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西藏列廷冈铁多金属矿床辉钼矿Re-Os定年及其地质意义

杨 毅[1] 多 吉[2] 刘鸿飞[3] 张金树[3] 王立强[4] 张 志[1] 胡正华[5]

(1. 成都理工大学, 四川 成都 610059; 2. 西藏国土资源厅, 西藏 拉萨 850000; 3. 西藏地质调查院, 西藏 拉萨 850000; 4. 中国地质科学院矿产资源研究所, 北京 100037; 5. 江西省地质调查院, 江西 南昌 330000)

提要: 列廷冈铁多金属矿床不仅是西藏林周盆地已发现的众多铁多金属矿床中工业价值、找矿远景最好的矿床之一, 而且是冈底斯成矿带Fe、Cu、Mo、Pb、Zn等多矿化元素组合的典型代表。本次研究利用辉钼矿Re-Os同位素年代学测试方法, 对列廷冈矿床8件辉钼矿进行了精确定年, 首次明确了矿床成矿时代。测试结果表明, 辉钼矿模式年龄为(60.97±0.92) Ma~(63.19±0.93) Ma, 等时线年龄为(62.28±0.66) Ma (MSWD=0.74), 矿床形成于古新世, 与印度—亚洲大陆主碰撞阶段在冈底斯成矿作用有关。矿床辉钼矿Re含量变化于0.54×10^{-6}~84.72×10^{-6}, 指示矿床成矿物质来源主要为壳幔混源。列廷冈矿床成矿时代和成矿物质来源的厘定, 对于区域上开展古新世铁多金属矿床的找矿预测具有十分重要的意义。

关 键 字: Re-Os同位素; 成矿时代; 列廷冈铁多金属矿; 林周盆地; 冈底斯成矿带

中图分类号: P611;P597 **文献标志码:** A **文章编号:** 1000-3657(2014) 05 -1554-11

冈底斯成矿带是近年来中国在世界三大斑岩铜矿带之一的喜马拉雅—特提斯成矿域中铜矿找矿取得重大突破的斑岩成矿带[1], 冈底斯东段优势矿床成矿系列预测是当前需要解决的重要问题[2]。近年来, 随着地质勘探工作的深入, 在冈底斯成矿带勘查并评价了一大批大型-超大型斑岩型Cu矿床和矽卡岩型铅锌多金属矿床, 如甲玛、驱龙、邦铺、蒙亚啊、亚贵拉等[3-7]。林周火山盆地是冈底斯成矿带东段的重要组成部分, 盆地内以普遍发育Fe-Mo-Cu-Pb-Zn成矿元素组合为特征的多金属矿床而区别于冈底斯成矿带东段目前已发现的斑岩Cu-(Mo)和矽卡岩Pb-Zn-Cu多金属矿床。在林周盆地已发现列廷冈、勒青拉、新嘎果、普琼朗等多个铁多金属矿床(图1), 而列廷冈是其最为典型、矿床规模最大的矿床。然而, 上述矿床成矿时代至今尚不明确, 这对于明确区域铁多金属矿床的成矿规律造成了一定影响。列廷冈矿床普遍发育辉钼矿, 为确定矿床成矿时代创造了良好的机遇。本次研究在野外调研的基础上, 首次对矿床中产出的辉钼矿进行了Re-Os同位素定年, 以厘定矿床成矿时代, 讨论矿床形成背景, 从而为总结区域铁多金属矿床成矿规律提供科学依据。

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作者简介: 杨毅,男,1983年生,博士生,矿物学、岩石学、矿床学专业,主要从事矿床学和矿产普查与勘探工作;E-mail:290744982@qq.com。
通讯作者: 王立强,男,1984年生,助理研究员,主要从事矿床学、矿床地球化学和区域成矿规律研究;E-mail:wlq060301@163.com。

