Fluid flow and mineralization of Youjiang Basin in the Yunnan-Guizhou-Guangxi area, China

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Abstract Comprehensive studies, based on isotope geochemistry of C, H, O, S and Sr, chronology, common element and trace element geochemistry of fluid inclusions for the epithermal Au, As, Sb and Hg deposits in the Youjiang Basin and its peripheral areas, suggested that the ore fluid was the basin fluid with abundant metallic elements and the large-scale fluid flow of the same source in the late Yenshan stage was responsible for huge epithermal mineralization and silicification. The ore fluid flowed from the basin to the platform between the basin and the platform and migrated from the inter-platform basin to the isolated platform in the Youjiang Basin. The synsedimentary faults and paleokast surface acted respectively as main conduits for vertical and lateral fluid flow.

Keywords: Youjiang Basin, basin fluid, fluid flow, epithermal mineralization.

Fluid flow and fluid interaction with rocks play a key role in the formation and distribution of many large-scale, superlarge-scale stratabound metal ore deposits and oil-gas field, and secondary migration and accumulation in sedimentary basins[1—6]. Episodic flow of basin fluid has been considered as a possible process involved in the generation of MVT lead-zinc mineralizations in North America[7]. The huge epithermal deposits of Au-As-Sb-Hg are distributed in the Youjiang Basin and carbonate platform or highs around the basin, which are located in huge epithermal mineralization areas of southwest China. For these epithermal deposits, geologists put their focus on geology of ore deposit of single ore deposit or species in the past years[8—12]. The fluid flow played a key role in the formation of microdisseminated gold deposits[13,14]. In this paper, the relationship among different epithermal deposits, the large-scale fluid flow and the huge epithermal mineralization will be revealed.

1 Geological setting

The Youjiang Basin located in the southwest margin of Yangtze massif was a rhomb-shaped basin, which developed since Devonian[15]. The Luodian-Ziyun-Nandan fault, Napo-Longzhou fault and Mile-Sizhong-Panxian fault separated the Youjiang Basin from the upper Yangtze carbonate platform (fig. 1). The Youjiang Basin extends along the northwest and is infilled with Devonian-Triassic. Extension and fault depression within the plate resulted in the development of isolated platform and inter-platform basin (fault trough) which alternated during Devonian to Triassic[15,16]. The isolated platform and platform margin are respectively the depositions of supralittoral zone and sublittoral zone carbonate rocks and reef limestone while the inter-platform basin is the deposition of mudstone, silicilith and turbidities. The synsedimentary faults developed between the Youjiang Basin and the carbonate platform, the inter-platform basin and the isolated platform in the basin. The Youjiang Basin is characterized by foreland basin and deposition of marine flysch during middle to late Triassic[16,17].

