

# **Zircon U-Pb and Molybdenite Re-Os Dating of Gangjiang Porphyry Cu-Mo Deposit in Nimu Ore Belt, Southern Tibet, China and Its Geological Significance**

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**Keywords:** zircon U-Pb; molybdenite Re-Os dating; Nimu Ore Belt; Gangjiang Porphyry Cu-Mo Deposit; geological Significance

**Abstract.** In order to determine the ages of magmatism and mineralization, and thus to disentangle the complicated magmatic evolution and the relationship between magmatic process and copper-molybdenum mineralization, the authors carried out a study of LA-ICP-MS zircon U-Pb dating of monzonite granite porphyry, granodiorite porphyry, quartz-mica diorite porphyrite in Gangjiang porphyry Cu-Mo deposit, corresponding with zircon U-Pb ages of  $16.6 \pm 0.3$  Ma,  $16.1 \pm 0.2$  Ma, and  $14.4 \pm 0.4$  Ma. Meanwhile, twelve molybdenite samples separated from quartz sulfides veins in Gangjiang copper orebodies were used for Re-Os dating; the model ages obtained range from  $13.24 \pm 0.20$  Ma to  $13.55 \pm 0.22$  Ma, with weighted average  $13.4 \pm 0.1$  Ma and isochron age  $13.6 \pm 1.6$  Ma. To combine our study results, field geological survey and previous research data, it is proposed that the intrusion sequence is ore-bearing monzonite granite porphyry → granodiorite porphyry → rhyolite porphyry (depth named as quartz-mica diorite porphyrite), the porphyry intrusion occurred range from 16.6 Ma to 14.4 Ma, and the mineralization age of Gangjiang porphyry Cu-Mo deposit is about 13.4 Ma, so the porphyritic granodiorite could responsible for the mineralization and related alteration. Diagenesis and mineralization is a continuous process of magmatic evolution. Gangjiang porphyry Cu-Mo deposit was formed in post-collisional extension setting of India-Asia continental collision orogenic belt during the Miocene.

## **1. Introduction**

The Gangjiang porphyry Cu-Mo deposit is one of the deposits in Nimu ore belt and located in the middle of the Gangdise metallogenic belt, Southern Tibet, China. The Nimu copper molybdenum ore belt is consisted of Tinggong copper-molybdenum deposit, Chongjiang copper-molybdenum deposit, Bairong copper-molybdenum deposit and several copper-molybdenum mineral prospects.

The Gangjiang deposit is discovered during the 1 : 1 million and 1 : 200,000 regional soil geochemical survey in the 1980s, and then the Geological Survey of Tibet conducted following detail geochemical survey to confirm the economic potential of the deposit. However, due to harsh environment and poor access to working area, the degree of deposit research is relatively low. the Gangjiang deposit had not been neither well explored and studied in early time. After the Yunnan Copper Group Lhasa Tianli Company and Sichuan Metallurgical and Geological Exploration Institute involving into the exploration in the area, relevant study was carried out. Based on field observation and analyzing the ages of intrusions, including monzonite granite porphyry, porphyritic quartz-mica diorite and porphyritic granodiorite and related ores with LA-ICP-MS (Laser Ablation Multicollector inductively Coupled Plasma Mass Spectrometry) zircon U-Pb dating and molybdenite Re-Os method, the study aim to understand the complicated magmatic history, ore forming process and source of metals; Moreover, to research-temporal evolution and spatial

distribution of the same type of ore deposits in the area will help to establish intrusions and ore-forming age framework of Gangdise metallogenic belt at post-collisional extension stage the and gives a brief overview of metallogenetic dynamics of the deposit.