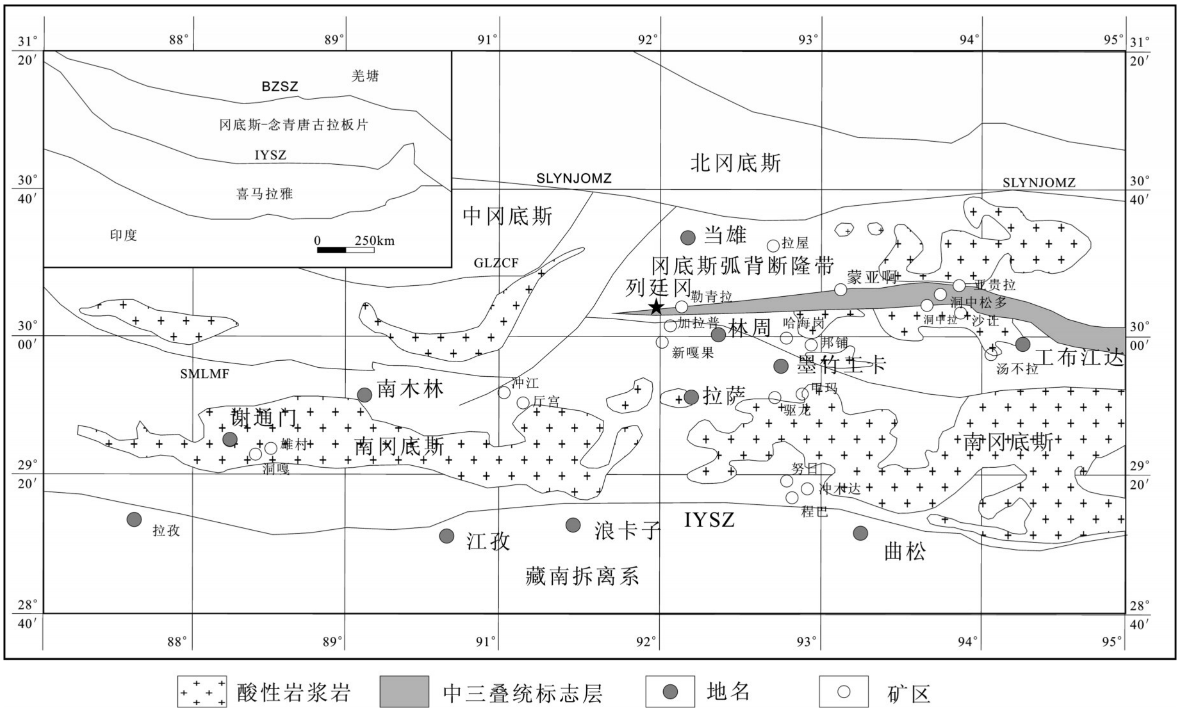


图1 西藏冈底斯东段构造单元划分及部分矿产分布图(据参考文献[8]修改)

SLYNJOMZ—狮泉河-拉来错-永珠-纳木错-嘉黎蛇绿岩混杂带; SMLMF—沙莫勒-麦拉-洛巴堆-米拉山断裂; GLZCF—噶尔-隆格尔-扎日南木错-错麦断裂带; BZSZ—班公湖-怒江缝合带; IYSZ—雅鲁藏布江缝合带

Fig.1 Division of tectonic units and distribution of partial ore deposits in the eastern segment of Gangdise, Tibet (modified after[8])

SLYNJOMZ-Shiquan River-Namco Melange Zone; SMLMF-Shalemo-Maila-Luobadui-Milashan Fault; GLZCF-Gaer-Longge'er-Zhari Namco-Cuomai Fault; BZSZ- Bangong Co-Nujiang River Suture Zone; IYSZ-Yarlung Zangbo River Suture Zone

1 矿床地质特征

除第四系外,矿区主要出露早—中三叠世查曲浦组($T_{1-2}c$)大理岩。矿区构造形式简单,以规模较小的断层构造为主。侵入岩分布广泛,主要岩石类型为花岗闪长岩、二长花岗岩、闪长玢岩、辉长岩、辉绿岩等。其中,与成矿关系最为密切的为花岗闪长岩、二长花岗岩(图2)。

现阶段,矿区范围内共圈定9个矿体,由西向东,依次编号为I~IX,矿体多呈囊状、透镜状或似层状产出,I~V号矿体构成西矿段,Ⅵ~Ⅸ号矿体构成东矿段,目前,矽卡岩型铁多金属矿体为主矿体,位于大理岩与斑岩体层间接触带。其中Ⅰ号矿体位于矿区最西侧,该矿体矿石类型以磁铁矿为主,其次为方铅矿和闪锌矿。Ⅱ号矿体为西矿段主矿体(图3-A),见矿海拔5050 m左右,矿石以磁铁矿、辉钼矿、黄铜矿为主,少量闪锌矿和方铅矿,矿体中Cu平均品位1.2%,Mo平均品位0.58%❶。Ⅲ号矽卡岩矿体以磁铁矿为主,次为黄铜矿,并含少量辉钼矿、闪锌矿、孔雀石,出露地表的Ⅲ号斑岩矿体主要为黄铜矿和辉钼矿,少量镜铁矿、黄铁矿。Ⅳ号矿体下部以磁铁矿为主,其次为黄铜矿和辉钼矿,其南侧花岗闪长岩和二长花岗岩中见浸染状和细脉状辉钼矿化。Ⅴ号矿体出露海拔位置较Ⅳ号矿体低,矿石以磁铁矿为主,黄铜矿次之。Ⅵ号矿体以磁铁矿为主,发育少量黄铜矿、闪锌矿和辉钼矿。Ⅶ号矿体以磁铁矿为主,闪锌矿、黄铁矿、磁黄铁矿为次,矿体不连续。Ⅷ号矿体以磁铁矿为主,可见少量辉钼矿、黄铜矿和孔雀石。Ⅸ号矿体为东矿段主矿体(图3-B),位于矿区最东端,以磁铁矿、黄铜矿

❶西藏地质调查院. 西藏自治区堆龙德庆县列廷冈铁矿区普查报告. 2012.