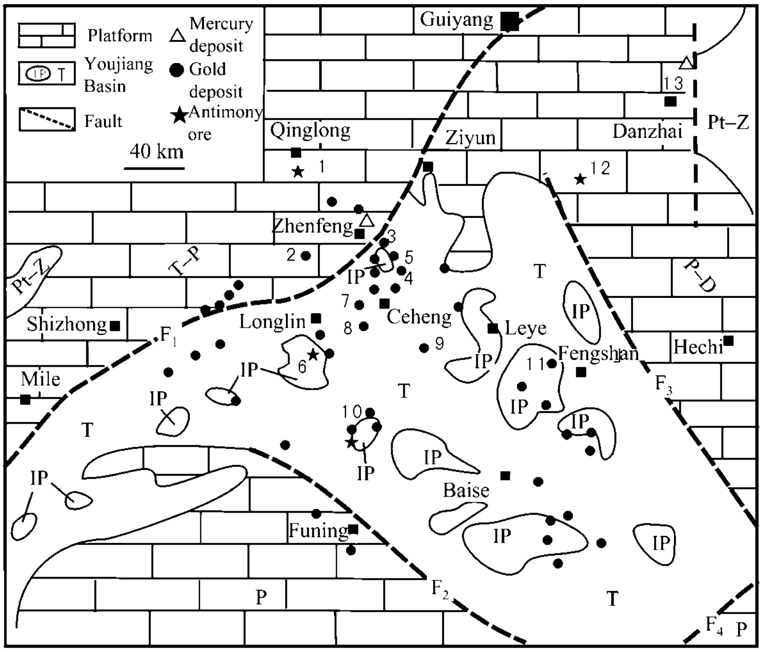

Fig. 1. Simplified geological map. F_1, Mile-Shizhong-Panxian fault; F_2, Napo-Longzhou fault; F_3, Luodian-Ziyun-Nandan fault; F_4, Pingxiang-Dongmen fault. T, Triassic; T-P, Triassic-Permian; P, Permian; P-D, Permian-Devonian; Z-Pt, Sinian-Proterozoic; IP, isolated Platform; 1, Dachang antimony ore; 2, Getang gold deposit; 3, Xingzhai gold deposit; 4, Linlou gold deposit; 5, Lannigou gold deposit; 6, Maxiong antimony ore; 7, Yata gold deposit; 8, Banqi gold deposit; 9, Baidi gold deposit; 10, Gaolong gold deposit; 11, Jinya gold deposit; 12, Dushan antimony ore; 13, Danzhai mercury-gold deposit.

The huge epithermal mineralization of Au-As-Sb-Hg has been identified in the Youjiang Basin and its peripheral areas[18,19]. It has been found that Sb, Hg and As occurred mainly as single ore species but Au was always associated or fractionated with As, Sb and Hg[20]. Most of these epithermal deposits occurred in the carbonate and clastic rocks of Permian-Triassic, and were characterized by stratabound ore, ore-forming temperature was about 200℃ or so. Most of the epithermal deposits occurred in the platform margin slope between the Youjing Basin and the carbonate platform, the isolated platform margins and their slopes in the Youjing Basin (fig. 1). In addition, most of the ore body occurred in the faults and their host rocks were mainly fine clastic rocks. The similar epithermal deposits in both the basin and the platform or the highs around the basin occurred mainly along the layers. For example, the Dachang antimony ore and Getang gold deposit in the platform were distributed along the paleokast surface on the top limestone of the Makou Formation.

The epithermal deposits in the basin were contemporary with that in the platform, the time of the epithermal mineralization has been constrained in the late Yenshan by various dating methods[21—24].

2 Basin fluid and mineralization

The basin fluid was defined as a fluid which infilled sediments pores and flowed inside the basin, and includes internally derived fluids such as formation water and hydrocarbons, and externally derived fluids such as meteoric and metamorphic fluids from the basement[25]. In fact, most of the basin fluids were mixtures of different type fluids.

During the stage of sedimentation, organic matter played a role in adsorbing and compounding the metallic elements and then having the Au, Sb and Hg concentrated in basin-faces fine clastic rocks or source rocks made up of impure carbonate rocks[18]. The hydrocarbon and metallic elements were released out of the source rocks[18] to form the basin fluid with abundant metallic elements during the primary migration of the hydrocarbon. The metallic elements were extracted and enriched further from the strata to form the ore fluid when the secondary migration of the basin fluid took place.

Abundant organic materials distinguished the basin fluid from other derivation fluids. Both ancient oil reservoirs and Au-As-Sb-Hg deposits in the Youjiang Basin and the platform or highs around the basin occurred in the same structural unit or close to each other[18], it showed that there were close genetic connections between the epithermal deposits and ancient oil reservoirs. Rich bitumen and hydrocarbon inclusions in the epithermal deposits and their host rocks[8,10—12,18] showed that the ore fluid was the basin fluid.