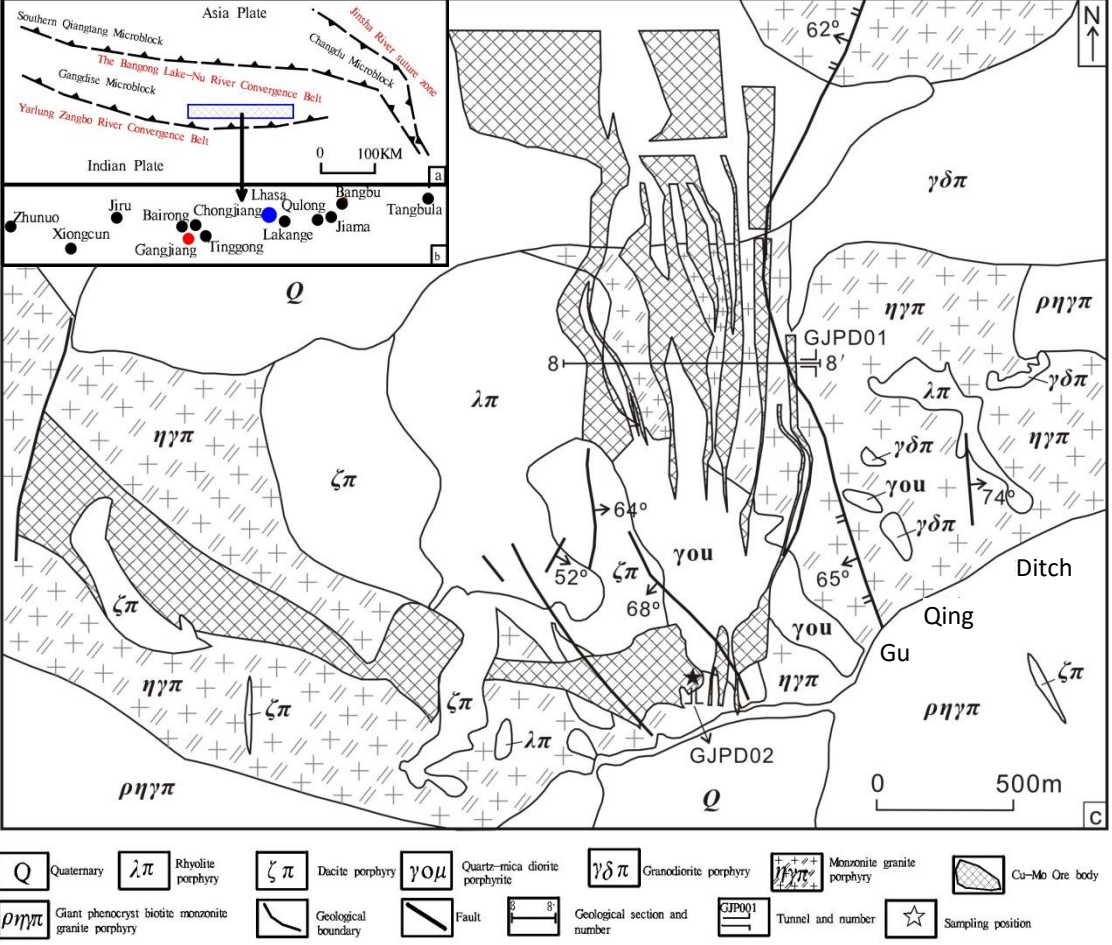


Fig.1 Tectonic location of the Gangdese metallogenetic belt ( a ) , the distribution of main porphyry deposits ( b ) , geological sketch of Gangjiang mining area ( c )<sup>[1][2][3]</sup>

## 2. LA-ICP-MS Zircon U-Pb Dating

**2.1 Sample Description.** The samples used for zircon U-Pb dating were collected from the drill core in the Gangjiang deposit. The sample includes fresh monzonite granite porphyry, eight granodiorite porphyry, and nine quartz-mica diorite porphyrite examples. The petrographic characteristics of the three types of rocks are as follows: ①monzonite granite porphyry (No. A5508-1) is light gray with massive and porphyritic structure (Fig. 2a, d). ②The granodiorite porphyry (No. A5508-2) is dark gray with massive and multi-plaque structure (Figure 2b, e). (Fig. 2c, f). ③The quartz-mica diorite porphyrite (No. A5508-3) is gray - gray and dark gray with massive and, porphyritic structure (Fig. 2C, f).

Table1 the collection location list of zircon U-Pb dating sample in Gangjiang copper-molybdenum deposit

Monzonite granite porphyry ( 8 in total )		Granodiorite porphyry ( 8 in total )		Quartz-mica diorite porphyrite ( 8 in total )	
ZKW0800-410m	ZK2411-512m	DZK1201-431m	QZK301-520m	ZK1604-425m	ZK2006-430m
ZK2411-512m	ZK807-140m	ZKN812-424m	BZK1514-425m	ZK802-81m	GJ18-84m
ZK2003-25m	ZK805-97m	ZK807-111m	ZK807-133m	ZK805-77m	GJ21-22m
ZK803-120m	ZK807-114m	ZK1204-102m	ZK1204-115m	ZK2005-49m	GJ15-95m
				ZK1204-119m	

