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ScienceDirect
Trans. Nonferrous Met. Soc. China 23(2013) 2726−2735
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Fluid inclusion and mineralization of Dafulou tin deposit in Dachang metal district, Guangxi, south China

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Received 14 June 2012; accepted 13 June 2013

Abstract: Based on the study of the petrology, mineralogy, structural geology and fluid inclusion of the Dafulou ore deposit in the Dachang ore field, the ore deposit geology and ore-forming fluids were analyzed. It shows that there are five main hydrothermal alteration types in the Dafulou ore district, namely the silicification, carbonate, sericite, pyrite and pyrrhotite. The mineralization types are composed of the stratiform type, interlayer type and stockwork type. The ore textures present as metasomatic texture, euhedral-subhedral granular texture and solid solution texture. The ore structure consists of massive structure, dissemination structure, fine veined structure, stockwork structure and brecciated structure. Four ore types are recognized, namely the disseminated ore, dense massive ore, veinlet ore and brecciated ore. Six types of fluid inclusions are determined, i.e. the single-phase gaseous fluid inclusions, single-phase salt solution fluid inclusions, two-phase vapour-rich fluid inclusions, two-phase liquid-rich fluid inclusions, three-phase CO_2-rich fluid inclusions and solid(s)-bearing fluid inclusions, all of which form in three dominant temperature scopes, 120−150, 230−270, 350−460 °C. But, the majority of them form in the high temperature environment (350−460 °C). The tectonism plays an important role in the mineralization, which usually controls the scale, occurrence and shape of the Sn orebody. There are four types of hydrothermal fluid systems, $H_2O-NaCl-CaCl_2$, $H_2O-CaCl_2$, $H_2O-NaCl-MgCl_2$ and $H_2O-MgCl_2$. Similar to the other ore deposits in the Dachang ore field, there also exists the multiple source of ore-forming fluids. Overall, the Dafulou ore deposit should be the result of the crust−mantle interaction.

Key words: fluid inclusion; mineralization; Sn-polymetallic deposit; Dafulou; Dachang

1 Introduction

The world famous Danchi mineralization belt, situated in Guangxi Autonomous Region (or Guangxi Province), south China, hosts a number of super large scale tin−polymetallic deposits, one of the largest, currently operational tin mine in China [1−3]. The Dafulou ore deposit is situated in the Danchi mineralization belt, approximately 17 km southeast of the county of Nandan and 12 km northeast of the town of Dachang [4,5]. The deposit was discovered in 1950 in the period of the exploration to ore body No. 0. The structural setting, mineralization and fluid compositions of the Dafulou ore deposit exhibit many similarities to the other ore in the Danchi mineralization belt, (i.e. Tongkeng deposit, Changpo deposit and Gaofeng deposit, etc).

Fluid inclusion studies have been widely used to interpret the fluid evolution, geodynamic mechanism, deposit model and as a cost-effective method of determining ore genesis [6−9]. In the past few years, these studies have been applied to many of the metal deposits in the Dachang ore district [10−14] and elsewhere [15−19].

In this paper, we present the new results of microthermometric measurements, ion chromatography and gas chromatography analyses on fluid inclusions in quartz and calcite from samples collected in production wells and the latest tunnels, assuring the experimental

Foundation item: Project (41202051) supported by the National Natural Science Foundation of China; Project (2012M521721) supported by China Postdoctoral Science Foundation; Project (CSUZC2013021) supported by Valuable Equipment Open Sharing Fund of Central South University, China
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DOI: 10.1016/S1003-6326(13)62790-9

precision and meeting the research needs.

The aim of this paper is to present and supplement the latest results of a geological, mineralogical and fluid inclusions study carried out in the Dafulou ore deposit. And, this preliminary information is integrated with additional data on the geological setting, ore mineralogy and ore-controlling structure, with a view to understanding the genesis of the cassiterite-sulphide deposits.

2 Geological setting

The Danchi ore belt lies in the southern border from the Proterozoic to the early Paleozoic, yet it is located in the second rifting basin of the Youjiang basin [20,21]. The main structures are composed of the NW-trending close linear double-fold tectonic zone, the NE-trending fault, the ring structure in the central of this ore field (see Fig. 1). The NW-trending duplex fold is characterized by the significant asymmetry, showing the slow east wing and the steep west wing, yet with locally overturned ones [22,23]. The rock emplacing always distributes in the crossing site both the NW-trending and NE-trending faults. The fault crossing between the NW-trending and NE-trending formed the more regular network, where is always regarded as the favorable prospecting sites. The distribution of the ore deposits is always characterized by the obvious direction and equal interval along the NW-trending structure. In the Dachang ore field, the NE-trending multiple folded fault belt presents as the Danchi and Dachang folded fault belts, which locate in the central and west, respectively [24,25].