Isotope composition of S, C, H and O suggested that the ore fluids belong to the basin fluid also. Comprehensive studies, based on S isotope composition of sulphide ores for micro-disseminated gold deposits (Getang gold deposit, Banqi gold deposit and Yata gold deposit), antimony ores (Maxiong antimony ore, Dushan antimony ore and Dachang antimony ore), and mercury deposits (Danzhai mercury-gold deposit), indicated that δS^{34} ranged from −16.6% to 22.3%[9,24,27] and that sulfur sourced from the sedimentary strata[9,27]. C isotope of all gold deposits except Zimudang gold deposit had a narrow variation range from −3.20‰ to 2.58‰ PDB and most of them were around −1‰—1‰ PDB[24,26]. This was similar to δC^{13} average value of marine carbonate, and indicated that the carbons in the ore fluids derived from the strata of host rocks[27]. H and O isotope composition of the antimony ore and the gold deposits[10,24, 27] was projected on similar areas of formation water in the Albert Basin and the Michigan Basin (fig. 2), implying that the ore fluids belong to the basin fluid.

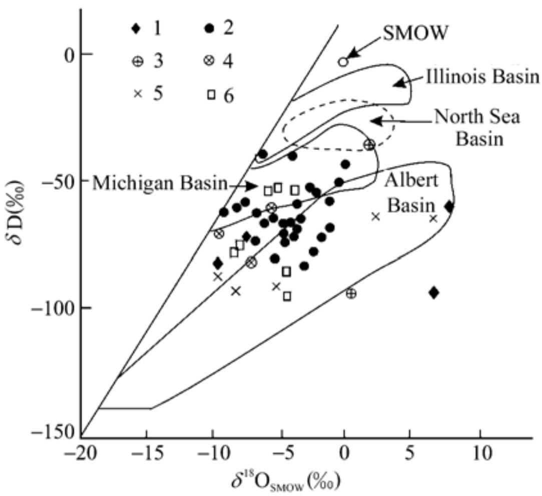

Fig. 2. The δD and δO values of ore fluids for Au, As, Sb, Hg epithermal deposits (background diagram after Shepperd[28]). 1, Maxiong antimony ore[27]; 2, Dusan antimony ore[10]; 3, Dachang antimony ore[27]; 5, Getang gold deposit (this paper); 6,Yata gold deposit[24]; 7, Banqi gold deposit (this paper).

3 Geology and geochemistry track of the basin fluid flow

3.1 Activity of huge fluids

Similar epithermal deposits of Au, As, Sb, Hg have been identified not only in the basin but also in the platform and highs around the basin, and their metallogenetic epoch was constrained mainly in the late Yenshang stage[21—24]. Even though there were some differences in ore species and host rock strata for these epithermal deposits located in the basin and the platform or highs, obvious similarity in host rocks alteration, mineral association, ore fluid and mineralization age indicated that the basin fluid was not constrained by the basin boundary and the fluid flow took place between the basin and platform.

Huge silicification and silicilith zone developed not only in the platform but also in the same strata of the isolated platform. For example, the silification around Qinglong-Getang in the platform along the paleokast surface between P_1 and P_2 developed a silification zone of a length of 70 km in longitude and a width of 20 km in latitude. Similar silicification has been recognized in the platform around the eastern side of the basin in the same strata. Strong silicification developed along the unconformity surface between P_1/P_2 and T_2/P_2 resulted in a ring silicification zone within the isolated platform such as Baiceng, Pinglao and Laizishan. Some times, the epithermal deposits are always associated with these silicification zones.

In the platform around the eastern and western sides of the basin, the silicification intensity decreased gradually from the basin to the platform. This implies that lateral fluid flow from the basin to the platform was responsible for the silicification around the basin peripheral areas.

The huge low-temperature fluid activity zone, which consisted of the huge silicification zone and the epitherthmal deposits or ore spots, showed that huge fluid activity and fluid migration had taken place, thus resulting in the large-scale epithermal mineralization in the late Yenshang stage.