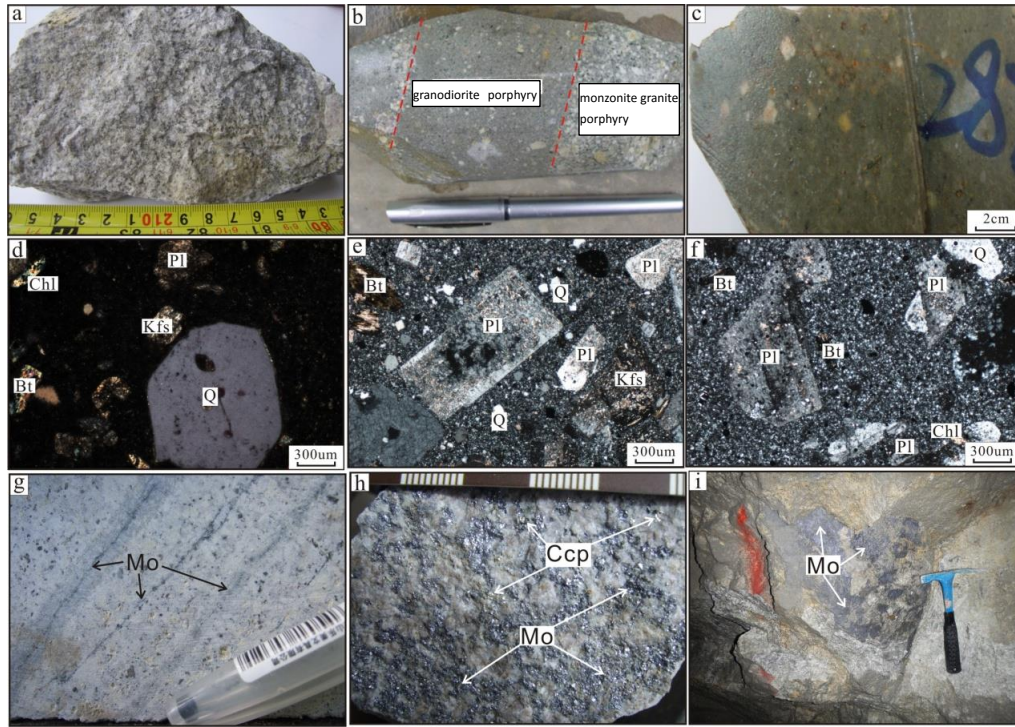


Fig.2 Photographs of hand specimens (a, b, c, g, h, i) and outcrops of Gangjiang copper-molybdenum deposit; Photomicrographs of samples from Gangjiang copper-molybdenum deposit(a.sample of the monzonite granite porphyry; b.sample of the granodiorite porphyry; c. sample of the quartz-mica diorite porphyrite; d. micrograph of the monzonite granite porphyry; e. Micrograph of granodiorite porphyry; f. Micrograph of the quartz-mica diorite porphyrite; g. Fine vein molybdenite mineralization; h Fine vein-like molybdenum mineralization cross section; i.Mine sampling location. Minerals Abbreviations: Bt.Biotite; Chl.Chlorite; Kfs.Potassium feldspar;Pl. Plagioclase; Q.Quartz; Ccp. Chalcopyrite; Mo. Molybdenite)

**2.2 Analytical Method.** Sample crushing, zircon sorting, cathode uminescence (CL) imaging were completed in Langfang, Hebei Province Institute of Geology and Mineral Resources Research Laboratory. Laser ablation LA-ICP-MS zircon U-Pb isotope analysis was carried out in the Australian Mineral Laboratory, and the analytical principles and procedures are described in the literature [4][5][6]. The analysis instrumentations were a HR ICP-MS mass spectrometer and a New Wave Research excimer laser ablation system. International standard zircon 91500 was used as a reference standard for calibration and controlling the conditions of analytical instrumentation the United States National Bureau of Standards Bureau of synthetic silicate glass NIST SRM610 was applied as external standard.  $^{29}\text{Si}$  was used as the internal standard for alibration of data. The elemental and isotopic ratios and age calculations for zircons were performed at ICPMS DataCal [7]. Zircon U-Pb harmonic plot and weighted mean age calculations were performed on the ISOPLLOT software [8][9].

**2.3 Zircon U-Pb Dating Results.** Eleven analyses were carried out on the zircon grains from monzonite granite porphyry. A total of fifteen analyses were conducted on twelve zircon from granodiorite porphyry. Thirteen analyses were completed in ten zircon from quartz diorite. The zircon U-Pb isotope test results are shown in Table 2. The zircon cathode luminescence (CL) images and measured point with corresponding  $^{206}\text{Pb} / ^{238}\text{U}$  ages are shown in Fig. 3. The Zircon  $^{207}\text{Pb} / ^{235}\text{U}$ - $^{206}\text{Pb} / ^{238}\text{U}$  harmonic diagram shown in Figure 4.