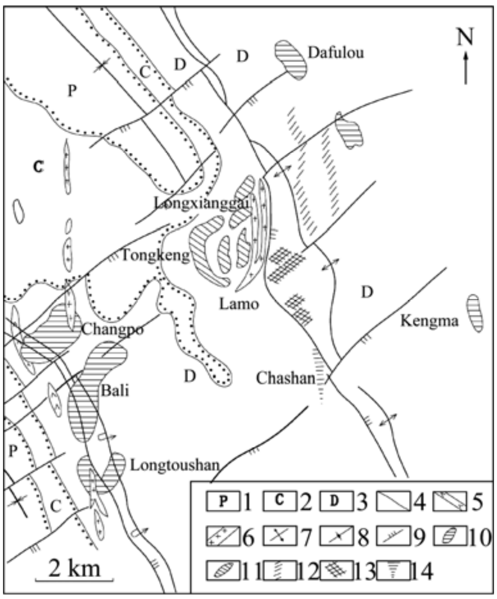

Fig. 1 Mineralization zone of Dachang ore field (compiled from China Nonferrous Metals Industry Corporation, 1987): 1 — Permian limestone and siliceous; 2 — Carboniferous limestone; 3 — Devonian limestone, shale and siliceous; 4 — Parallel unconformity stratigraphic contact; 5 — Diorite porphyrite; 6—Granite and granite porphyry; 7—Anticline axis; 8—Syncline axis; 9—Faults; 10—Tin orebody; 11—Zn−Cu orebody; 12 — Scheelite veins; 13 — Wolframite veins; 14—Antimony veins

This area experienced three great historical phases: the intracontinental and continental margin rifting stages from the Proterozoic to the early Paleozoic, the intracontinental and continental margin rifting stages from the Devonian to the early Permian, and the back-arc rifting stage from the late Permian to the Triassic. The Danchi ore belt belongs to a fault basin, which is located in the Youjiang passive continental margin-rifting basin in the Hercynian−Indosinian phase [3].

In the Danchi district, the tin−polymetallic ore belt spreads in the northwest-southeast more than a hundred miles, with the northwestern part of the ore belt beginning from the Guizhou and Guangxi border and the southeastern border beginning from the southern Wuxu county. The southwestern border begins from the Yilan mercury deposit and the northeast border spreads along the Lama−Layi−Beixiang−Hongsha.

3 Ore deposit geology

3.1 Geological and structural setting

The Dafulou deposit, which belongs to the eastern mineralization belt of the Dachang tin ore field and has been mined for some degree before the foundation of the People’s Republic of China, is located in the eastern flank of the NNW–SSE-trending Danchi anticlinorium. Besides the Dafulou ore deposit in the eastern mineralization belt, there are some small-scale Sn ore deposits, such as Huile, Tongkan, Hunaglaqiao, Maopingchong and Dawan, Lanichong− Maomao-chongding W deposit [26]. The most important structures in the Dafulou ore district are the NW-trending faults, such as overthrust fault, which developed parallel to the axis of the Dachang anticlinorium. In addition, the NE-trending and SN-trending structures are also very important to the Dafulou Sn−polymetallic mineralization, especially at the intersection of the NW-trending and the NE-trending structures [23].

From the point of spatial relations, the ore deposits array in equal distance, i.e. the Dafulou deposit, the Huile deposit, the Kengma deposit. Leading to this results, it is just because of the superposition of the NW-trending and the NE-trending structures, which control the orebodies Nos. 0, 21 and 22 in the Dafulou ore district [5]. Additionally, because of the strong compression, many NW-trending fracture parallels to the axis of the Danchi anticlinorium in the eastern.

About the genesis of the Dachang Sn−polymetallic ore deposit, there are some debates, particularly to the genesis of stratiform-like orebody. In the Dafulou ore district, the main types of ore body consist of vein-style ores and stratiform-like orebody which is characterized by the stable occurrence and the large scale. So, the further study to the stratiform-like orebody has a particular significance.

3.2 Stratigraphy

The Dafulou ore deposit is located in the east ore belt of the Dachang ore field. Similar to the west ore belt, the Devonian is also the important host strata in the Dafulou ore district, mainly involving upper Devonian (Liujiang formation), middle Devonian (Luofu formation, Nabiao formation), lower Devonian (Tangding formation), among which the lower Devonian Tangding formation is the main host strata (e.g. the Nos. 21 and 22) [3,5,11].

Upper-Devonian Liujiang Formation (D_3^1,60−80 m thick) is composed mainly of gray-black thick-layered siliceous and siliceous limestone, with intercalated carbonaceous limestone, limestone and argillaceous limestone, among which the limestone is characterized by dense and hard, thick layer, quartz vein development, gray-dark gray. There are plenty of breccias, which are cemented by limestone, with various shapes, i.e., elongated, spindle and pea. The breccias, with medium psephicity and parallel arrangement approximately, are less than 20 cm in length and 8 cm in width.

Middle-Devonian Luofu Formation (D_2^2, 424−654 m thick) is composed mainly of charcoal grey-grey black calcareous argillaceous, shale and charcoal grey argillaceous limestone, limestone, which were weathered to yellow shale, argillaceous. The fresh rock is gray black shale, carbonaceous shale and charcoal grey−gray black limestone. The Luofu Formation contacts with the lower stratum conformably.