3.2 Sr isotope data

Some representative epithermal deposits from the basin and the platform such as Lannigou gold deposit, Jinya gold deposit, Dachang antimony ore and Danzhai gold deposit, have been chosen to study their Sr isotope. ^{87}Rb attenuation and ^{87}Sr accumulated effects need to be taken into account because these epithermal deposits mainly formed in the late Yenshang stage[21—24], initial $(^{87}Sr/^{86}Sr)_i$ values of ore fluids are listed in table 1 after Sr isotope values of all samples were calibrated as Lannigou gold deposit forming age of 106 Ma[22]. The Sr isotope values of pyrite-arsenopyrite inclusion, host rocks of siltstone and mudstone from Jinya gold deposit in table 1 were an average value of 9 and 7 samples, respectively.

Table 1 Sr isotope data of the ore fluids and host rocks for the epithermal deposits from the platform and the basin

	Location and name of deposit	Time of host rocks	Types of the sample	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$(^{87}Sr/^{86}Sr)_i$	Reference
Youjiang Basin	Lannigou gold deposit	T_2	inclusions of quartz	0.1034	0.71051	0.7104	this paper
				0.2276	0.70176	0.7103	
				0.2543	0.71054	0.7102	
				0.8402	0.71127	0.7100	
				0.6624	0.71132	0.7103	
			calcite	0.2882	0.71078	0.7108	
	Jinya gold deposit	T_2	inclusions of pyrite-arsenopyrite	0.3661	0.71078	0.7100	[29]
			siltstone and mudstone	1.4895	0.71460	0.7124	[29]
Platform	Dachang antimony ore	P_2	fluorite		0.71038		[31]
			fluorite		0.70829		
			limestone		0.70733		
	Danzhai mercury-gold deposit		ore			0.7108	[30]

The $(^{87}Sr/^{86}Sr)_i$ average of the ore fluid for the Lanigou gold deposit was 0.7102, which is similar to that for the Jinya gold deposit and the Danzhai mercury-gold deposit (table 1), similarity of the Sr isotope indicated that the ore fluids of these deposits from the basin were cogenetic with that of those deposits from the platform. The $(^{87}Sr/^{86}Sr)_i$ of the ore fluid for the Jinya gold was much different from that of its host rocks (table 1), hence, the ore fluid was an introduced fluid and migrated from source to nowadays site where they deposited. An introduced fluid and fluid flow can also be suggested for the Dachang antimony ore by difference of the $^{87}Sr/^{86}Sr$ between the fluid inclusions of fluorite and the host rocks of limestone (table 1).

3.3 REE distributed pattern of the fluid inclusions

The analysis method in ref. [32] was employed to define the REE contents in the quartz fluid inclusions. Some representative samples from the basin such as Xingzhai gold deposit, Linlou gold deposit and Lannigou gold deposit, and from highs around the basin such as Danzhai mercury-gold deposit, were analyzed and results are listed in table 2. The REE distributed pattern of fluid inclusions showed the characteristics of enriched LREE, depleted HREE and obvious fractionation between LREE and HREE (fig. 3). Similarity of REE distributed patterns indicated that the deposits from both the basin and highs around the basin have the same ore fluid source, and the fluid flow or fluid exchange between the basin and the platform can be suggested.

Table 2 REE contents of fluid inclusions ($\times 10^{-6}$)

Sample No.	Name of deposit	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Yb	Lu
N9250	Lanigou gold deposit	41.556	30.540	27.066	22.738	13.002	6.849	4.655	1.995	1.417	1.843	1.729	1.231	1.348
XZ-04	Xingzhai gold deposit	7.392	6.700	4.876	3.099	2.137	1.233	0.846	0.922	1.533	0.684	0.933	1.439	1.471
WL-02	Linlou gold deposit	5.930	4.786	3.977	3.827	2.608	1.612	1.574	1.280	1.438	0.754	1.072	1.218	1.000
DP-03	Danzhai gold deposit	18.820	11.055	10.195	7.265	4.690	2.927	1.852	1.515	1.481	0.804	1.168	0.945	1.508