The  $^{206}\text{Pb} / ^{238}\text{U}$  ages of the monzonite granite porphyry (A5508-1) can be divided into three groups: old, middle and young. The maximum age of point 4.1 is 32.4Ma, The nucleus is the core of inheriting magmatic nucleus, and the shape is round, the color is deeper than the edge, and the edge of zircon is ambiguous, which could reflect remelting. Points 2.1, 5.1 and 10.1 give ages of

20.2Ma, 20.0Ma and 20.0Ma respectively, and the projection points were obviously deviated from the concordia curve. 8.1 point shot on the edge of zircon grain and the result shows strong contamination so it should not be used on weighted average calculation. The rest of analyses points are located on the concordia and nearby,, and have ages range from 17.9 to 15.1Ma Basically no lead loss or gain has been identified, then U-Pb system should remain closed <sup>[10]</sup>, The weighted mean age of zircon <sup>206</sup>Pb / <sup>238</sup>U data is  $16.6 \pm 0.3\text{Ma}$ (MSWD = 0.94),.

The ages of the granodiorite porphyry (A5508-2) are obviously older than the others two units (6.18), and the projection is located on the concordia curve (8.2 and 10.1). The weighted mean age of zircon <sup>206</sup>Pb / <sup>238</sup>U data from granodiorite porphyry is  $16.1 \pm 0.2\text{Ma}$ , MSWD = 1.07.

The ages of quartz-mica diorite (analysis points 2.1, 3.1, 3.2, 4.1, 5.1 and 8.1) were significantly older than other ages from quartz-mica diorite, so these ages are consider nvalid data (Table 3).The ages from seven other effective analysis points values varied from 16.3 to 13.1Ma, and calculated the weighted average age is  $14.4 \pm 0.4\text{Ma}$  ( MSWD=1.12).

Table 2 LA-ICP-MS zircon U-Pb dating results of rocks in Gangjiang copper-molybdenum deposit

Testing points	Isotope ratio						Age (Ma)	
	<sup>207</sup> Pb/ <sup>206</sup> Pb	±%	<sup>207</sup> Pb/ <sup>235</sup> U	±%	<sup>206</sup> Pb/ <sup>238</sup> U	±%	<sup>206</sup> Pb/ <sup>238</sup> U	±1σ
A5508-1 (Monzonite granite porphyry)								
1.1	0.0556	18.53	0.0170	16.12	0.0023	11.91	15.1	1.6
1.2	0.0613	48.51	0.0216	56.52	0.0026	18.12	16.7	0.2
2.1	0.0964	69.04	0.0395	72.72	0.0031	29.09	20.2	1.2
2.2	0.1270	73.80	0.0410	92.32	0.0026	14.60	16.4	0.3
3.1	0.0573	34.65	0.0199	31.77	0.0028	34.06	17.8	1.1
4.1	0.0513	18.03	0.0333	23.00	0.0050	17.96	32.4	2.0
5.1	0.1379	39.88	0.0570	36.88	0.0031	20.14	20.0	1.3
5.2	0.0581	36.35	0.0192	35.71	0.0025	13.39	15.9	0.7
6.1	0.0684	47.13	0.0242	53.65	0.0027	31.89	17.1	0.4
7.1	0.1499	47.62	0.0566	54.85	0.0028	11.81	17.9	1.2
8.1	0.1036	46.09	0.0396	54.65	0.0029	25.36	18.4	1.7
8.2	0.0502	30.84	0.0163	30.06	0.0025	19.64	16.2	0.5
9.1	0.0633	44.20	0.0215	50.43	0.0025	18.89	16.2	0.5
10.1	0.1933	57.63	0.0897	94.92	0.0031	28.31	20.0	1.4
11.1	0.0484	39.74	0.0162	40.86	0.0025	11.75	16.1	0.6
A5508-2 (Granodiorite porphyry)								
1.1	0.0559	31.52	0.0197	29.17	0.0026	21.33	16.9	0.7
2.1	0.0665	61.17	0.0247	73.83	0.0026	13.62	16.9	0.8
3.1	0.0638	15.21	0.0190	24.30	0.0023	26.64	14.9	1.2
4.1	0.0545	27.50	0.0188	29.95	0.0026	14.88	16.7	0.4
5.1	0.0653	42.44	0.0226	50.15	0.0025	20.35	16.0	0.2
5.2	0.0643	51.95	0.0235	52.82	0.0027	15.37	17.2	1.1
6.1	0.0538	26.90	0.0239	23.02	0.0034	21.31	21.8	1.2
7.1	0.0519	38.19	0.0169	39.80	0.0024	24.69	15.6	0.6
8.1	0.0765	60.94	0.0256	49.16	0.0026	24.19	16.6	0.5
8.2	0.0939	31.28	0.03161	31.92	0.0026	30.23	17.1	1.0
9.1	0.0718	17.57	0.0202	18.57	0.0022	10.10	14.2	1.9
10.1	0.0951	44.87	0.0356	47.26	0.0028	22.77	17.8	1.5
10.2	0.0645	20.73	0.0207	16.25	0.0025	13.34	16.0	0.2
11.1	0.0683	33.06	0.0204	30.32	0.0023	14.77	15.0	1.1
12.1	0.0552	23.83	0.0168	22.83	0.0024	15.99	15.3	0.8
A5508-3 (Quartz-mica diorite porphyrite)								
1.1	0.0859	62.46	0.0274	72.79	0.0024	12.68	15.1	0.2