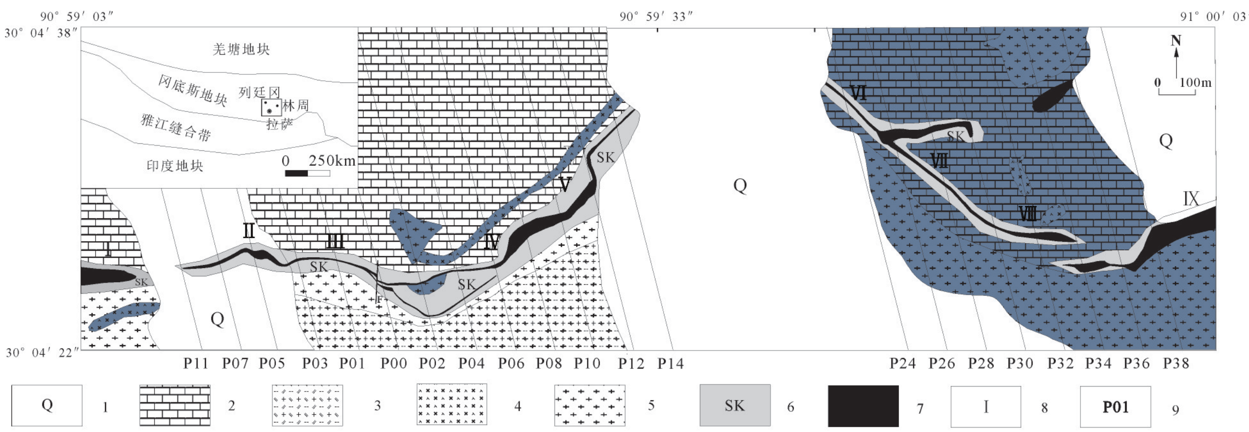


图2 西藏列廷冈铁多金属矿床地质简图(据❶修改)

1—第四系; 2—大理岩; 3—二长花岗岩; 4—辉绿岩; 5—花岗岩; 6—矽卡岩; 7—矿体; 8—矿体编号; 9—勘探线及编号

Fig.2 Simplified geological map of the Lietinggang Fe polymetallic ore deposit(modified after ❶)

1−Quaternary; 2−Marble; 3−Monzonitic granite; 4−Diabase; 5−Granite; 6−Skarn; 7−Orebody; 8−Serial number of orebody; 9−Exploration line and its serial number

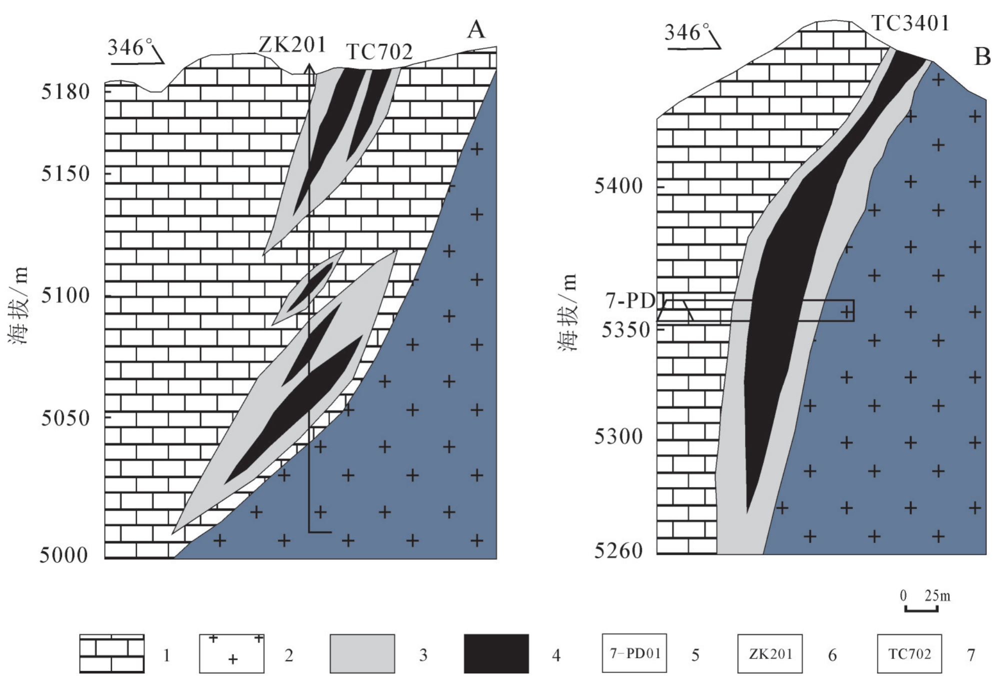


图3 列廷冈Ⅱ号矿体7号勘探线剖面图(A)、Ⅸ号矿体36号勘探线剖面图(B)(据❶修改)

1—查曲浦组大理岩; 2—花岗岩; 3—矽卡岩; 4—矿体; 5—平垌及编号; 6—孔及编号; 7—探槽及编号

Fig. 3 Geological section along No. 7 exploration line in No. 2 orebody of Lietinggang (A); geological section along No.36 exploration line in No. 9 orebody of Lietinggang (B) (modified after ❶)

1−Marble; 2−Granite; 3−Skarn; 4−Orebody; 5−Adit and its serial number; 6−Drill hole and its serial number; 7−Trial trench and its serial number

❶西藏地质调查院. 西藏自治区堆龙德庆县列廷冈铁矿区普查报告. 2012.