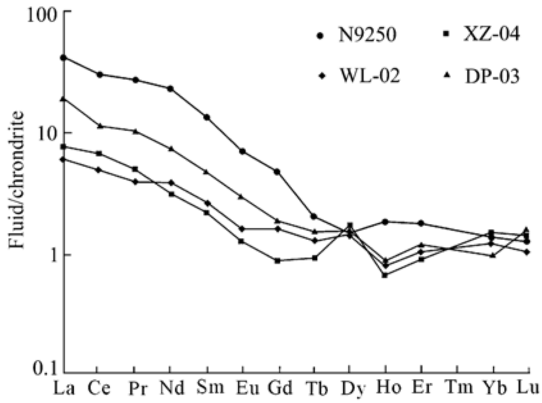

Fig. 3. The REE distributed pattern of the fluid inclusions. DP-03, Danzhai mercury-gold deposit; XZ04, Xingzhai gold deposit; WL-02, Linlou gold deposit; N9250, Lannigou gold deposit.

3.4 Composition of fluid inclusions

Composition of fluid inclusion can be defined as positive and negative ion concentration in fluid inclusion solution. Atomic absorption spectrometry and luminosity analysis have been employed to define the ion concentration in the solution of quartz inclusions, which can be collected by way of thermal fracture and ultrasonic extraction. Some representative epithermal deposits from the basin and the platform have been sampled for the composition of the fluid inclusion (fig. 4). Although the ion concentrations of the ore fluid for all deposits even the same ore species varied widely, the characteristic composition ration of the ore fluids had a narrow variation range (more details will be given in another paper). Although these deposits occurred in different locations of the basin and platform, there was a linear correlation between positive and negative ion composition of the ore fluids (fig. 4), fluid flow of the same source was one of possible reasons for the linear correlation.

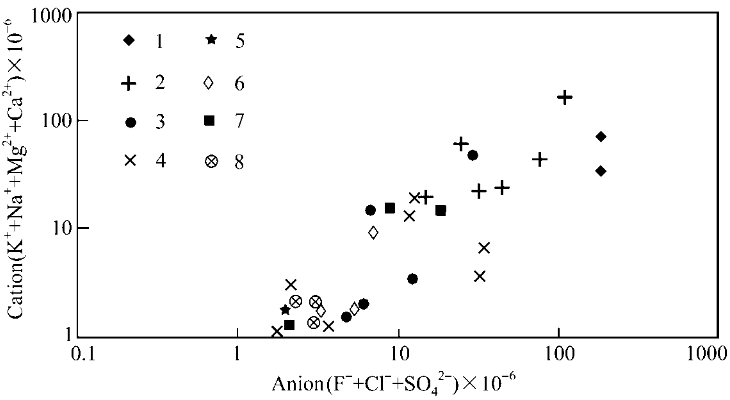

Fig. 4. Diagram of the fluid inclusion composition. 1, Danzhai mercury-gold deposit; 2, Dachang antimony ore; 3, Baidi gold deposit; 4, Yata gold deposit (this paper and [24]); 5, Getang gold deposit (this paper); 6, Zhimudang gold deposit; 7, Banqi gold deposit (this paper); 8, Lannigou gold deposit. Refs. [1—3,6,8] after Zhu Laimin1).

In a word, Sr isotope, REE and characteristic composition ration of common elements revealed that the ore fluid of the epithermal deposits from the basin was similar to that from the platform and both of them derived from the same source. The fluid flow between the basin and the platform will be responsible for similarity of Sr isotope and composition of the ore fluid, huge epithermal mineralization and the silicification.

1) Zhu Laimin, Elements association and fractionation mechanism in epithermal metal mineralization areas of southwest Yangtze massif, Postdoctor report, 1998.