Testing points	Isotope ratio						Age (Ma)	
	$^{207}\text{Pb}/^{206}\text{Pb}$	$\pm\%$	$^{207}\text{Pb}/^{235}\text{U}$	$\pm\%$	$^{206}\text{Pb}/^{238}\text{U}$	$\pm\%$	$^{206}\text{Pb}/^{238}\text{U}$	$\pm 1\sigma$
2.1	0.1666	37.31	0.0534	42.55	0.0024	21.51	15.7	0.6
3.1	0.3632	51.42	0.1996	70.10	0.0040	29.38	25.7	1.5
3.2	0.2339	53.81	0.1121	90.62	0.0032	32.24	20.5	0.9
4.1	0.1393	82.71	0.0675	159.91	0.0025	61.90	16.2	1.0
4.2	0.1322	36.19	0.0424	56.54	0.0023	22.53	14.9	0.2
5.1	0.1653	81.51	0.0573	66.78	0.0026	23.67	16.9	1.7
6.1	0.0853	21.70	0.0241	25.85	0.0021	18.17	13.6	1.6
7.1	0.1401	46.11	0.0470	54.41	0.0025	24.08	16.3	1.3
7.2	0.0946	37.37	0.0265	44.30	0.0021	15.04	13.3	1.6
8.1	0.1901	77.91	0.0836	122.76	0.0027	40.34	17.1	1.9
9.1	0.0630	17.54	0.0183	24.82	0.0020	12.10	13.1	2.0
10.1	0.1039	40.96	0.0309	38.48	0.0022	12.53	14.2	0.8

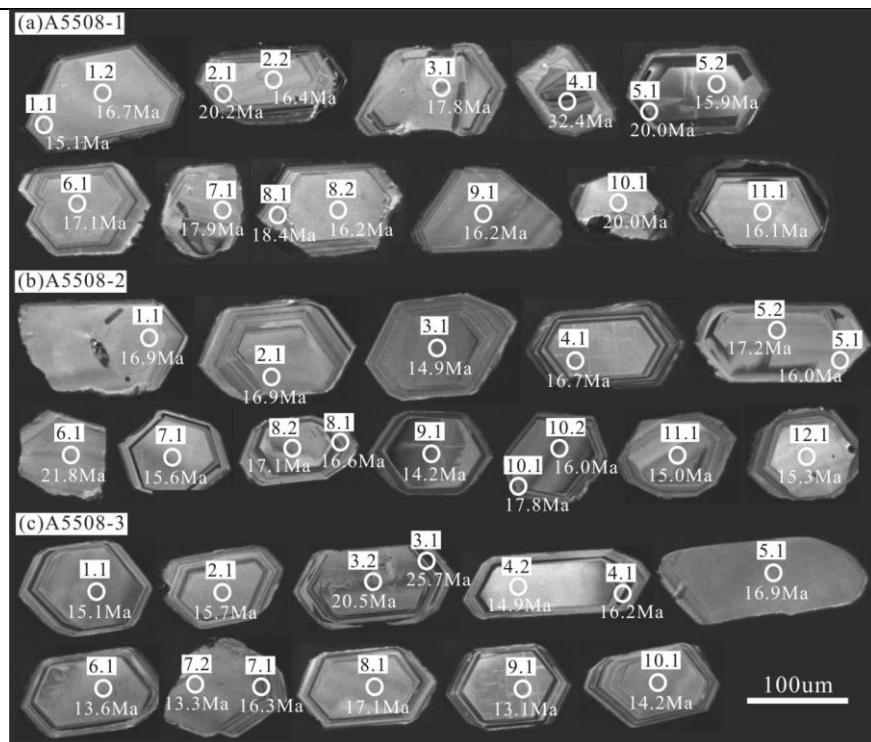


Fig. 3 CL images of zircons from monzogranite (a), granodiorite (b) and tonolity (c) in Gangjiang copper-molybdenum deposit