Middle-Devonian Nabiao Formation (D_2^1, 305−852 m thick) is composed mainly of gray black carbonaceous limestone and limestone, with intercalated calcium nodule, argillaceous limestone and fine sandstone. The outcrop is weathered strongly with brownish yellow, which is soft and fragile because of the higher content of argillaceous than the lower stratum.

Lower-devonian Tangding Formation (D_1^3, 225−328 m thick) is composed mainly of gray black calcareous argillaceous (shale), with intercalated thin-layer argillaceous limestone. The rock has high content carbonaceous, which leads to the fragile and the special mechanical properties. In the Dafulou ore district, the orebodies Nos. 21 and 22 are hosted by the Tangding Formation.

3.3 Igneous rocks

In the Danchi mineralization belt, the intrusive rocks consist of biotite granite, granite porphyry, quartz diorite porphyry, quartz porphyry, dacite porphyrite, alaskite and a little sillite [27,28]. It is characterized by the frequent magmatic activities and many sorts of rock types, in which the biotite granite is dominated, exposing on the Longxianggai surface as veinlet and being a small top large bottom conical in the whole. For a long time, a variety of different views exist about the intrusive phase, but it is agreed that the magmatic activity belongs to the late Yanshanian event. In the mineralization belt, the intrusive rocks concentrate in the north Mangchang and central Dachang [29]. Yet, in the Dachang metal district, the intrusive rocks mainly distribute in the central Longxianggai and west Tongkeng-Bali. In the west Tongkeng−Bali, NS-trending granite porphyry and quartz diorite porphyry exist, forming the relatively large-scale steep dike, with 80−2400 m in length and 1−130 m in width. The secondary rock is the small scale NW-trending and NE-trending dyke or rock branch [30,31]. The granite porphyry and quartz diorite porphyry distribute in both sides of the Tongkeng−Changpo ore deposit, being called east dyke and west dyke, respectively.

In the Danchi mineralization belt, the main magma activity occurred in the medium and late period of Yanshan, belonging to shallow–super shallow magma rocks, which distribute in the area of Longxianggai, Dachang, Mangchang in the way of dykes, rock strain, rock bed, etc. The rock types consist of biotite granite, granite porphyry, quartz porphyry, fraidronite and diorite porphyry, etc. In the Danchi mineralization belt, the granite belongs to alkali−calcium rock series and near to the alkali rock series, which is rich in silicon, aluminum and poor magnesium, iron, calcium. It is characterized by high alkali and potassium-rich, ferrous-rich, calcium-rich, magnesium-rich, silicon-poor for the porphyritic biotite granite. Grain porphyritic biotite granite is silicon-high and potassium-rich, ferrous-rich, calcium-rich, magnesium-rich and silicon-poor. All of these suggest that the formation environment of granite belongs to molten magma crust type series, which reflects the product of magma activity in different phases and different stages. In the Danchi mineralization belt, the rock body is characterized by small size and buried in the deep, whose wall rock alters in large area and outputs several kinds of endogenic metal deposits. In this area, there is close relationship between intrusive rock and regional structure. All kinds of rock body intrude along both sides of the Danchi fault.

3.4 Hydrothermal alteration

In the Danchi mineralization belt, there is different hydrothermal alteration to different mineralization types. For example, the hydrothermal alteration of cassiterite-sulfide orebody is very strong relatively, which is relevant to high temperature hydrothermal alteration and medium-high temperature hydrothermal alteration, especially with a close relation to K-feldspar and tourmalinization. And it is characterized by weak hydrothermal alteration for stratabound bodies.

In the Dafulou ore district, the main types of the hydrothermal alteration involve silicification, carbonate, sericite, pyrite and pyrrhotite, etc. Silicification is one of the main hydrothermal alteration types, characterized by dense and hard rock, such as siliceous limestone and silicified marble. The carbonation was mainly shown as marbleization, such as marbleization biological clastic limestone. Pyritization is also very common to the Dafulou ore district, and specially appears in the wall rock of stratiform-like and vein-type orebody. Pyrrhotitezation always occurs with pyrite, which alters the ore-hosting rocks such as limestone, shale, argillaceous limestone, carbonaceous limestone.

4 Ore mineralogy

4.1 Mineralization type

In this area, the mineralization type is very complicate. It consists of three types, stratiform type, interlayer type and stockwork type.

1) Stratiform type

It is characterized by the similar occurrence with the stratum in the ore body No. 22, usually with the flat interface to the footwall rocks, yet with an irregular contact boundary to the hanging wall rock, in which the ore body usually fills in the shape of comb. This type is visible in both the stratiform ore body and the vein ore body, but more common to the stratiform ore body.

2) Interlayer type

The ore body fills the interlayer crack or the quartz vein. This type, whose occurrence is consistent to the crack, is controlled by the crack form in the period of the mineralization. It is characterized by the fine ore vein and distributes in the brittle wall rock, which is affected by the carbonaceous content, such as the steeply inclined No. 0 ore body.

