文章编号: 0258-7106 (2021) 02-0273-20

中国斑岩铜(钼)矿床中辉钼矿 Re 含量变化 及控制因素*

孙鹏程^{1,2},李 超^{1,2**},周利敏^{1,2},屈文俊^{1,2},孙 豪³,李欣尉^{1,2},赵 鸿^{1,2},杜安道^{1,2} (1国家地质实验测试中心,北京 100037;2中国地质调查局 Re-Os 同位素地球化学重点实验室,北京 100037; 3中国地质科学院矿产资源研究所,北京 100037)

摘 要 铼作为战略性关键金属之一,越来越受到人们的关注。Re 主要以类质同象的形式赋存在辉钼矿中, 然而,不同成因、不同类型矿床的辉钼矿中 Re 含量差异较大。在钨、锡矿床中 Re 含量较低,在斑岩型铜(钼)矿床 中 Re 含量较高,后者是全球 Re 资源的主要载体。前人对于辉钼矿中 Re 元素的研究主要基于 Re-Os 同位素年代 学,而对于不同区域、不同时代、不同类型斑岩型铜矿床中辉钼矿 Re 含量的变化规律及其控制因素的研究较少。 文章通过汇总前人发表的斑岩型铜(钼)矿床的 Re-Os 同位素数据,从含矿斑岩的 Sr、Nd、Hf 等数据与辉钼矿中平 均 Re 含量的关系等角度,探讨了其变化规律及控制因素。结果表明:中国斑岩型铜(钼)中 Re 含量随着成矿物质 从地幔到地壳,依次减少;成矿流体的氧逸度、辉钼矿的产状、与其伴生的硫化物种类及不同的成矿阶段等因素共 同控制了辉钼矿中 Re 的含量。

关键词 地球化学;斑岩型矿床;辉钼矿;Re 含量;成矿带;物质来源 中图分类号:P618.41;P618.65;P597 **文献标志码**:A

Variations and controlling factors of Re content of molybdenite in porphyry Cu (Mo) deposits of China

SUN PengCheng^{1,2}, LI Chao^{1,2}, ZHOU LiMin^{1,2}, QU WenJun^{1,2}, SUN Hao³, LI XinWei^{1,2},

ZHAO Hong^{1, 2} and DU AnDao^{1, 2}

(1 National Research Center for Geoanalysis, Beijing 100037, China; 2 Key Laboratory of Re-Os Isotope Geochemistry, China Geological Survey, Beijing 100037, China; 3 Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China)

Abstract

Re (rhenium), as one of the key strategic metals, has attracted more and more attention among researchers. Re occurs mainly in molybdenite in the form of isomorph. However, Re content in molybdenite varies with different geneses and types of deposits. Re content in tungsten and tin deposits is relatively low, while that in porphyry copper (molybdenum) deposits is relatively high, which serve as the main carrier of Re resources in the world. Previous studies of Re in molybdenite have been mainly based on Re-Os isotope chronology, but the studies of the variation rules and controlling factors of Re content in molybdenite of porphyry copper deposits in different regions, ages and types have been very insufficient. In this study, by collecting the available Re-Os isotope data of porphyry copper (copper-molybdenum) deposits, the relationship between Sr-Nd-Hf of ore-bearing rocks and

^{*} 本文得到国家自然科学基金项目(编号:41673060,41873065)共同资助

第一作者简介 孙鹏程, 男, 1992年生, 硕士研究生, 分析化学专业。Email: pengchengsun1225@163.com

^{**} 通讯作者 李 超,男,1983 年生,副研究员,从事 Re-Os 同位素及矿床地球化学研究。Email: Re-Os@163.com

收稿日期 2020-10-31;改回日期 2021-02-26。张绮玲编辑。

the average Re content in molybdenite was investigated. The results show that the Re content in porphyry copper (copper-molybdenum) deposits in China decreases with the change of metallogenic material from the mantle to the crust. Re content in molybdenite is controlled by oxygen fugacity of ore-forming fluid, the modes of occurrence of molybdenite, the types of sulfides associated with molybdenite, different metallogenic stages and other factors.