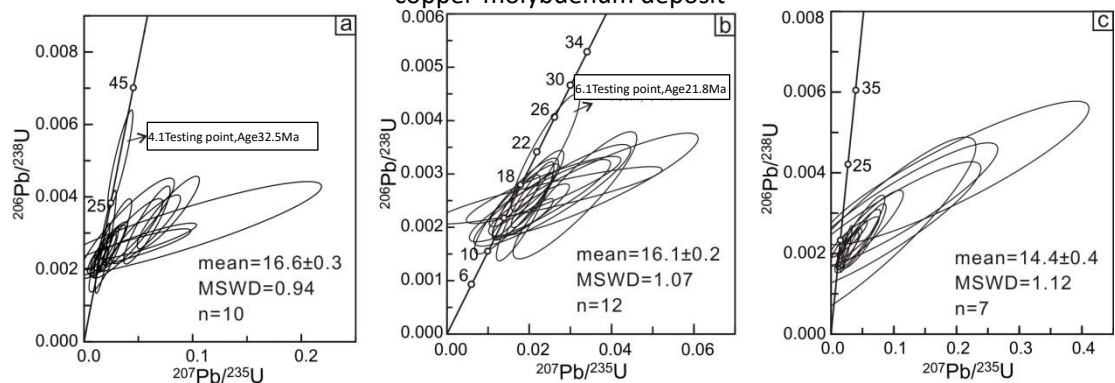


Fig. 4 Zircon U-Pb concordia diagram from monzogranite (a), granodiorite (b) and tonolity (c) in Gangjiang copper-molybdenum deposit

### 3. Molybdenite Re-Os isotope Dating

**3.1 Sample Collection and Testing.** Twelve molybdenite samples were collected from a location 101m of the GJPD02 tunnel (Fig. 1, Fig. 3i). The sample numbers are BSPD2-03-1 ~ BSPD2-03-12. Those molybdenite samples are hosted in the veinlets of two feldspar porphyritic granite, Notably, there is disseminated chalcopyrite distributed around the molybdenite veins (Fig. 2g, h).

The molybdenite Re-Os isotope analysis of was completed by the National Geological Experimental Test Center, China. The molybdenite samples with purity of 99% are obtained by manual selection, grinding and microscopic removal. The samples are decomposed by Carius tube, The isotope ratios of Re and Os were determined by inductively coupled plasma mass spectrometry (TJA X-series ICP-MS). The Re level of JDC was  $0.00021 \pm 0.0002$  ng / g,  $0.00010 \pm 0.00002$  ng / g and  $0.00021 \pm 0.00006$  ng / g for Os and  $^{187}\text{Os}$ , and the Re content of the standard sample JDC was  $(17.22 \pm 0.14)$  ug / g and the Os content was  $(25.23 \pm 0.17)$  ng / g, which were consistent with the recommended values, which confirmed that the age data obtained in this study were accurate and reliable. The model age  $t$  can be calculated from the content of  $^{187}\text{Re}$  and  $^{187}\text{Os}$ . The formula is:  $t = [\ln (1 + ^{187}\text{Os} / ^{187}\text{Re})] / \lambda$ , where  $\lambda$  ( $^{187}\text{Re}$  decay constant) =  $1.666 \times 10^{-11}$  a $^{-1}$ .

**3.2 Molybdenite Re-Os Analysis Results.** The Re-Os isotopic result of twelve molybdenite samples from Gangjiang porphyry copper-molybdenum deposit are shown in Table 3. The general Os content in molybdenite is very low and tends to 0, indicating that the  $^{187}\text{Os}$  are almost completely decayed from  $^{187}\text{Re}$ , which is in accordance with the Re-Os isotope system model age. The change of the content of Re in molybdenite  $(155.4 + 1.1)$  ug/g ~  $(171.1 + 1.5)$  ug/g, average 162.9ug/g,  $^{187}\text{Re}$  content is coordinated with the change of  $^{187}\text{Os}$  content.

The ages range from  $13.2 \pm 0.20$ Ma to  $13.55 \pm 0.22$ Ma, and the weighted average age is  $13.4 \pm 0.1$  Ma (MSWD = 0.65) (Fig.5b). Using the ISOPLOT software of the twelve groups of isochron age data fitting [8],the testing obtain a better  $^{187}\text{Re}$ - $^{187}\text{Os}$  isochron slope according to the calculated isochron age of  $13.6 + 1.6$  Ma, MSWD=1.2 (Figure 5a).