3) Stockwork type

It mainly presents as comb-shaped, gossamer mesh for the pyrite and pyrrhotite filling along the fine cracks.

4.2 Ore texture

1) Metasomatic texture belongs to the main type and more in the microscopic identification, such as arsenopyrite replacing pyrite, pyrrhotite replacing pyrite, arsenopyrite replacing pyrrhotite, chalcopyrite replacing pyrrhotite, galena replacing pyrrhotite, bismuthinite replacing pyrrhotite, chalcopyrite replacing pyrrhotite, chalcopyrite replacing arsenopyrite.

2) Euhedral-subhedral granular texture is more in the quartz, such as at the stope No. 21 around the hot spring.

3) Solid solution texture is usually the chalcopyrite solid solution in the marmatite or the solution side in the galena and marmatite.

4.3 Ore structure

1) Massive structure belongs to the most common structure type in the Dafulou metal district. The ore minerals are composed mainly of pyrite and cassiterite. The gangue minerals usually consist of calcite and quartz.

2) Dissemination structure widespreads in the polished sections and slices, such as the disseminated pyrite, the disseminated euhedral arsenopyrite.

3) Fine veined structure is characterized by the filling of the pyrite, cassiterite, pyrrhotite and arsenopyrite along the quartz vein or the wall rock.

4) Stockwork structure is characterized by the filling of the mineralization along the multi-phase stockwork fine quartz vein. It mainly distributes in the tunnel.

5) Brecciated structure is usually characterized by low psephicity. The majority of breccia encapsulated by pyrite and quartz are variably sized.

4.4 Ore type

1) Disseminated ore is composed mainly of the pyrite and pyrrhotite, which occurs primarily in disseminated distributions in the wall rock. It is more in the polished section.

2) Dense massive ore consists of pyrite, marmatite, pyrrhotite and galena. It is characterized usually by hard, dense and large block.

3) Veinlet ore is affected by the structure and stratum and filled along the crack. They are usually intertwined in the shape of stockwork or comb, along or a cross the layer.

4) Brecciated ore is mainly the limestone breccia, which usually occurs in the tunnel and outcrop, and is characterized by low psephicity and cemented by pyrite, pyrrhotite, quartz and calcite.

5 Fluid inclusion studies

5.1 Fluid inclusion petrography

In this study, six types of fluid inclusions have been recognized on the basis of optical observations and microthermometric data.

Type I (single-phase gaseous fluid inclusions): This type consists predominantly of vapour, with little vapour CH_4 and vapour H_2S. The inclusion size varies from 3 to 15 μm. These inclusions are of various shapes, such as rice-shaped, ellipse, polygon, irregular.

Type II (single-phase salt solution fluid inclusions): Fluid inclusions belonging to this type consist of pure saline. This is by far the content of 15% to 65%. The size of fluid inclusions ranges from 1 to 15 μm. These inclusions are of various shapes, such as ellipse, rice-shaped, polygon, irregular, with the distribution of freedom mostly, but little orientation distribution along the microfissure of quartz.

Type III (two-phase vapour-rich fluid inclusions): This type contains two phases: a vapour bubble V_{H_2O} and a liquid water L_{H_2O}, with various shapes, i.e. ellipse, polygon, rectangle, irregular, etc. The volume of this type in the fluid inclusions accounts for 30% to 55%. Fluid inclusions belonging to this type consist of pure saline and vapour water, which distribute dominantly with the form of freedom and small groups.

Type IV (two-phase liquid-rich fluid inclusions): Fluid inclusions belonging to this type consist of pure saline and vapour water. The percentage of this type fluid inclusion is 15%−50%, which shows various shapes, such as polygon, rectangular, oval, subhedral and little irregular. The size of fluid inclusions ranges from 2 to 25 μm. Most of the fluid inclusions belong to negative crystal.

Type V (three-phase CO_2-rich fluid inclusions): There are three phases: liquid water (L_{H_2O}), liquid CO_2 (L_{CO_2}), and vapour CO_2 (V_{CO_2}). The percentage of this type fluid inclusion is only 5%. The size of fluid inclusion ranges from 5 to 15 μm. The shape of fluid inclusions is diversity, but oval dominantly, polygon and negative crystal secondly, which distributes freely or mixing distribute with other type.

Type VI (solid(s)-bearing fluid inclusions): The typical feature of this type is the content of daughter mineral NaCl. This type consists of three phases: liquid water (L_{H_2O}), vapour water (V_{H_2O}), and solid NaCl (S_{NaCl}). The size of fluid inclusions is 5−30 μm, with various shapes, such as oval, polygon, rectangle. The form of distribution is free or mixed with other type.