Key words: geochemistry, porphyry deposit, molybdenite, Re content, metallogenic belt, material source

斑岩型铜矿主要分布在环太平洋、特提斯-喜马 拉雅、古亚洲(中亚成矿带)3个全球性成矿域(Yang et al., 2019; 王瑞等, 2020)。斑岩型铜矿床约占所有 类型铜矿的42%(Chen et al., 2013),提供了世界上 近 75% 的 Cu、50% 的 Mo 和 20% 的 Au (Sillitoe, 2010; Sun et al., 2015)。另外,还包括一些关键金 属,如铼(Re)、硒(Se)和碲(Te)等在一些斑岩型铜矿 床中富集。虽然在一些斑岩型矿床中Re平均品位 较低(通常w(Re) < 10 µg/g),但储量较大,约80%的 Re都来自于斑岩型矿床。Re主要以类质同象形式 取代 Mo 进入辉钼矿晶格中(Stein et al., 2001; 2003; 李超等,2011)。然而,不同矿床辉钼矿中的Re含量 差异较大,在钨锡矿床中的辉钼矿 Re含量较低,而 在斑岩型铜(钼)矿床中的辉钼矿Re含量相对较高, 是Re资源的主要载体。前人对于辉钼矿Re-Os同位 素分析主要集中于成矿年代学研究(唐菊兴等, 2009;Leng et al., 2013; Zhu et al., 2015), 而关于辉钼 矿微量元素含量的研究相对较少,特别是对于不同 区域、不同时代、不同类型斑岩型铜矿床中辉钼矿 Re含量的变化规律以及控制因素研究更少。

本文以中国斑岩型铜(钼)矿床为研究对象(图 1),收集了前人发表的中国冈底斯成矿带、玉龙成矿 带、多龙成矿带、中甸成矿带、哀牢山成矿带、中亚成 矿带、中条山成矿带、长江中下游成矿带、东南沿海 带及其他一些成矿带的斑岩型铜(钼)矿中辉钼矿 Re-Os同位素数据及含矿斑岩的Sr、Nd和Hf同位素 数据(陈超等,2013;戴盼等,2018;高一鸣等,2012; 高永宝等,2015; Hou et al., 2013; 贾丽琼等, 2013; 2015; 郎兴海等, 2010; 冷成彪等, 2007; 冷秋锋等, 2015;2016;李光明等,2005;2006;吕博等,2014;孟 祥金等,2003a;2003b;芮宗瑶等,2002;孙燕等, 2013; 唐菊兴等, 2009a; 2010; 王召林等, 2008; 吴云 辉等,2013;辛洪波等,2009;杨志明等,2011;赵一鸣 等,1997;赵元艺等,2009;曾普胜等,2004;2012;朱 明田等,2010;祝向平等,2015a;2015b),探讨了辉钼 矿中Re的分布行为及控制因素。

1 Re含量变化规律及控制因素

关于中国斑岩型铜矿床的岩浆源区存在多种观 点。有些研究者认为,含矿斑岩主要来自于加厚下 地壳的部分熔融(Zhang et al., 2001; Hou et al., 2003; 2019; Wang et al., 2018)。而对于大陆环境, 侯增谦 等(2007)认为直接起源于古老下地壳的长英质岩浆 一般不能形成斑岩型铜矿床,而含矿斑岩的岩浆源 区主要为加厚的新生镁铁质下地壳或拆沉的古老下 地壳与地幔物质的混合。铼在大陆地壳中的丰度为 w(Re) 0.18~2 ng/g,平均为 0.4 ng/g(Taylor et al., 1995)。据估算, 斑岩型铜(钼) 矿床中 Re 的品位一 般在 0.03~ 0.n g/t 之间 (Millensifer et al., 2013)。斑 岩型铜(钼)矿床中的Re大多数以类质同象的形式 取代 Mo 进入辉钼矿 (Stein et al., 2003; 李超等, 2011) 晶格中, w(Re)从<10 µg/g到几万 µg/g不等。相 比之下,斑岩型钼矿尽管Mo的品位很高,但辉钼矿 的Re含量通常较低(多数*w*(Re)≤100 μg/g)。

