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The Lead Isotopic Evidence of The Metal Sources of Ore-Forming Materials of The Lala IOCG Deposit, Kangdian Area, SW China

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1 Introduction

The Lala IOCG deposit(Li et al.,2002;Chen and Zhou ,2011) is located in the west margin of the Yangtze craton, and the middle piece of the Kangdian earth's axis. Previous study mainly discussed its genetic mechanism (Sun and Li,1989), mineralogenetic epoch (Huang et al.,2012;Zhou et al.,2009,2011), protolith restoration (Xiao and Sun ,1992;He et al.,2008,2010). However, the origin of the metal sources of ore-forming materials is still poorly understood.

The lead isotopic composition of sulphide minerals in the ores is a direct and effective way to trace the metal source of ore-forming materials , but The conventional isochron calculations and global growth curves can not explain the anomalous nature of the lead isotope of the Lala IOCG deposit. Therefore the authors employ the mixing line isochrones model(Andrew et al.,1984) to explain the nature of the lead isotope and discuss the metal sources of ore-forming materials of the Lala IOCG deposit.

2 Geology of Lala IOCG deposit

The Lala IOCG depsit is hosted in the Hekou Group (Pt_1*hk*), which is in fault contact with the Huili Group (Pt_1*hl*) to the W and NE and overlain unconformably by Sinian and Phanerozoic strata to the NW and E-ES. The Hekou Group composed of the Dayingshan(Pt_1*d*), Luodang(Pt_1*l*) and Changchong(Pt_1*ch*) Formations from the base upward. The Hekou Group was intruded by gabbroic intrusions. Rocks of the gabbroic intrusions close to orebodies are strongly altered to chlorite, actinolite, albite, and magnetite.The intrusions are commonly crosscut by abundant calcite-cholcopyrite and quartz - hematite veins.

The Lala IOCG deposit consists of the Luodang Open-pit mining area, Luodong,and Shilong underground mining area from West to East. Orebodies are all hosted in the upper part of the Luodang Formation of the Hekou Group, and the Formations has the rhythmic interbeds of magnetite-quartz-albitite granulite and garnet-biotite-schist. Orebodies occur chiefly as irregular lenses and veins and are roughly strata bound.

The ores consist primarily of magnetite, chalcopyrite, pyrite, molybdenite, minor bornite, apatite-bearing REE, cobaltite, pyrrhotite, and trace native gold, native silver, chalcocite, with rare telluride. Gangue minerals include albite, carbonate, biotite, quartz, fluorite, almandine, sericite, and K-feldspar, with minor chlorite and tourmaline. The total metal resource is estimated at 200 Mt, with averaging 0.92%Cu, 0.018% Mo, 0.022% Co, 0.25% RE_2O_3, 0.49ppm Au, and 1.89 ppm Ag.

Three different paragenetic stages(Wang et al.,2012) of Cu-Fe have been identified, and the alteration assemblages are associated with the Cu-Au-Mo-U-REE mineralization. Stage I is about 1680Ma, the submarine vulcanian eruption crystallizing and depositing diagenesis was taken place at this time. Magnetite+ chalcopyrite +REE-bearing-apatite and pyrrhotite were formed in this stage. Stage II, at about 1000Ma, the stage of metamorphic hydrothermal mineralization is the primay mineralization period in the Lala deposit. Chalcopyrite+ pyrite+ molybdenite+ purple fluorite+ ankerite and early stage calcite are formed in this stage, and the molybdenite is always intergrowths with the purple fluorite. The purple flourite are usually riched in REE. Dolomite / calcite-chalcopyrite viens, quartz and some white flourite which is not enriched in REE were formed in stage III at about 850Ma, the mineraliztion of this stage is probably associated with the gabbro instrusion.

3 Interception of the lead isotope

Based on the data of lead isotopic composition, we can conclude which is variational in both minerals and host

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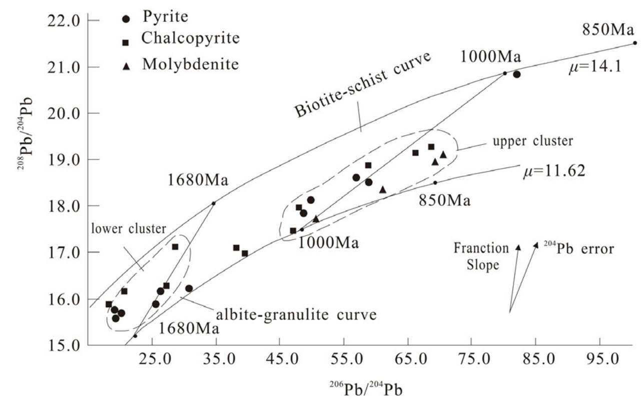

FIG.1. Plot of $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ of the Lala IOCG deposit .