The the model age is similar to that in the error range, indicating the reliability of the test data. By field observation, the Gangjiang Cu-Mo deposit was mainly developed in monzonite granite porphyry with stock work and chalcopyrite. Therefore, the formation age dating of molybdenite Re-Os isotope have basically represent the Gangjiang copper-molybdenum deposit, metallogenic event occurred in the Miocene.

Table 3 Re-Os isotopic data of molybdenites from Gangjiang Cu-Mo deposit

Sample number	Sample weight	Re $\pm 2\sigma$	Os $\pm 2\sigma$	$^{187}\text{Re} \pm 2\sigma$	$^{187}\text{Os} \pm 2\sigma$	Model age
	g	ug/g	ng/g	ug/g	ng/g	Ma
BSPD2-03-1	0.00504	161.3 $\pm$ 1.4	0.0016 $\pm$ 0.0371	101.4 $\pm$ 0.9	22.38 $\pm$ 0.17	13.24 $\pm$ 0.20
BSPD2-03-2	0.01006	163.8 $\pm$ 1.8	0.0652 $\pm$ 0.0184	102.9 $\pm$ 1.1	23.23 $\pm$ 0.14	13.55 $\pm$ 0.22
BSPD2-03-3	0.01053	165.0 $\pm$ 2.0	0.1152 $\pm$ 0.0253	103.7 $\pm$ 1.2	23.22 $\pm$ 0.17	13.44 $\pm$ 0.23
BSPD2-03-4	0.01028	161.0 $\pm$ 1.4	0.0008 $\pm$ 0.0502	101.2 $\pm$ 0.9	22.81 $\pm$ 0.13	13.52 $\pm$ 0.19
BSPD2-03-5	0.01044	155.9 $\pm$ 1.3	0.0915 $\pm$ 0.0178	98.0 $\pm$ 0.8	21.92 $\pm$ 0.16	13.42 $\pm$ 0.20
BSPD2-03-6	0.01018	165.0 $\pm$ 1.4	0.1051 $\pm$ 0.033	103.7 $\pm$ 0.9	23.16 $\pm$ 0.15	13.41 $\pm$ 0.19
BSPD2-03-7	0.01038	171.1 $\pm$ 1.5	0.1059 $\pm$ 0.0253	107.6 $\pm$ 0.9	23.95 $\pm$ 0.14	13.36 $\pm$ 0.19
BSPD2-03-8	0.01036	164.8 $\pm$ 1.4	0.1108 $\pm$ 0.0182	103.6 $\pm$ 0.9	23.08 $\pm$ 0.16	13.38 $\pm$ 0.20
BSPD2-03-9	0.01007	165.8 $\pm$ 1.3	0.0928 $\pm$ 0.0184	104.2 $\pm$ 0.8	23.18 $\pm$ 0.14	13.35 $\pm$ 0.19
BSPD2-03-10	0.01096	162.5 $\pm$ 1.3	0.0007 $\pm$ 0.1199	102.2 $\pm$ 0.8	22.72 $\pm$ 0.16	13.35 $\pm$ 0.19
BSPD2-03-11	0.01036	155.4 $\pm$ 1.1	0.0604 $\pm$ 0.026	97.7 $\pm$ 0.7	21.75 $\pm$ 0.16	13.36 $\pm$ 0.19
BSPD2-03-12	0.01073	162.9 $\pm$ 1.2	0.0924 $\pm$ 0.0252	102.4 $\pm$ 0.8	22.79 $\pm$ 0.22	13.36 $\pm$ 0.21

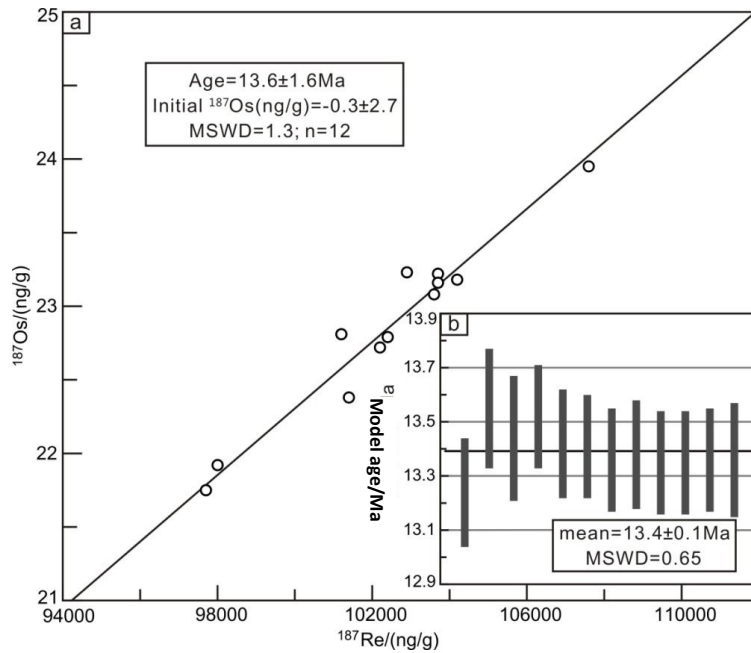


Fig.5 Re-Os isotopic isochron (a) and weighted mean model age (b) of molybdenite in Gangjiang deposit