为主,少量辉钼矿、孔雀石和闪锌矿,矿体产状由西向东逐渐变陡。

矿区金属矿物主要为磁铁矿、黄铜矿、辉钼矿,其次为闪锌矿、方铅矿,少量孔雀石、黄铁矿、镜铁矿、磁黄铁矿等;非金属矿物主要有石榴子石、阳起石、透辉石、绿泥石、绿帘石、电气石、石英、钾长石、绢云母,少量硅灰石和萤石。矿石构造主要以块状、浸染状构造为主,次为网脉状、条带状等。围岩蚀变主要有矽卡岩化、硅化、阳起石化、电气石化和碳酸盐化;矿床南侧花岗闪长岩和二长花岗岩地表发育大量青磐岩化,呈不均匀的团斑状、细脉状和网脉状,伴随青磐岩化岩体中发育团斑状或条带状黄铜矿化和辉钼矿化。

根据脉体穿插关系和矿物共生组合关系,可将矿床成矿期次初步划分为:矽卡岩期、石英硫化物期、碳酸盐期。磁铁矿主要形成于矽卡岩期,黄铜矿、辉钼矿、闪锌矿、方铅矿等主要形成于石英硫化物期,而碳酸盐期基本无矿化,方解石具有自形晶特点。

2　样品采集与测试

2.1样品采集

用于分析测试的辉钼矿主要取自Ⅱ号矿体的矽卡岩矿石以及与成矿关系密切的二长花岗闪长岩。其中,矽卡岩矿石中辉钼矿样品4件,斑岩中产出辉钼矿样品4件,共计8件,样品特征见表1和图4。

2.2 样品分析方法

样品经过分离并挑纯(纯度大于99%),送实验室进行分析测试。辉钼矿Re−Os同位素分析测试在国家地质实验测试中心完成,样品主要实验仪器为电感耦合等离子体质谱仪TJA X−series ICP−MS。对于Re含量很低的样品(HM03)采用美国热电公司(Thermo Fisher Scientific)生产的高分辨电感耦合等离子体质谱仪HR−ICP−MS Element 2进行测试。详细流程参考相关文献[9−12]。

2.3 测试结果

辉钼矿的Re−Os同位素定年测试结果Re含量主要介于0.54×10^{-6}~84.72×10^{-6},Re与^{187}Os含量变化协调,8件样品的模式年龄在(60.97±0.92) Ma~(63.19±0.93) Ma,加权平均年龄为(61.96±0.58) Ma (MSWD=2.4)(表2),利用ISOPLOT软件将8件样品数据回归到一条直线,得到等时线年龄为(62.28±0.66) Ma(MSWD=0.74)(图5),该年龄代表了辉钼矿形成时年龄,测年精确。矿床成矿时代属古新世。

3　讨　论

3.1 成矿时代与意义

在林周盆地发育一系列具有Fe、Mo、Cu、Pb、Zn元素组合为其特点的矿床(点),如列廷冈、加拉普、普琼朗、勒青拉,但在该区域内,成矿时代一直是悬而未决的问题。目前,勒青拉与成矿有关的花岗闪长岩体的成岩年龄为45 Ma,认为成矿时代是喜马拉雅早期[13],加拉普与成矿作用最密切的花岗闪长岩锆石U−Pb定年显示成岩年龄63.5 Ma[14]。本次研究通过对列廷冈成矿时代的确定,补充了林周盆地铁多金属矿成矿时代,将列廷冈Fe、Mo、Cu、Pb、Zn元素组合类型成矿事件呈现于众,弥补林周盆地和隆格尔弧背断隆南缘矽卡岩型铁多金属矿成矿时代缺少的遗憾,也为林周盆地北西缘铁多金属矿成矿时代厘定奠定了坚实的基础,本次实验8件样品的加权平均年龄(61.96±1.17) Ma,等时线年龄为(62.28±0.66) Ma,吻合较好,可以断定列廷冈辉钼矿形成时代为古新世。

通过对比冈底斯成矿带典型矿床成矿时代(表3)发现,除了雄村矿床外[15],成矿高峰在13~20 Ma和40~65 Ma(图6)[16−32],主要是印度板块与亚洲板块发生碰撞的结果,而侯增谦在板块俯冲、碰撞的基础上,认为冈底斯成矿带包括印度−亚洲大陆碰撞的主碰撞期65~40 Ma、碰撞向伸展转换期40~26 Ma和碰撞后伸展期25~0 Ma[33−35],列廷冈与大多数冈底斯主碰撞期典型矿床(如亚贵拉、查个勒)一样,属于冈底斯成矿带碰撞期成矿事件的一员。