Lines joining the Biotite-schist and albite-granulite curve are called mixing line isochrones;they are resulted from the mixing of lead from two reservoirs:the upper crust,and the lower crust and/or upper mantle.

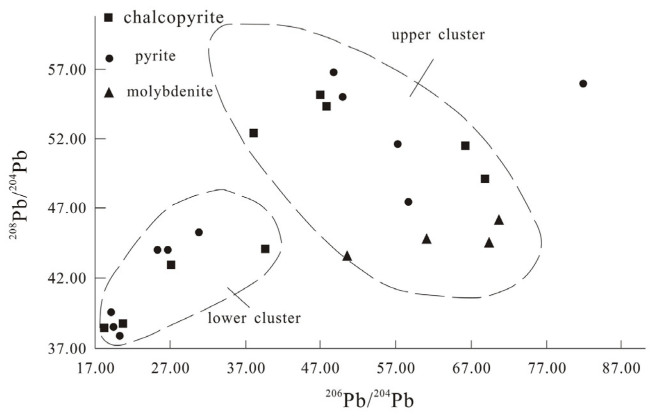

FIG.2. Plot of $^{208}Pb/^{204}Pb$ vs .$^{206}Pb/^{204}Pb$ of the Lala IOCG deposit .

rocks. $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratio for the minerals range from 18.103 to 81.941, 15.596 to 20.851, 37.798 to 56.662, respectively. While for the host rocks, $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratio range from 18.636 to 39.314, 16.184 to 17.136, 39.019 to 45.522, respectively. All the samples have a very high content of radiogenic lead, which is much higher in the minerals than the host rocks.

All the data we collected form the two distinctive clusters on the conventional $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ diagram(Fig.1). Each of these clusters represent a group of related minerals and each cluster elongate trend that does not parallel to either fraction or ^{204}Pb error lines. Generalized global growth curves, such as that of Stacy and Kramers(1975) and multistage evolution models, are not applicable to interpret the data. It was largely an attempt to provide an explanation of these linear trends that led to their interpretation as mixing line isochrones.

We corrected the lead isotopic composition of the uranium-contained host rocks based on the principle of radioactive decay and the three diagenesis-mineralization stages above. The initial lead isotopic composition also has a large varation and a high content of radiogenic lead. As for garnet-biotite schist, μ range from 9.55 to 22.66, with an average of 14.1. κ（Th/U）range from 1.71 to 4.48，with an average of 2.62.while to the magnetite-quartz-albite granulite, μ:9.57-17.16，with an average of 11.62；κ:1.36-3.6, with an average of 3.35.The former shows a high μ low κ feature, and the latter shows a low μ high κ feature.

The shale curve, defined by Godwin and Sinclair(1982), which represents the best estimate of average lead isotope in shale-hosted deposits, which reflects the evolution of lead in the upper crust environment. And the Bluebell curve, build by Andrew(1984), which is used to estimate the evolution of the lower crust, and/ or the upper mantle. Linear data arrays joining the same ages on the two growth curves is the mixing line isochrones. And interpret such isochrones to be the result of simple mixing between two fundamental reservoirs, the upper crust and the lower crust and/or upper mantle. Folowing the steps that they build the curves, we define the Biotite-schist curve and the Albite-granulite curve (Fig.1) of the Lala IOCG deposit. The protolith of the Biotite-shcist is felsic sedimentary rock(He et al.,2010), adding its high μ low κ feature, which suggesting a uranium-enriched, thorium-depleted environment, such an environment could be the upper crust(Doe and Zartaman,1979) . And the Biotite-schist curve can represent the upper curst environment, and it is corresponding to its initial neodymium isotope($\varepsilon Nd_{(t)}$ =0.48-2.01)(He et al.,2010) .The sodium magmatic rock is the protolith of the Albite-granulite, which was erupted in the continental-rift environment, has the feature of bimodal volcanic rocks(Wang et al.,2012;Xiao and Sun,1992), adding its low μ high κ feature, suggesting that the magma originated from the upper mantle was contaminated by the lower crust. So the Albite-granulite curve represent a contaminated environment of the upper mantle and the lower crust. It is also corresponding to its initial neodymium isotope($\varepsilon Nd_{(t)}$=-7.50)(He et al.,2009) . Both of the shale and sodium magmatic rock have experienced the three-stages geological process.