Sr、Nd以及Hf同位素具有重要的示踪意义,在 矿床地质研究中常用于示踪成矿物质来源、含矿流 体、深源熔体的壳幔混染作用(Tatsumoto et al., 1992; Zhang et al., 2002; Yang et al., 2006; Wang et al., 2018)。

统计结果显示(图 2a),中国斑岩型铜矿含矿斑 岩的初始 Sr 同位素比值在 0.703~0.718之间,说明成 矿物质有地幔来源,也有壳幔混合源。⁸⁷Sr/⁸⁶Sr 初始 值与辉钼矿中 Re 的平均含量呈负相关,表明地壳物 质大量参与斑岩型矿床的形成,不利于 Re 在辉钼矿 中富集。由图 2b 可知, Re 含量随着 $\epsilon_{Nd}(t)$ 变大,有增 高的趋势,说明中国斑岩型铜矿的成矿物质来自于 地幔,形成的辉钼矿中 Re 含量较高。在岩浆演化 过程中, $\epsilon_{Hf}(t)$ 示踪成矿物质来源类似于 $\epsilon_{Nd}(t)$ 。由 图 2c 可知,中国斑岩型矿床的成矿物质来源于地 幔,则形成的辉钼矿 w(Re)较高,常大于 100 μ g/g。 随着 $\epsilon_{Hf}(t)$ 增加,辉钼矿中 Re 含量有增加的趋势,说





明随着地幔超镁铁-镁铁质熔体的不断分异演化, 有利于Re的迁移和富集。Sr、Nd、Hf同位素统计 结果表明,中国斑岩铜(钼)矿床的成矿物质有壳 源、幔源和壳幔混合源3种,当成矿主体来源于地 幔时,辉钼矿中Re含量最高,壳幔混合源次之,壳 源含量最低。

如图 3a 所示,中国斑岩型铜(钼)矿床中辉钼矿 平均 Re含量与斑岩型铜(钼)矿中 Cu的储量呈一定 的正相关性。由图 3b 可知,含矿斑岩的 Cu/Mo 与斑 岩体中辉钼矿的 Re含量整体上呈正相关,说明 Re 和 Mo 的来源可能一致。矿床 Re 储量与 Cu、Mo 储 量呈正相关(图 3c、3d),表明地幔物质大量参与斑岩 型矿床的形成,有利于 Re 在辉钼矿中富集。据图 3e,Cu与 Mo 储量没有相关性,可能反映了 Cu与 Mo 的来源有差异。

图4表明,中国斑岩型铜(钼)矿床主要形成于 新近纪、古近纪、白垩纪、侏罗纪、三叠纪、泥盆纪、志 留纪、奥陶纪和寒武纪。其中,白垩纪、侏罗纪和三 叠纪形成的斑岩矿床中辉钼矿Re平均含量最高,泥 盆纪和志留纪次之,新近纪、古近纪、奥陶纪和寒武 纪最低。据统计,二叠纪和志留纪目前没有发现斑 岩型矿床,这可能与局部区域在这一时期没有发生 大的地质构造作用有关,说明不同的地质构造背景 可能会影响辉钼矿中的Re含量。

2 讨 论

2.1 成矿物质来源

Mao等(1999)研究表明:成矿岩浆来源于地幔 形成的辉钼矿 Re含量高于壳源和混合来源的辉钼 矿。Stein等(2001)同样认为地幔的底侵或交代作 用、基性和超基性岩的熔融,形成的辉钼矿 Re含量 要高于壳源。在板块俯冲过程,随着洋壳向深处运 移,由于大洋沉积物、海水等组分的加入,使得地幔 楔发生部分熔融。Sun等(2003;2004)研究表明,在 岛弧环境中,地幔楔 Re的富集实际上是在板块俯冲 过程中加入的。Sun等(2004)证实了 Re在俯冲带流 体中是活动的,并且在俯冲板块脱水释放流体的同



图2 含矿岩体的初始⁸⁷Sr^{/86}Sr (a)、 $\epsilon_{Nd}(t)$ (b)、 $\epsilon_{Hd}(t)$ (c)与辉钼矿中平均Re含量关系图解