5.2 Microthermometry

In the salt solution type inclusions, the water content of the salt solution type inclusions ranges from 10% to 70%. The eutectic temperature and freezing temperature are −36.5 °C to −56 °C, −15.0 °C to −22.0 °C, respectively (see Table 1). This type inclusion usually has multiple homogenization temperature and salinity. According to the parameters of the water content and homogenization temperature [32,33], it is indicated that with the increase of water content, the homogenization temperature also increases accordingly, which shows that the water content can affect the homogenization temperature to a certain extent. The salinity of the salt solution type inclusions ranges from 17.2% NaCl to 22.44% NaCl. In this type inclusion, there exist three kinds of solution system, such as H_2O−$CaCl_2$ system, H_2O−NaCl−$CaCl_2$ system and H_2O−NaCl−$MgCl_2$ system. Yet, the H_2O−NaCl−$CaCl_2$ system is dominant obviously. The density is 0.970−1.105 g/cm^3, which is affected by the water content to some degree.

The eutectic temperature and freezing temperature of B type two-phase inclusions are −32 °C and −14.2 °C to −15.0 °C, respectively. The corresponding salinity and homogenization temperature range from 18.1% to 18.8% NaCl and from 380 °C to 410 °C, respectively.

In the NaCl-bearing daughter mineral type fluid inclusions, the salinity is 28.95% to 30.08% NaCl, and the corresponding density is 1.153 to 1.137 g/cm^3. Maybe it belongs to H_2O−$MgCl_2$ solution system. The total homogenization temperatures of NaCl daughter mineral range from 129 to 162 °C, but the dominant temperature is roughly 150 °C (Fig. 2), characterized by the low temperature phase in the whole.

The homogenization temperature of the water solution in the NaCl-bearing daughter mineral type fluid inclusions is 270−290 °C (see Fig. 3), but the main temperature is approximately 280 °C.

Three-phase eutectic temperature of CO_2-rich type inclusion ranges from −58.5 to −57.3 °C, and the clathrate compound melting temperature is from −4.0 to −1.5 °C. CO_2 partial homogenization temperature ranges from 12 to 26 °C with the density of CO_2 ranging from 0.158 to 1.5 g/cm^3 (see Table 2).

Table 1 Microthermometric data for salt solution type inclusions

$\varphi(V_{H_2O})$/%	Eutectic temperature/°C	Freezing temperature/°C	Salinity/% NaCl	Homogenization temperature/°C	Density/(g·cm^{-3})	Solution system
10−15	−55− −56	−21.3− −22.0	21.9−22.44	120−145	1.098−1.105	H_2O−NaCl−$CaCl_2$
15−25	−42.5− −44.6	−18.2− −19.3	19.8−20.7	240−265	0.974−0.984	H_2O−$CaCl_2$
30−35	−36.5− −37.5	−15.2− −16.5	18.9−20.0	350−395		H_2O−NaCl−$MgCl_2$
10−15	−49− −52	−15.2− −15.5	17.3−17.6	120−145	1.052−1.069	H_2O−NaCl−$CaCl_2$
10−15	−52.5− −54	−18.5− −19.0	20.0−20.3	230−260	0.970−0.996	H_2O−NaCl−$CaCl_2$
30−35	−51.5− −52	−17.5− −18.0	19.2−19.5	390−420		H_2O−NaCl−$CaCl_2$
60−70	−49.5− −51.0	−15.0− −15.5	17.2−17.6	380−430		H_2O−NaCl−$CaCl_2$

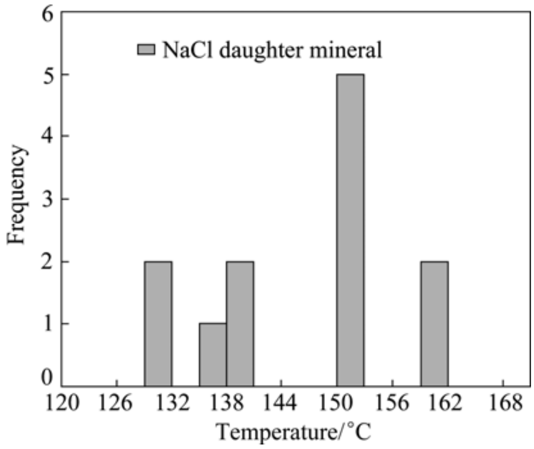

Fig. 2 Histogram showing total homogenization temperatures (t_h) of NaCl daughter mineral inclusions

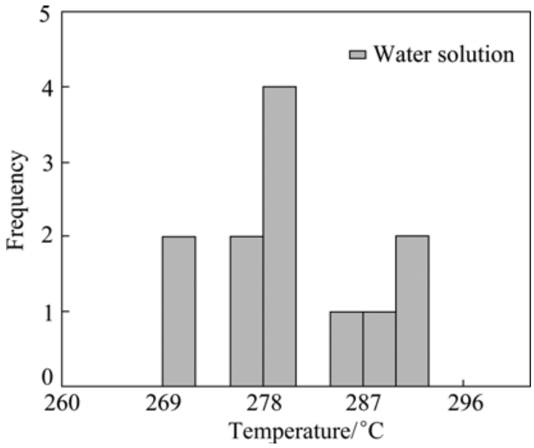

Fig. 3 Histogram showing total homogenization temperatures (t_h) of water solution inclusions

As shown in Fig. 4, there exist three main temperature scopes to the fluid inclusions, 120−150 °C, 230−270 °C and 350−460 °C. But the different type inclusions are characterized by different homogenization temperatures. Two-phase vapour-rich fluid inclusions are characterized by the low homogenization temperatures, 120−150 °C mostly, yet ranging from 240 to 270 °C and 350 to 400 °C in the minority. The homogenization temperatures of two-phase liquid-rich fluid inclusions are mainly 230−270 °C and 380−440 °C, which are higher than the homogenization temperatures of two-phase vapour-rich fluid inclusions. Yet, the homogenization temperature of CO_2-rich fluid inclusions is the maximum among all (see Fig. 4), ranging from 380 to 460 °C.