4 Flow path and model of the basin fluid

4.1 Fluid flow between the basin and the platform

Biomarks are characteristic organic compounds, which are relatively stable during diagnesis, secondary alteration and migration, and can reflect the primitive organism character of parent source[33]. There are different sources for organic matter conserved in sediments, the same biomarks can be found only in the organic matters from the same source. Hence, biomarks as fingerprinting fossil such as isoprenoid alkane, triterpane and sterane have been widely used to track the source and migration path of oil and gas in the study of petroleum geology[34,35]. The epithermal deposits of Au, As, Sb, Hg were cogenetic with oil and were accumulated with oil[18], hence, we can make use of biomarks to track the migration path of the ore fluids. Abundant hydrocarbons in the ore, host rocks and the fluid inclusions of the epithermal deposits make it possible to trace migration path of the ore fluid.

The biomarks such as carbon member distribution and main carbon peak of isoprenoid hydrocarbons and the trinorhopane ration in terpanes which reflect the source of material or sterane parameters which reflect the extent of thermal alteration of organic matter in extract of bitumen from fluorite of the Dachang antimony ore in the platform, are similar to that in the extract of kerogene (pyroclastic rocks) from the Permian Linghao Formation in the Youjiang Basin[18] (table 3).

Table 3 Biomarks in the extract of kerogene from the basin and bitumen from the ore in the platform[11]

Organic matter type	Content of extract (%)	Normal alkane			Alkyl cyclic hexane		Isoprenoid alkane			Pentacyclic triterpane			Sterane	
		carbon No. and range	main peak carbon	OEP	carbon No. and range	main peak carbon	carbon No. and range	main peak carbon	Pr/Ph	Tm/Ts	22R/(22S+22R) αβ-C_{31}	20S/(20S+20R) αβ-C_{27}	ααα-C_{28}/ααα-C_{29}	ααα-C_{27}/ααα-C_{29}
Bitumen from the fluorite	>0.01	C_{16}—C_{35} Double peak	C_{17}—C_{18} C_{25}—C_{29}	0.8117	single peak	C_{24}	single peak	C_{20}	0.5—0.61	2.712	0.403	≈ 0.52	0.4438	0.6012
Kerogene of pyroclastic rocks from Linghao Formation in the basin	0.0047—0.0057	C_{14}—C_{32} double peak	C_{17} C_{25}—C_{30}	weak odd carbon number predominate	single peak	C_{17}	single peak	C_{19}	1.02—1.16	2.174	0.447	≈ 0.54	0.4242	0.4118

There are three geochemically abnormal horizons in southwest Yangtze massif: Lower Cambrian, Upper Devonian and Upper Permian Linghao Formation[36]. The content of Sb in the Linghao Formation was (0.8—6.3) × 10^{-6} and 1—5 times higher than that in overlying and underlying strata[11], so, the Linghao Formation was one of important source beds.

The similarity of the biomarks, source bed cognate with source rocks[18] and high metallic elements background value in the Linghao Formation[11] suggested that the ore fluids and the source bed of the Dachang antimony ore originated from Linghao Formation in the Youjiang Basin, and the basin fluid migrated from the basin to the platform. The ore fluid derived from the Youjiang Basin laterally migrated from the basin to the platform at least 50 km according to the fluid source and distance between the Dachang antimony ore and west boundary of the basin.

The facts that the ore fluid in both the basin and the platform have the same fluid source and the ore fluid in the platform derived from the basin, supported that the large-scale fluids flow from the basin to the platform had taken place. The fluids lateral migrated along the paleokast surface acted as main conduits and triggered off widespread silification and mineralization.