图中数据来源:Guo et al., 2012; Huang et al., 1996; Huang et al., 2017; Leng et al., 2012; Li et al., 2005; Meng et al., 2003; Wang et al., 2016; 陈超等, 2013; 陈华安等, 2013; 戴盼等, 2018; 高旭等, 2018; 高一鸣等, 2012; 高永宝等, 2015; 郭保健等, 2006; 郭周平等, 2015; 郝金华等, 2012; 何书 跃等, 2009; 和文言等, 2013; 侯增谦等, 2003; 黄勇等, 2015; 贾丽琼等, 2013, 2015; 康永建等, 2014; 冷成彪等, 2007; 冷秋锋等, 2015; 2016; 李利等, 2018; 梁清玲等, 2012; 林涛等, 2017; 吕博等, 2014; 屈迅等, 2009; 曲凯等, 2014; 任江波等, 2011; 任涛等, 2014; 佘宏全等, 2009; 孙燕等, 2013; 唐菊兴等, 2009; 王保弟等, 2010; 王世伟等, 2012; 2014; 吴良士等, 1997; 吴伟中等, 2013; 吴云辉等, 2013; 肖兵等, 2017; 谢桂青等, 2006; 萨春纪等, 2011; 杨富全等, 2012; 杨贵才等, 2014; 杨震等, 2017; 杨志明等, 2011; 袁顺达等, 2013; 张达玉等, 2010; 张刚阳等, 2008; 张连昌等, 2013; 张涛等, 2015; 张玉泉等, 1998; 张志欣等, 2009; 张作衡等, 2006; 赵晓燕等, 2017; 赵一鸣等, 1997; 赵元艺等, 2009; 赵云等, 2013; 郑有业等, 2004; 2007; 朱明田等, 2010; 祝向平等, 2011; 2015a

Fig. 2 Correlation diagram of ⁸⁷Sr/⁸⁶Sr(a), $\varepsilon_{Nd}(t)$ (b), $\varepsilon_{Hf}(t)$ (c) in ore-bearing porphyry and average Re content in molybdenite The data source: Guo et al., 2012; Huang et al., 1996; Huang et al., 2017; Leng et al., 2012; Li et al., 2005; Meng et al., 2003b; Wang et al., 2016; Chen C et al., 2013; Chen H A et al., 2013; Dai et al., 2018; Gao X et al., 2018; Gao Y M et al., 2012; Gao et al., 2015; Guo B et al., 2006; Guo et al., 2015; Hao et al., 2012; He S et al., 2009; He W et al., 2013; Hou et al., 2003; Huang et al., 2015; Jia et al., 2015; Kang et al., 2014; Leng C et al., 2007; Leng Q et al., 2015; 2016; Li et al., 2018; Liang et al., 2012; Lin et al., 2017; Lv et al., 2014; Qu X et al., 2009; Qu K et al., 2014; Ren J et al., 2011; Ren T et al., 2014; She et al., 2009; Sun et al., 2013; Tang et al., 2009; Wang B et al., 2010; Wang S et al., 2012; 2014; Wu L et al., 1997; Wu W Z et al., 2013; Wu Y H et al., 2013; Xiao et al., 2017; Xie et al., 2006; Xue et al., 2011; Yang F et al., 2012; Yang G et al., 2014; Yang Z et al., 2017; Yang Z M et al., 2011; Yuan et al., 2013; Zhang D et al., 2010; Zhang G et al., 2008; Zhang L et al., 2013; Zhang T et al., 2015; Zhang Y et al., 1998; Zhang Z et al., 2009; Zhang Z H et al., 2006; Zhao X et al., 2017; Zhao Y M et al., 1997; Zhao Y Y et al., 2009; Zhao Y et al., 2013;