All the data of lead isotope of the Lala IOCG deposit plot on or between the two curves. Data of the samples which are not plot on the curves apparently contain an important of lead that is not of upper curst origin or the contamination environment. The linear data in Figure 1 can be explained in terms of mixing of two end member lead compositions which plot on the bounding lead evolution curves, the Biotite-schist curve and the Albite-granulite curve. Extraction and mixing of lead from these two reservoirs must have taken place at the time of mineralization, so the mixing lines will join points of equal time, and it is another type of isochrones.

The lower cluster(Fig.1) join the period of stage I, while the upper cluster join the period of stage II, it seems that we didn't collected the lead isotope of the third stage yet. We calculated the lead isotope parameters of each cluster, the lower cluster has the feature of low μ while the upper cluster has the feature of high μ, and the range of variation of μ is very large. All the features above may suggest that the the metal metallogenic materials come from different μ value source regions.

Figure 2 is a $^{208}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ plot. The data can also be divided into two cluster, the upper cluster and the lower cluster, the samples in each cluster is consistent with its place in clusters in Figure 1.From the diagram we can conclude that the earlier period ores has the feature of low κ while the later ones has the feature of high κ. Thus, the earlier period ores have the feature of low μ low κ and the later period ores are high μ high κ. Lead concentrations are higher in the upper crustal lead than in the lower crust or upper mantle(Armstrong,1981;Doe and Zartaman,1979), even small amounts of contamination by upper crustal material may cause a significant change in the ratio. The features of the lead isotope above are support the hypothesis that the metal sources of ore-forming materials of the Lala IOCG deposit is a mixed source.

4 The metal sources of ore-forming materials

Contamination of sedimentary lead by lead from the intrusions is the simplest explanation for the mixing lines; However, this process could take place in a variety ways：(1)assimilation of sedimentary rocks by magma leading to a pluton with mixed isotopic characteristics; (2) mixing between meteoric and magmatic hydrothermal fluids producing vein deposits with mixed isotopic characteristics; (3)contamination of ore fluids moving from the pluton into sedimentary rocks.

The west margin of Yangtze Block is in the environment of continental rift basin at Paleoproterozoic, about 2000-1680Ma.The ore-bearing sodic magma forming the sub-alkali-igneous rocks was originated from the upper mantle and deposited in the basin, which was contaminated by the lower crust materials during the eruption. The ore-bearing felsic materials from the upper curst deposited in the basin and formed the sedimentary rocks. The two kinds of host rocks are the two reservoirs of the lead isotope of Lala IOCG deposit. The two kinds of host rocks are the two reservoirs of the lead isotope of Lala IOCG deposit. The elements of Fe, Cu, Mo, Au, Co, REE, P and F possibly concentrated firstly in the eruption-deposition stage. The δS^{34} of sulfides are 1.92~2.22‰, suggest a deep S source.Part of Fe, Cu, P, and REE formed Magnetite, chalcopyrite(I) and pyrite(I), the core of REE-bearing apatite(I). The radiogenic lead isotope divorced from the original U-Th system and entered in the sulfides along with the crystallization of the minerals, which have the feature of low μ low κ. Then we can infer that the metallogenic materials are mainly derived from the contaminated environment.

The metamorphism of the Kangdian basement rocks along the western margin of Yangtze carton took place accompanying by the convergent event of super-continent Rodinia(Hao and Zhai,2004), at ~1000Ma, which is also called The Jinning Movement. The felsic sedimentary rocks turn into (garnet) biotite-schist, and the sodic igneous rocks become the albite-granulite. $\delta^{34}S$ of sulfides are 3~4‰, $\delta^{18}O$ and δD are -1.2 ~ 11.49‰ and -21.62 ~ -80‰ respectively, which suggest that the ore-forming fluid of this stage is metamorphic hydrothermal fluids. Cu, Mo, Au, Co, F and part of Fe and REE remobilized and moved into the metamorphic fluid, then forming the stage II mineral assemblages after the peak of the metamorphism and the mineral assemblages occuring as stripped and parallel to the shear foliation. In this stage, the metal ore-forming materials come from the upper crust materials and the contaminated materials were mixed thoroughly by the metamorphic hydrothermal fluids, so did the radiogenic lead came from the two reservoirs by the eluviation of the fluids. Therefore the sulfides of stage II shows a feature of high μ high κ, and content of radiogenic lead is lower in the host rocks than in the minerals. But it seems that the migmatization was not homogeneous, because the eigenvalue μ is various, likewise hinting a multi-sources of the radiogenic lead .