4.2 Fluid flow in the basin

Most of the epithermal deposits in the basin occurred around the isolated-platform or inside the isolated-platform, which indicated that fluid tended to accumulate around these sites. The synsedimentary faults always developed around the isolated-platform and acted as very important conduits for vertical flow of the ore fluids when they mobilized during successive deformation. Paleo-buried hills and drape structure tended to develop in the isolated platform according to the basin tectonic and sedimentary evolution history. Paleokastification and other lithogenesis resulted in development of abundant dissolution pores and secondary pores during development of paleo-buried hills, a great number of pores was helpful to the fluid flow and the drape structure provided an important structure trap for the fluid afflux. This is one of important reasons why the fluids tended to accumulate in the isolated platform and its peripheral areas. Hence, the fluids flowed from the inter-platform basin to the isolated platform in the basin, the paleokast surface and the unconformity surface acted as very important conduits for the fluid lateral migration when the fluids were introduced into the isolated platform.

4.3 Model of the fluid flow

The fluids tended to flow from the center to the margin of the basin due to the reduction of gravity potential[2,6]. The large-scale lateral flow of the fluids from the basin to the platform had taken place. Regional faults developed between the basin and the platform, a great number of epithermal deposits occurred in the basin side close to fault upside, it implies that the regional faults prevented the fluid from lateral migration to some extent. The fluid flow path was changed from lateral to vertical along the regional fault zone when the fluids penetrated into the regional fault, otherwise, strong silicification, carbonation and mineralization along faults could not be observed. If pressure of upward fluids was lower than that of downward groundwater, or the fluids were blocked by fault plug-back, the upward fluids were introduced into the platform along the paleokast surface or the unconformity surface, on which the large-scale fluids flow and mineralization took place; the Dachang antimony ore discussed above was an excellent example of fluid lateral flow along the paleokast surface. In the basin, when fluids migrated upward along the reactivated synsedimentary faults around the isolated platform and met the paleokast surface or the unconformity surface, lateral flow would take place in the isolated platform (fig. 5). In a word, the large-scale fluid flow played a very important role in the huge epithermal mineralization.

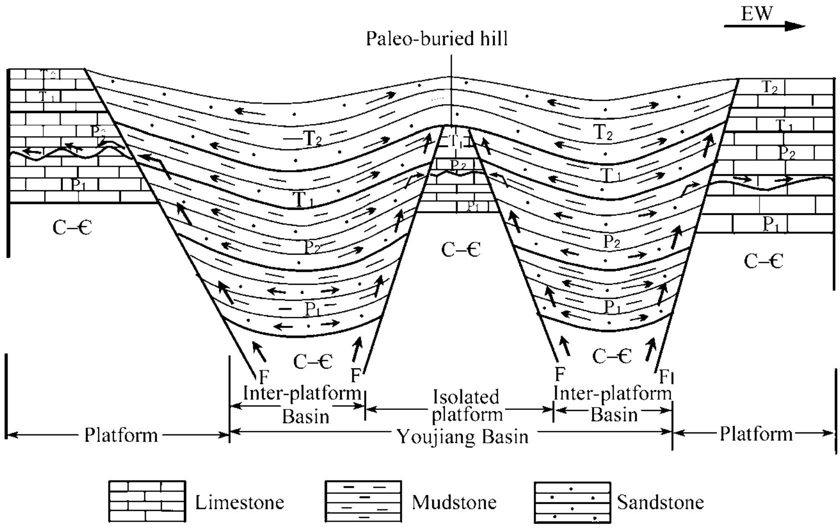

Fig. 5. Flow model of the basin fluid. F, Fault; T_2, middle Triassic; T_1, upper Triassic; P_2, upper Permian; P_1, lower Permian; C—Є, Carboniferous-Cambrian. The arrow indicates the direction of fluid flow.

5 Conclusion

The ore fluids of Au-As-Sb-Hg deposits from the Youjiang Basin and platform belong to basin fluid with abundant metallic elements, and they derived from the same source.

The vertical and lateral flow of the ore fluids along the synsedimentary faults and paleokast surface had taken place. The ore fluids flowed laterally on a large scale from the basin to the platform between the basin and the platform while they flowed from the inter-platform basin to the isolated platform.

The large-scale fluid flow was responsible for huge epithermal mineralization.

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