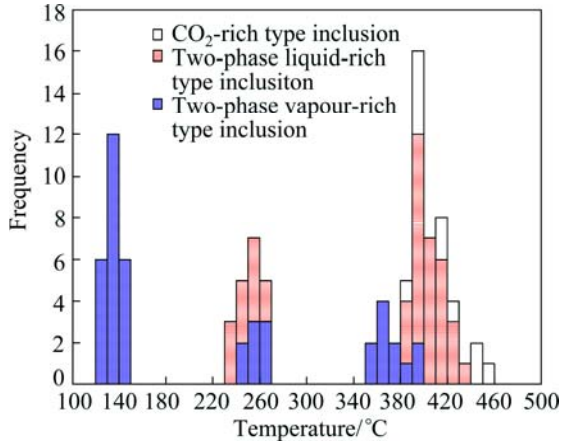

Fig. 4 Histogram showing homogenization temperatures of different types of inclusions

Overall, in the Dafulou ore district, it experiences three mineralization temperature phases, including the low temperature phase (120−150 °C), the medium temperature phase (230−270 °C) and the high temperature phase (350−460 °C). And, the high temperature phase is the dominant mineralization period of Sn-polymetallic mineral in the hydrothermal process, in which several kinds of fluid inclusions form, involving two-phase vapour-rich fluid inclusions, two-phase liquid-rich fluid inclusions and CO_2-rich fluid inclusions.

5.3 Component

In order to find out the composition of the ore-forming fluid, the experiment of ion chromatography and gas chromatography was conducted in the Geology Laboratory of School of Geoscience and Environmental Engineering, Central South University, China. Both the ion chromatograph (type DX−120) and the gas chromatography (Varian−3400) were imported from USA.

It is suggested that water is the main component. For example, the water content of quartz is more than 1700 μg/g, ranging from 1717 to 2320 μg/g. The sphalerite has lower water content than quartz, only 978 μg/g. The calcite is characterized by the lowest water content, 242 μg/g. The gas component of inclusions mainly consists of CO_2 and H_2O. The H_2O contents of inclusion in quartz, sphalerite, calcite range from 1717

Table 2 Microthermometric data for CO_2-rich type inclusions

$\varphi(L_{H_2O})$/%	$\varphi(L_{CO_2})$/%	$\varphi(V_{CO_2})$/%	t_e/°C	t_m/°C	Salinity/% NaCl	$t_h(CO_2)$/°C	$\rho(CO_2)$/(g·cm^{-3})
60	30	10	−57.3	−3.0− −4.0	18.11−18.7	25−26	0.688−0.703
30	30	40	−58.5	−2.0− −3.0	17.3−18.1	12−16	0.158−0.164
30	30	40	−58.5	−1.5− −2.0	17.0−17.4	16−17	1.3−1.5

t_e is the eutectic temperature; t_m is the melting temperature of clathrate to 2320 μg/g, 978 μg/g and 242 to 342 μg/g, respectively. The CO_2 content of quartz exceeds 500 μg/g, ranging from 520 to 660 μg/g. To sphalerite, the content of vapour-CO_2 is only 260.270 μg/g. And the vapour-CO_2 content of calcite is 96.802 to 98.201 μg/g. The other gas content is very low, such as H_2, CH_4, O_2, CO and C_2H_6.

Based on the ion chromatography composition testing, it is suggested that the main cations consist of Ca^{2+}, secondly Mg^{2+}, K^+ and Na^+, only a little of Li^+ and NH_4^+. The mole ratio of Ca^{2+}/Mg^{2+} has a large scale, from 1.281 to 87.906. The Ca^{2+} content of fluid inclusions in quartz exceeds 15 μg/g (18.321, 16.109, 20.658, 18.765, 22.912, 20.123, 18.239, 15.291, 17.627 μg/g), with an average value of 18.672 μg/g. The Ca^{2+} contents of two calcite fluid inclusions are 7.326 and 8.474 μg/g respectively. In the sphalerite, the content of Ca^{2+} is just 6.241 μg/g. Yet, the anion content of SO_4^{2-} ranges from 5.269 to 56.115 μg/g. The calcite has lower content of SO_4^{2-}, only 5.269−5.926 μg/g. The fluid inclusions in quartz have a medium content of SO_4^{2-}, ranging from 8.926 to 24.862 μg/g, with an average value of 16.072 μg/g. Besides the anion SO_4^{2-}, there are many others, such as Cl^-, NO_3^- and a little of F^- and PO_4^{3-}.