3.2 地球动力学背景

白垩纪时遍布于拉萨陆块的岩浆活动,到古近纪之后只发生在陆块的南部[36],而新特提斯板块“后旋”的模式解释了这一现象,即新特提斯洋俯冲角度在晚白垩纪时由缓变陡[37];在65 Ma印度—亚洲大陆开始碰撞(在西藏南部)[38],大陆地壳的直接碰撞,减低了板块的俯冲速度,使先期俯冲的洋壳与陆壳板块之间出现俯冲速度差[39],下覆板块发生“后旋”,上覆俯冲板片断折,引发地慢楔的部分熔融作用,造成了岩浆的底侵集聚[40],岩浆底侵于壳−幔边

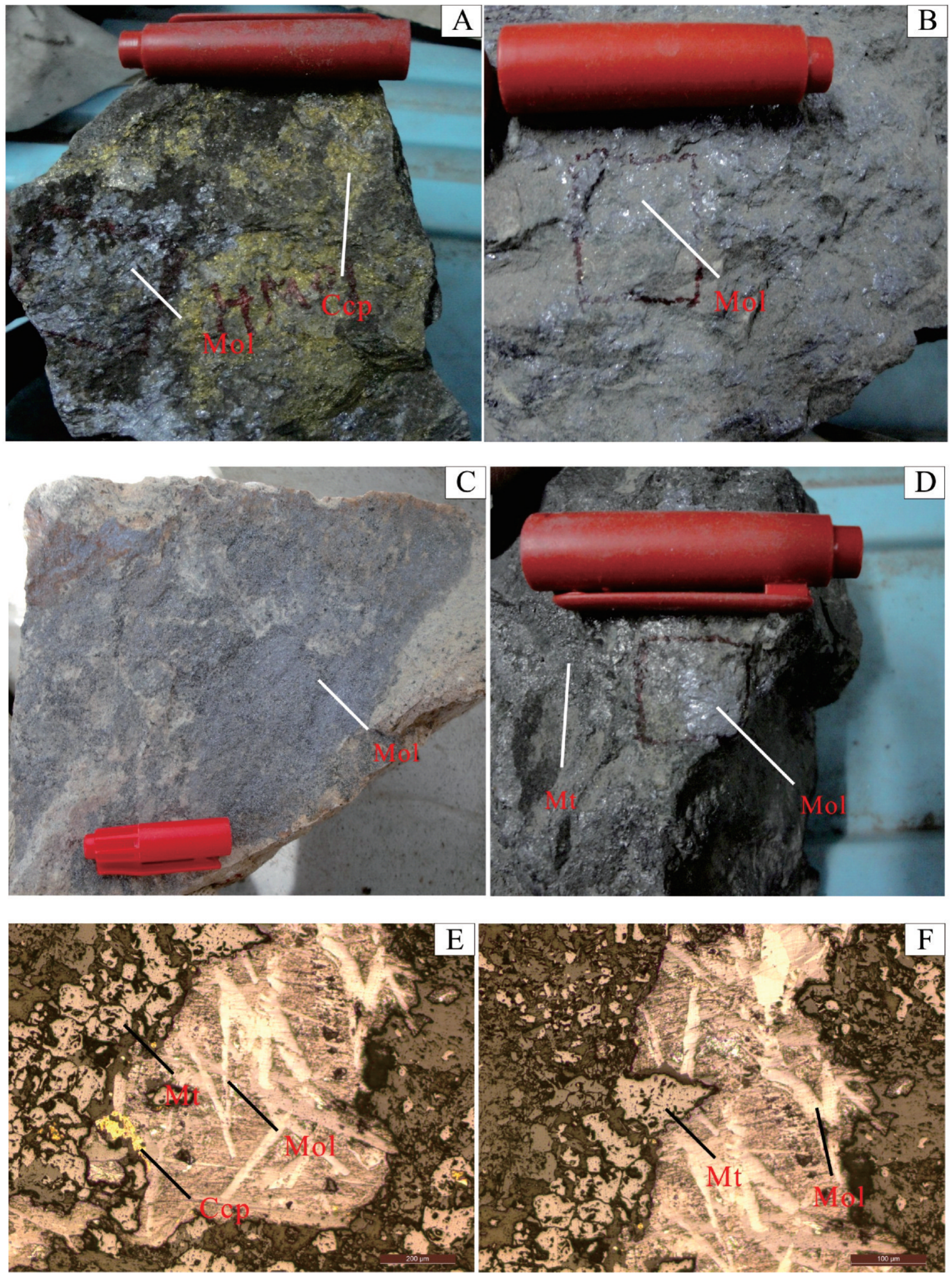


图4列廷冈矿床辉钼矿矿石特征
A—矽卡岩铜钼矿石中辉钼矿; B—块状辉钼矿矿石; C—二长花岗斑岩裂隙面呈膜状辉钼矿; D—鳞片状辉钼矿; E和F—片状辉钼矿; Mt—磁铁矿; Ccp—黄铜矿; Mol—辉钼矿

Fig.4 Characteristics of molybdenite ore in the Lietinggang deposit
A–Molybdenite in the copper–molybdenum ore of skarn; B–Molybdenite ore from the massive skarn; C–Thin–layer molybdenite in the fracture surface of granite porphyry; D–Flaky molybdenite in the skarn; E and F–Schistose molybdenite; Mt–Magnetite; Ccp–Chalcopyrite; Mol–Molybdenite