#### 4. Conclusion

(1) The LA-ICP-MS zircon U-Pb geochronology results present that the formation ages of monzonite granite porphyritic granite, porphyritic granodiorite and quartz-mica diorite are  $16.6 \pm 0.3 \text{ Ma}$ ,  $16.1 \pm 0.2 \text{ Ma}$  and  $14.4 \pm 0.4 \text{ Ma}$ . Molybdenite Re-Os dating shows that Re-Os isochron age is  $13.6 \pm 1.6 \text{ Ma}$  and the weighted average age is  $13.4 \pm 0.1 \text{ Ma}$ ; which reveal the mineralization age of Cu-Mo system. According to the combination of field geological investigation and LA-ICP-MS zircon U-Pb dating results, the magmatic intrusion sequence in the study area is as follows: ore-bearing monzonite granite porphyry  $\rightarrow$  granodiorite porphyry  $\rightarrow$  rhyolite porphyry (depth named as quartz-mica diorite porphyry).

(2) the Gangjiang content changes of molybdenite Re copper molybdenum deposit in  $155.4 \mu\text{g/g}$   $\sim$   $171.1 \mu\text{g/g}$ , average  $162.9 \mu\text{g/g}$ , indicating the addition of mantle-derived components in ore-forming fluid.

(3) Mineralization age of the Gangjiang Cu-Mo deposit is consistent with the age of other deposit at (17  $\sim$  13 Ma) in the Gangdese metallogenic belt. Those deposit, including Gangjiang are formed in extensional environment of the post Indian-Asian collisional stage.

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#### References

- [1] Rui, Z. Y., Li, G. M., Zhang, L. S., et al., 2004. The Response of Porphyry Copper Deposits to Important Geological Events in Xizang. *Earth Science Frontiers*, 11(1): 145-152.

- [2] Leng, Q. F. , Tang, J. X. , Zheng, W. B. , et al. , 2015. Re-Os Dating of Molybdenite from the Lakange Porphyry Cu-Mo Deposit in Tibet and Its Geological Significance. *Geology in China*, 42(2): 570-584 (in Chinese with English abstract).
- [3] Zhang, Q. S. , Zheng, L. B. , Wang, G. W. , et al. , 2012. Geological Characteristics of Gangjiang-Bairong Porphyry Cu-Mo Deposit in Tibet and Ore-Searching Directions. *Contributions to Geology and Mineral Resources Research*, 27(3): 300-307.
- [4] Song, B. , Zhang, Y. H. , Wang, Y. S. , et al. , 2002. Mount Making and Procedure of the SHRIMP Dating. *Geological Review*, 48(Suppl. ): 26-30.
- [5] Gao, S. , Liu, X. M. , Yuan, H. L. , et al. , 2002. Analysis of Forty-Two Major and Trace Elements of USGS and NIST SRM Glasses by LA-ICP-MS. *Geostandard Newslett*, 22: 181-196.
- [6] Liu, X. M. , Gao, S. , Yuan, H. L. , et al. , 2002. Analysis of 42 Major and Trace Elements in Glass Standard Reference Materials by 193 nm LA-ICP-MS. *Acta Petrologica Sinica*, 18(3): 408-418.
- [7] Andersen, T. , 2002. Correction of Common Lead in U-Pb Analyses that Do not Report  $^{204}\text{Pb}$ . *Chemical Geology*, 192(1-2):59-79. doi: 10. 1016/s0009-2541(02)00195-x
- [8] Ludwig, K. R. , 1999. A Geochronological Toolkit for Microsoft Excel. *Geochronology Center*, Berkeley.
- [9] Hou, K. J. , Li, Y. H. , Tian, Y. R. , 2009. In Situ U-Pb Zircon Dating Using Laser Ablation-Multi Ion Counting-ICP-MS. *Mineral Deposits*, 28(4): 481-492.
- [10] Fang, G. C. , Chen, Y. C. , Chen, Z. H. , et al. , 2014. Zircon U-Pb and Molybdenite Re-Os Geochronology of the Panggushan Tungsten Deposit in South Jiangxi Province and Its Significance. *Acta Geoscientica Sinica*, 35(1): 76-84.