6 Discussion

6.1 Role of structural factors

In the Dachang ore field, the general morphology and paragenesis of the veins and their relative complexities at the intersections of two fault systems are the results of certain structural factors, which also control the location of mineralization. The ore No. 0 is controlled strictly by the steeply inclined fracture, which passes through several groups stratums, with the depth of 500 m and the length of 1250 m. The ores Nos. 21 and 22 are also controlled by different levels of fracture. The stratiform type ores always distribute in the interlayer fracture zone, which should be the result of regional tectonism, forming the NW- and NE-trending fault structures. And, the two sets of structures are characterized by the equal interval, which belong to the tectonic product in the same stress field. So, the equidistant fracture site is usually regarded as one of the important prospecting criteria. Based on the on-site survey, the intersections of two fault systems are the important prospecting zone. In the whole, no matter what the vein ore or the stratiform ore, the tectonic activity plays an important role in the period of tin-polymetallic mineralization (see Fig. 5). And there usually exists the cutting between the veins, which indicates the result of the different phases tectonic activity. So, in the Dafulou ore district, both the vein and stratiform ores have a close relation with the tectonism, which controls the scale, occurrence, shape and contacting relationship with the wall rock to some degree. Therefore, it should be one of the important factors for exploration in the depth or periphery, from the view of tectonic ore-controlling.

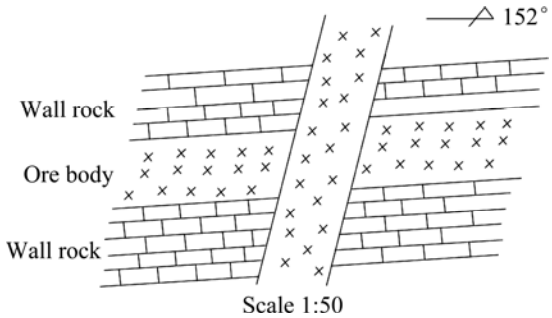

Fig. 5 Tectonic mineralized point of stope Nos. 8−5 for ore body No. 22

6.2 Characteristics of hydrothermal fluids

The temperature and salinity of the samples from the Dafulou ore district were analyzed and calculated. Two-phase vapour-rich fluid inclusions of sample Y05-3 consist of three types of temperatures and salinities: 1) homogenization temperature 120−145 °C, salinity 21.9%−22.44% NaCl, and 2) homogenization temperature 240−265 °C, salinity 19.8%−20.7% NaCl, and 3) homogenization temperature 350−395 °C, salinity 18.9%−20.0% NaCl. The CO_2-rich fluid inclusion has two kinds of homogenization temperatures and salinities: 1) homogenization temperature 380−420 °C, salinity 18.11%−18.7% NaCl, and 2) homogenization temperature 390 to 410 °C, salinity 17.3%−18.1% NaCl. The homogenization temperature of NaCl-bearing fluid inclusion ranges from 280 to 310 °C. Yet, the homogenization temperature of NaCl mineral is higher than 400 °C, with the according salinity 46% NaCl.

The homogenization temperature of sample Y05-3 mainly distributes in three scales, 120−150 °C, 240−270 °C and 350−430 °C. The homogenization temperature of sample Y09-2-1 (two-phase liquid-rich fluid inclusions) ranges from 120 to 145 °C, with the salinity 17.3%−17.6% NaCl. Two-phase liquid-rich fluid inclusions of sample Y29-4 has three homogenization temperatures and salinities: 1) homogenization temperature 230−260 °C, salinity 20.0%−20.3% NaCl, and 2) homogenization temperature 390−420 °C, salinity 19.2%−19.5% NaCl, and 3) homogenization temperature 380−430 °C, salinity 17.2%−17.6% NaCl. Three-phase homogenization temperature of CO_2-rich fluid inclusions ($L_{H_2O}+L_{CO_2}+V_{CO_2}$) of sample Y29-4 ranges from 390 to 410 °C, with the salinity 17.0%−17.4% NaCl. The

NaCl-bearing fluid inclusion ($L_{H_2O}+V_{H_2O}+S_{NaCl}$) has two kinds of homogenization temperatures, 270−290 °C and 130−160 °C, with the salinity 28.95%−30.08% NaCl. So, it is suggested that there are three temperature scales, 130−160 °C, 230−290 °C and 380−450 °C, for sample Y29-4.

All of these show that the different minerals are characterized by the according homogenization temperature and salinity. To quartz and calcite, their average homogenization temperatures are 240−420 °C, 120−145 °C, and their average salinities are 17%−30% NaCl, 17.3%−17.6% NaCl. Overall, the quartz has higher homogenization temperature and salinity than calcite. The homogenization temperature from fluid inclusions of quartz has mainly three scales, 120−160 °C, 220−300 °C and 360−450 °C. The fluid inclusions hydrothermal systems are composed primarily of four types (H_2O−NaCl−$CaCl_2$ system, H_2O−$CaCl_2$ system, H_2O−NaCl−$MgCl_2$ system and H_2O−$MgCl_2$ system) [6].