界, 同时下地壳也发生部分熔融, 底侵岩浆聚集量的增大, 使地壳发生大规模熔融, 从而引起岩浆混合作用, 混合后的铁镁质岩浆也沿着某种薄弱带上侵, 进入上部的岩浆房[41], 深部铁镁质岩浆进入及参与地壳结晶, 在隆格尔弧背断隆南缘这样的薄弱带, 就形成以Fe–Cu–Mo–Pb–Zn为特征的列廷冈

表1 列廷冈辉钼矿样品产出特征

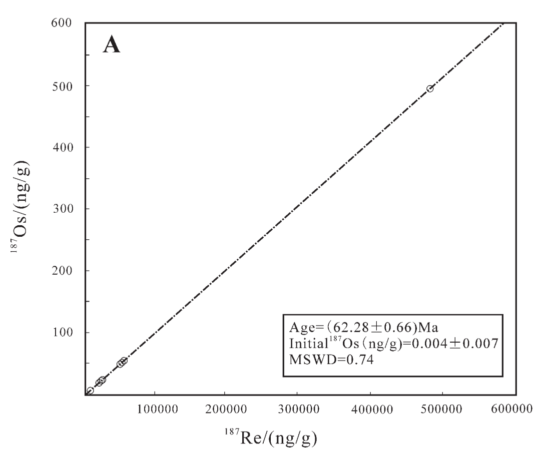
Table 1 Features of molybdenite samples from the Lietinggang deposit

样号	赋存岩性	采样位置			产状	形态	矿物组合
		北纬 N	东经 E	海拔 H/m			
HM03	花岗闪长岩	30°04′25″	90°59′15″	5373	浸染状分布于裂隙面	片状	辉钼矿
HM04	二长花岗岩	30° 04′26″	90° 59′17″	5245	浸染状分布于裂隙面	片状	辉钼矿
HM11	花岗闪长岩	30° 04′29″	90° 59′21″	5238	条带状分布于石英脉	薄膜状	辉钼矿+黄铜矿
HM12	花岗闪长岩	30° 04′27″	90° 59′26″	5255	脉状	薄膜状	辉钼矿
HM01	矽卡岩	30° 04′31″	90° 59′17″	5244	块状	细粒	辉钼矿+黄铜矿
HM02	矽卡岩	30° 04′27″	90° 59′15″	5183	块状	细粒	辉钼矿+磁铁矿
HM07	矽卡岩	30° 04′25″	90° 59′16″	5211	团斑状	细粒	辉钼矿
HM10	矽卡岩	30° 04′26″	90° 59′19″	5059	块状	细粒	辉钼矿+磁铁矿

表2 列廷冈铁多金属矿辉钼矿 Re-Os 同位素测试结果

Table 2 Re-Os isotope data for molybdenite from the Lietinggang iron and polymetallic deposit

样号	样重/g	Re/(μg/g)		普 Os/(ng/g)		^{187}Re/(μg/g)		^{187}Os/(ng/g)		模式年龄/Ma	
		测定值	误差	测定值	误差	测定值	误差	测定值	误差	测定值	误差
HM03	0.20	0.54	0.00	0.01	0.00	0.30	3.04	0.34	0.00	60.97	0.92
HM04	0.09	10.01	0.08	0.02	0.00	6.00	51.83	6.62	0.06	63.19	0.93
HM11	0.00	764.48	8.54	0.13	0.54	480.00	5.37	493.71	4.20	61.64	1.00
HM12	0.20	30.48	0.43	0.01	0.00	19.00	0.27	19.96	0.16	62.49	1.13
HM01	0.12	37.05	0.42	0.08	0.00	23.00	0.27	24.46	0.23	63.01	1.07
HM02	0.01	80.63	0.72	0.02	0.04	51.00	0.45	52.36	0.46	61.98	0.93
HM07	0.05	7.77	0.06	0.00	0.01	5.00	0.04	5.00	0.05	61.37	0.90
HM10	0.20	84.72	3.27	0.02	0.00	53.00	2.05	54.16	0.51	61.02	2.47



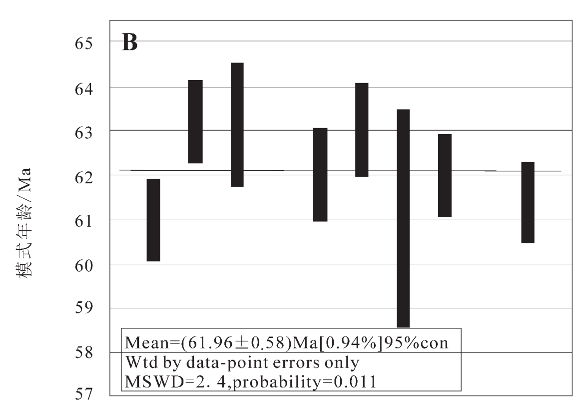


图5 列廷冈铁多金属矿辉钼矿 Re-Os等时线图(A)和加权平均年龄图(B)