With the breakup event of Rodinia, the gabbros originated from mantle plume invaded in the Hekou Group, and formed lots of brittle fractures, at ~850Ma (Zhou et al.,2009). Finally, The meteoric and oxidized fluids (Chen and Zhou, 2012)filled into brittle fractures, precipitating veined mineralization assemblages(Stage III).

5 Conclusion

The features of lead isotopic composition of sulfides suggest that the metal sources of ore-forming materials of the Lala IOCG deposit is a mixed source. The metal materials mainly derived from the felsic sedimentary and the sodic bimodal volcanic rocks, the former represent a upper environment and the latter represent an environment contaminated by the lower crust and the upper mantle materials.

The Cu-Au-Mo metamorphic mineralization hosted in the Kangdian basement is considered as the response to convergent event of super-continent Rodinia.

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Reference:

Andrew,A., Godwin ,C.I., and Sinclair,A.J.,1984,Mxing line isochrons: a new interception of galena lead isotope data from southeastern British Columbia. *Economic Geology*, 79:912-932.

Chen Weiterry and Zhou Meifu, 2012,Paragenesis, Stable Isotopes, and Molybdenite Re-Os Isotope Age of the Lala Iron-Copper Deposit, Southwest China . *Economic Geology*, 107:459-480.

Doe,B.R., and Zartman, R.E.,1979, Plumbotectonics,the Phanerozoic, in Barnes,H.L.,ed.,Geochemistry of hydrothermal ore deposits: *New York, John Wiley*, 22-70.

Godwin ,C.I., and Sinclair,A.J.,1982,Average lead isotope growth curve for shale-hosted zinc-lead deposits, Canadian Cordillera.*Economic Geology*,77:675-690.

Hao Jie, Zhai Mingguo,2004.*JinNing Movement and sinian system in China:their relationship with Rodinia supercontinent* . Chinese Journal of Geology, 39(1):139-152 (in Chinese)

He Defeng, Zhong Hong and Zhu Weiguang ,2008.*The protolith of metamorphic in Lala copper deposit.* Bulletin of Mineralogy Petrology and Geochemistry, 27(S1):370-371(in Chinese).

He Defeng, Zhong Hong, Zhu Weiguang and Xiao Fang, 2010. *Geochemical characteristics of the ore-bearing strata metasedimentary host rocks in the Lala copper deposit, Sichuan Province*. Earth science Frontiers,17(4):218-226(in Chinese).

Huang Congjun, Li Zeqin, Wang Jiangzhen and Wang Dan ,2012. *Metallogenic epoch analysis of Lala Fe-Oxide-Cu-Au-U deposit* . Journal of Henan Normal University (Natural Science), 40(6):80-84(in Chinese).

Li Zeqin, Hu Ruizhong, Wang Jiangzhen, Liu Jiajun, Li Chaoyang , Liu Yuping and Ye Lin,2002.*Lala Fe-oxide-Cu-Au-U-REE ore deposit, Sichuan China—An example of Superimposed mineralization* . Bulletin of Mineralogy Petrologyand Geochemistry, 21(4):258-260 (in Chinese).

Wang Jiangzhen, Li Zenqin and Huang Congjun,2012.*The main geological events of the kangdian proterozoic eon and response from to the La-La IOCG deposit*. Advances in Earth Science, 27(10): 1074-1079(in Chinese).

Xiao Yuanfu and Sun Yan ,1992. *The petrologic characteristics and metamorphic preexisting rocks of the ore-bearing rock formation in Lala copper deposits*.Journal of Chengdu College of Geology, 19(2):41-48(in Chinese).

Zhou Jiayun，Mao Jingwen，Liu Feiyan，Tan Hongqi, Shen Bing, Zhu Zhimin, Chen Jiabiao, Luo Liping, Zhou Xiong and Wang Yue , 2011.*SHRIMP U-Pb Zircon chronology and geochemistry of albitite from the Hekou Group in the western Yangtze Block.* Journal of Mineralogy and Petrology，31 (3):66-73(in Chinese).

Zhou Jiayun，Zheng Rongcai，Zhu Zhimin，Chen Jiabiao, Shen Bing, Li Xiaoyu and Luo Liping ,2009.*Geochemistry and Sm-Nd dating of the Gabbro in the Lala copper ore district，SichuanProvince，China*. Bulletin of Mineralogy，Petrology and Geochemistry，28(2) : 111-122(in Chinese).