Zheng et al., 2004; 2007; Zhu et al., 2010; Zhu X P et al., 2011; 2015a



图 3 Cu储量与Re储量(a)、Cu/Mo与辉钼矿Re含量(b)、Mo储量与Re储量(c)、Cu储量与Re储量(d)及Cu储量与Mo储量(e)图解

数据来源:高一鸣等,2012;侯增谦等,2003;黄勇等,2015;贾丽琼等,2015;康永建等,2014;Leng et al.,2013;冷秋锋等,2015;李光明等,2005, 2006;Li et al.,2015;孟祥金等,2003a;2003b;Ouyang et al.,2014;屈迅等,2009;芮宗瑶等,2002;王保弟等,2010;王立本等,1997;王世伟等, 2012;2014;吴良士等,1997;谢桂青等,2006;Xie et al.,2007;杨富全等,2012;杨贵才等,2014;Zhang et al.,2015;张刚阳等,2008;张志欣等, 2009;赵冰爽,2018;赵一鸣等,1997;赵云等,2013;Zhao et al.,2014;郑有业等,2004;周雄等,2013;朱明田等,2010

Fig. 3 The diagrams of Re reserves versus Cu reserves(a), Cu/Mo versus Re content in molybdenite(b), Mo reserves versus Re reserves(c), Cu reserves versus Re reserves(d) and Cu reserves versus Mo reserves(e)

The data source: Gao et al., 2012; Hou et al., 2003; Huang et al., 2015; Jia et al., 2015; Kang et al., 2014; Leng et al., 2013; Leng Q et al., 2015; Li G et al., 2005; 2006; Li et al., 2015; Meng et al., 2003a, 2003b; Ouyang et al., 2014; Qu et al., 2009; Rui et al., 2002; Wang B et al., 2010; Wang L et al., 1997; Wang S et al., 2012; 2014; Wu et al., 1997; Xie G et al., 2006, 2007; Yang F et al., 2012; Yang G et al., 2014; Zhang et al., 2015; Zhang G et al., 2008; Zhang Z et al., 2009; Zhao B et al., 2018; Zhao Y M et al., 1997; Zhao Y et al., 2013; Zhao et al., 2014; Zheng et al., 2004; Zhou et al., 2013; Zhu et al., 2010

时得到了富集。

富有机质黑色岩系为斑岩型铜矿(钼)的形成提 供了一部分还原性物质(Rowins, 2000; Wilkinson, 2013; Richards et al., 2017; Shen et al., 2017)和少量 的金属元素 Cu、Mo等。黑色页岩等富有机质沉积 岩中富含 Re,如黑海和日本海黑色页岩的 w(Re)分 别为43 ng/g和12 ng/g(Crusius et al., 1996);挪威的 黑色页岩w(Re) > 20 ng/g(Lipinski et al., 2003),而大



图 4 不同时代矿床中Re含量变化图解 Fig. 4 Diagram of Re content changes in ore deposits of different ages

陆上地壳的 w(Re) 仅为 2 ng/g (Sun et al., 2003)。黑 色岩系作为 Re 的赋存迁移载体之一, 很可能是斑岩 型铜矿中 Re 的物质来源之一。

因此,成矿物质来源于地幔,如果在后期成矿过 程有少量富有机质黑色岩系参与,会使得矿床中辉 钼矿的Re含量增高。

2.2 Cu和Mo储量

由图 3c 可知, Mo 在矿床中储量越高,其主要载 体辉钼矿在矿体中所占比例就越多,则 Re 在矿体中 就越分散。因此, 所测单颗辉钼矿样品中 Re 含量就 相对越低。Cu 通常与 Cl-或 SO₄²⁻等结合成络合物在 流体中迁移(Pokrovski et al., 2005; Berry et al., 2009; Webster et al., 2011), Mo 在流体中会与 O、Cl-等结合形成络合物(Ulrich et al., 2008)而稳定存在, Mo 在流体中的稳定性主要受流体温度压力变化的 影响(Klemm et al., 2008), 表明成矿温度可能是影响 辉钼矿中 Re 含量的另一个关键因素(Berzina et al., 2005)。