Fig.5 Re-Os isochron (A) and weighted mean of Re-Os model ages (B) of molybdenites from the Lietinggang deposit

式矽卡岩型矿床。

3.3 区域找矿意义

目前冈底斯东段主要以铜多金属、钼多金属斑岩矿床和铅锌多金属矿床主,列廷冈铁多金属矿的发现是近几年在林周盆地重要找矿进展,其独特性、典型性不仅丰富了主碰撞期成矿类型,而且拓展了在林周盆地找矿方向,同时对追溯古新世与印−亚碰撞有关的斑岩矿床的动力学背景、深部岩浆过程具有重要意义,也对冈底斯东段成矿序列的划分、元素分带的确立奠定了基础,暗示在林周盆地存在其他铁多金属矿找矿潜力。

从成矿时代上看,在冈底斯成矿带横向,由西向东的矿床如恰功、沙让、亚贵拉成矿时代在51~67 Ma,而位于沙让、亚贵拉与恰功之间的冈底斯中段是主碰撞期成矿的空白区,而列廷冈成矿时代厘定,连接了恰功—沙让—亚贵拉矿集区为代表的冈底斯主碰撞期矿床,由此,在冈底斯成矿带东西向形成一条成矿时代在主碰撞期的成矿亚带。从区域元素分布规律上看,在林周盆地已发现列廷冈、勒青拉、普琼朗、加拉普等铁多金属矿床,可能是潜在的铁多金属成矿带;在冈底斯成矿带东段纵向上,北缘以铅锌多金属矿为主,以查个勒、亚贵拉、蒙亚啊等矿区为代表,而南缘以铜多金属和钼多金属矿床为主,以甲玛、驱龙、邦铺为代表,而处于冈底斯东段中部林周盆地的列廷冈、勒青拉、普琼朗、加拉普以磁铁矿、黄铜矿、辉钼矿、闪锌矿、方铅矿等矿物组合为其特点,既区别于冈底斯北缘的铅锌多金属矿,也不同于南缘的铜钼多金属矿,印证了在冈底斯东段成矿元素从南往北的分布规律: Cu−Au(斑岩型)→Mo−W(Cu)(斑岩−矽卡岩型)→Cu−Mo−Pb−Zn(Au、Ag)(斑岩−矽卡岩型)→Mo(Cu)(斑岩)→Pb−Zn−Mo−W−Fe(斑岩−矽卡岩型)→Pb、Zn(Ag)(热液脉型)[42],从而在冈底斯东段中部的林周盆地内,以列廷冈为代表的铁多金属矿床,形成一条矿物组合以磁铁矿、黄铜矿、辉钼矿、闪锌矿、方铅矿为其特点的矿化亚带。这条成矿亚带的建立,有助于加拉普(磁铁矿和黄铜矿)、勒青拉(磁铁矿和方铅矿、闪锌矿)等其他林周盆地铁多金属矿实现找矿突破,根据列廷冈目前勘探成果来看,矿体赋矿层位主要在矽卡岩中,矿体形成都与斑岩体侵位有关,这条成矿亚带的铁多金属矿都具有与之相似的特点。

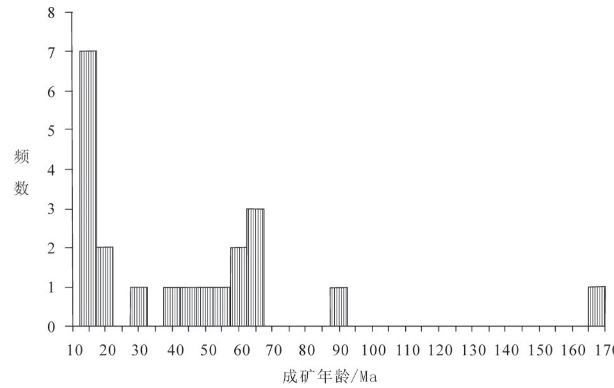


图6 西藏典型矿床同位素年龄分布直方图
Fig.6 Distribution of geochronological data of the major deposits in Tibet

表3 西藏典型矿床放射性同位素年龄数据
Table 3 Age data of radioactive isotopes from typical ore deposits in Tibet

矿床名称	矿化元素组合	测试方法	测试对象	等时线年龄/ Ma	资料来源
雄村	Cu-Au	Re-Os	辉钼矿	165~173	[15]
列廷冈	Fe-Cu-Mo	Re-Os	辉钼矿	62.28±0.66	本文
亚贵拉	Pb-Zn	Re-Os	辉钼矿	65.0±1.9	[16]
沙让	Mo	Re-Os	辉钼矿	51.0±1.0	[17]
查个勒	Pb-Zn	Re-Os	辉钼矿	61.49±0.60	[18]
纳如松多	Pb-Zn	Ar-Ar	绢云母	57.90±1.70	[19]
吉如	Cu-Mo	Re-Os	辉钼矿	49.2±1.7	[20]
洞中拉	Pb-Zn	Ar-Ar	石英	42.2±1.7	[21]
努日	Cu-Mo-W	Re-Os	辉钼矿	23.36±0.49	[22]
				23.62±0.97	[23]
程巴	Mo-Cu	Re-Os	辉钼矿	30.17 ± 0.94	[24]
甲玛	Cu-Mo-Pb	Re-Os	辉钼矿	15.18±0.98	[25]
	Cu-Mo		辉钼矿	15.34±0.10	[26]
驱龙	Cu-Mo	Re-Os	辉钼矿	16.41±0.48	[27]
冲江	Cu	Re-Os	辉钼矿	14.04± 0.16	[28]
	Cu		辉钼矿	14.85±0.69	[29]
朱诺	Cu	Re-Os	辉钼矿	13.72±0.62	[30]
邦铺	Mo-Cu	Re-Os	辉钼矿	15.32±0.79	[31]
	Mo-Cu	LA-ICP-MS	花岗斑岩	16.23±0.19	[32]