6.3 Source of ore-forming fluids

The discussion of fluid source is the basic scientific problem to the ore deposit genesis, which can reflect the geodynamic processes and crust-mantle interaction to some degree. About the fluid and ore source of the Dachang ore field, there exist some debates for a long time, which also restricts the theoretical research and the mineral resource exploration. So, based on the analysis of fluid inclusion, the forming pressures of the samples are calculated to be 630×10^5−650×10^5 Pa, 336×10^5−406×10^5 Pa and 120×10^5−150×10^5 Pa, and the according inferred ore-forming depthes are 2.1−2.16 km, 1.12−1.35 km and 0.4−0.5 km, respectively. So, according to the limited data, the ore-forming fluids should be derived from the crust and may be the upper mantle. Recent years, some scholars have got the similar conclusions to the Dachang ore field. CAI et al [34] pointed out that the deep source fluids from the mantle might have participated in the formation of the Tongkeng−Changpo deposit. ZHAO et al [35,36] thought that the ore-forming fluids were likely the mixture of seawater and mantle-derived fluids. LIANG et al [37] thought that there exist the multiple sources of the crust and mantle for the Dachang tin-polymetallic deposit. So, all of them agreed the multiple material sources of the tin-polymetallic ore deposit and the participation of the mantle material or fluid in the period of the mineralization. Likewise, in terms of the Dafulou ore deposit, it is characterized by the similar ore source with the other ore deposits in the Dachang ore field. Overall, in this ore field, the tin-polymetallic ore deposits are the results of the crust-mantle interaction.

7 Conclusions

1) The main hydrothermal alteration types consist of silicification, carbonate, sericite, pyrite and pyrrhotite, among which the silicification is one of the dominant hydrothermal alterations.

2) The mineralization types are composed of stratiform type, interlayer type and stockwork type. The ore textures involve the metasomatic texture, muhedral-subhedral granular texture and solid solution texture, and the ore structure consists of five types, namely, massive structure, dissemination structure, fine veined structure, stockwork structure and brecciated structure.

3) Six types of fluid inclusions were determined, namely, single-phase gaseous fluid inclusions, single-phase salt solution fluid inclusions, two-phase vapour-rich fluid inclusions, two-phase liquid-rich fluid inclusions, three-phase CO_2-rich fluid inclusions and solid(s)-bearing fluid inclusions. Usually, the quartz has higher homogenization temperature and salinity than calcite.

4) There exist three main temperature scopes for the fluid inclusions, 120−150, 230−270, 350−460 °C. But the majority of fluid inclusions form in the high temperature system. The hydrothermal fluid systems are composed primarily of H_2O−NaCl−$CaCl_2$ system, H_2O−$CaCl_2$ system, H_2O−NaCl−$MgCl_2$ system and H_2O−$MgCl_2$ system.

5) The geological structure is one of the dominant factors to the mineralization, and the intersections of two fault systems are relatively the favorable prospecting zone. The ore-forming fluids are characterized by the multiple sources, showing the result from interaction between the crust and mantle.

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广西大厂矿区大福楼锡矿床流体包裹体及成矿作用

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摘 要：通过对大厂矿田大福楼矿床的岩石学、矿物学、构造地质学以及流体包裹体等方面的系统分析，解析矿床地质以及成矿流体特征。结果表明，大福楼矿区主要发育硅化、碳酸盐化、绢云母化、黄铁矿化以及磁黄铁矿化等 5 种围岩蚀变类型，产出有层状、穿层状以及网脉状等矿化类型。矿石结构主要为交代结构、自形−半自形粒状结构、固溶体结构等，矿石构造表现为块状、浸染状、细脉状、网脉状和角砾状等，主要发育有浸染状、致密块状、细脉状和角砾状等多种矿石类型。研究显示，大福楼矿床主要存在 6 种流体包裹体类型，包括单相气相包裹体、单相盐水溶液包裹体、两相富蒸汽包裹体、两相富液体包裹体、三相含 CO_2 包裹体以及富 NaCl 子矿物包裹体，流体形成的主体温度范围为 120~150 °C、230~270 °C 以及 350~460 °C。然而，成矿流体则主要形成于高温环境下，即 350~460 °C。成矿过程中，构造作用至关重要，通常控制着锡矿体的规模、产状以及形态。鉴别出 4 种热液流体类型，包括 $H_2O-NaCl-CaCl_2$ 体系、$H_2O-CaCl_2$ 体系、$H_2O-NaCl-MgCl_2$ 体系以及 $H_2O-MgCl_2$ 体系。与大厂矿田的其他矿床具有相似之处，大福楼矿床也同样具有多种成矿流体来源的特征，总体上属于壳幔联合作用的产物。

关键词：流体包裹体；成矿作用；锡多金属矿床；大福楼；大厂

(Edited by Hua YANG)