92	0.14	0.50
T132-1	58.98	492.77	0.09		1.62	0.21	1.68
T152-2	75.58	640.53	0.11		0.23	0.26	0.56
Sample No.	**Liquid phase (μg/g)**						
	Na^+	K^+	Ca^{2+}	Mg^{2+}	F	Cl	SO_4^{2-}
T9207	0.296	0.289	0	0	0.013	0.187	0.528
T133-1	0.600	0.563	0	0	0.029	0.118	1.168
T132-1	0.308	1.123	0	0	0.044	0.227	1.448
T152-2	1.447	7.402	0	0	7.859	6.274	

related to mineralization were Indosinina cryptoexplosive breccia and quartz monzonitic porphyry (beschtauite) therein. The magmatic cryptoexplosion gave rise to ore-hosting spaces with high porosity and permeability in breccia, in which postmagmatic hydrothermal ore fluids filled and replaced the breccia, thus forming the gold deposit. The ore mineral assemblage, ore mineral chemical composition, alteration characteristics and data of inclusion measurements not only show the typical characteristics of hydrothermal mineralization (Hayba et al., 1986; Chen et al., 1987; Heald et al., 1987; Spooner, 1993), but also show the characteristics of meso- and epithermal mineralization. Based on those, the Puziwan gold deposit genetically should belong to a sulphur-high type (alunite-kaolin type) meso- and epithermal gold deposit related to subvolcanic rocks. The deposit formed during the Indosinian stage (245.9±0.3 Ma) and then was influenced by a thermal event during the Yanshanian stage (142.9±0.5 Ma).

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