3.4 Re含量与成矿物质来源

辉钼矿中Re的含量可以用来指示成矿物质的来源,从幔源、壳幔混源到壳源,Re含量从$n\times10^{-4}$~$n\times10^{-5}$~$n\times10^{-6}$各级递减一个数量级[43]。列廷冈辉钼矿(除去HM11样品)Re的含量0.54×10^{-6}~84.72×10^{-6},平均3.58×10^{-6},这低于幔源矿床辉钼矿的Re含量

(如雄村铜金矿床辉钼矿Re含量为$1015\times10^{-6}\sim7657\times10^{-6}$)[44],而高于壳源矿床辉钼矿的Re含量(如寨凹钼矿床辉钼矿Re含量$0.665\times10^{-6}\sim4.832\times10^{-6}$)[45],表明成矿物质来源介于幔源与壳源之间,更偏向壳源一端,地壳物质混染较为强烈。

4 结 论

(1)列廷冈辉钼矿模式年龄(60.97±0.92) Ma~(63.19±0.93) Ma,加权年龄(61.96±0.58) Ma,等时线年龄为(62.28±0.66) Ma (MSWD=0.74),辉钼矿成矿时代属古新世,与主碰撞期大规模成矿作用有关。

(2)列廷冈成矿时代厘定,在冈底斯成矿带上,连接恰功与沙让、亚贵拉构成的一条50~65 Ma的成矿亚带;在元素分带性上,在冈底斯东段林周盆地,与加拉普、勒青拉等矿床(点)构成一条铁多金属矿成矿亚带,同时,列廷冈的发现丰富了主碰撞期成矿类型,对于开展区域上古新世铁多金属矿床的找矿预测具有十分重要的意义,也拓展了林周盆地找矿方向。

(3)采用的8件样品中Re含量主要集中在$0.54\times10^{-6}\sim84.72\times10^{-6}$,指示成矿物质来源主要为壳幔混源。

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Re−Os dating of molybdenite from the Lietinggang iron polymetallic deposit of Tibet and its geological significance

YANG Yi[1], DUO Ji[2], LIU Hong−fei[3], ZHANG Jin−shu[3],
WANG Li−qiang[4], ZHANG Zhi[1], HU Zheng−hua[5]

(1. *Chengdu University of Technology, Chengdu* 610059*, Sichuan, China;* 2. *Department of Land and Resources of Tibet, Lhasa* 850000*, Tibet, China;* 3. *Geological Survey of Tibet, Lhasa* 850000*, Tibet, China;*4. *Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing* 100037*, China;* 5. *Geological Survey of Jiangxi Province, Nanchang* 330000*, Jiangxi, China*)

Abstract: Among lots of polymetallic deposits, the Lietinggang deposit in the Lhunzhub Basin of Tibet is one of the deposits with best industrial value and exploration prospect. It is a typical deposit where Fe, Cu, Mo, Pb and Zn have been found. High precision Re−Os dating was conducted for 10 molybdenite samples for determining the mineralization age of the Lietingang deposit. It is for the first time that the high precision mineralization age of the deposit has been obtained. The test result indicates that the Re−Os model ages vary in the range of (60.97+0.92) Ma−(63.19+0.93) Ma, and the isochron age is (62.28+0.66) Ma, with MSWD being 0.74. During the main Indosinian collision period in the Gangdise belt, the deposit was formed in the Paleocene. The Re values of 8 pieces of molybdenite are mainly concentrated in the range of $0.54\times10^{-6}-84.72\times10^{-6}$. The sources of the ore−forming materials were mainly from the Earth's mantle and crust. The determination of the ore−forming epoch and metallogenic material of the Lietinggang deposit is of great significance for the regional ore−prospecting prognosis of early Paleocene iron−polymetallic deposits.

Key words: Re−Os isotope; metallogenic epoch; Lietinggang iron polymetallic deposit; Lhunzhub Basin; Gangdise metallogenic belt

About the first author: YANG Yi, male, born in 1983, doctor candidate, mainly engages in the study of mineral deposits; E−mail: 290744982@qq.com.

About the corresponding author: WANG Li−qiang, male, born in 1984, assistant researcher, engages in the study of mineralogy, petrology and mineral deposits; E−mail: wlq060301@163.com.