Re主要赋存于辉钼矿中,Mo常与硫结合生成 辉钼矿(MoS₂),在辉钼矿大量结晶阶段,成矿岩浆或 热液中赋存迁移的Re尽可能多的进入到辉钼矿晶 格。在一定范围内(Mo储量约 0.03 Mt),随着矿床 Mo储量的持续增加,Re储量急剧增加,这可能说明 在这一阶段流体中的Re大规模进入辉钼矿晶格,使 得矿体中Re储量明显增高。当超出此范围时,随着 Mo储量的持续升高,矿体Re储量增加缓慢。说明 在辉钼矿大量的结晶阶段,流体的氧逸度、温度和组 分等发生变化,一些硫化物(黄铁矿、黄铜矿等)开始 结晶,消耗残余流体中少量的Re,使得进入辉钼矿 晶体中的Re减少。矿床中Mo储量与Cu储量没有 明显的相关性(图3e),可能反映了中国斑岩型铜 (钼)矿床的Mo与Cu的来源存在差异,或者说明成 矿物质在上升过程通过与围岩相互作用等,改变了 含矿熔体的性质,促使Cu与Mo体系解耦。结合图 3,可能说明金属Re不是单一的来源,有多个端员的 贡献。

2.3 氧逸度

含辉钼矿较少的斑岩型 Cu-Mo(Cu-Au 或 Cu-Mo-Au)体系中,辉钼矿 Re含量通常较高,而辉钼矿 含量较高的斑岩型 Mo矿床中(如:Climax 型钼矿), Re在辉钼矿中的含量则相对较低。相比之下,斑岩 型 W-Mo(Mo-W)矿床中辉钼矿 Re含量最低。 Zhong等(2017)认为这主要与偏还原性的成矿流体 有关,偏还原性的岩浆不利于 Re在辉钼矿中富集, 可能由以下几种因素控制:① Re具有亲硫(铜)的地 球化学性质,在偏还原环境中,Re常与 S²⁻结合形成 ReS₂而沉淀。因此,含还原性硫较多的岩浆或熔体 不利于 Re的迁移;② 相比于硅酸盐岩浆,Re更倾向 于进入硫化物(Righter et al., 1998);③ 在源区偏还 原或还原环境下,还原性的硫很容易在硅酸盐体系 达到饱和,而残留在岩浆源区,随岩浆迁移的S和Re 含量较少,导致后期成矿过程进入辉钼矿中的 Re含 量偏少。Sun 等(2013)研究表明:氧化性Fe³⁺在后期 斑岩型矿床形成时具有重要意义,而还原性的岩浆 或熔体,Fe³⁺通常含量较少,同样不利于Re在后期进 入辉钼矿晶格。而斑岩型Cu-Mo-Au矿床,氧逸度相 对高,S主要以SO²⁻等形式出现,有利于Re进入硅 酸盐岩浆。驱龙斑岩型Cu-Mo矿床是中国目前发现 的最大的斑岩型矿床,含矿斑岩体中含有大量的岩 浆成因石膏,说明此矿床的初始成矿岩浆或热液成 矿系统具有较高的氧逸度(Yang et al., 2009; Wang et al., 2014)。

尽管地球的氧逸度在不同时期有一定的波动, 但整体上呈上升趋势。可能反映了随着大气氧逸 度的增加,对一些较为富集 Re的矿物(辉钼矿、黄 铁矿、黑色页岩及沥青等)剥蚀加剧,增大了大陆对 成矿体系的补给量。Golden 等(2013)表明,在3.0 Ga以来,近地表的氧逸度逐渐增加,有利于 Re 在 其中迁移富集,这可能说明岩浆的氧逸度在一定程 度上影响了斑岩型铜(钼)矿床中辉钼矿的 Re 含量。

2.4 成矿时代

统计结果显示,在515 Ma以前,很少发现中国 典型斑岩型铜矿(图4),这可能与新元古代(750~ 542 Ma) 时期的全球性氧化事件 (Reinhard et al., 2017)有关,或在这一时期内地层受到强烈的构造挤 压,使得地层抬升剥蚀加剧。而斑岩矿床是一个浅 成系统,使得早期形成的斑岩型矿体部分被剥蚀。 Reinhard等(2017)也提出,新元古代出现过全球性 大氧化事件。这一时期,相对富集 Mo 和 Re 的黑色 页岩大量出现,黑色页岩等富集Re的矿物在板块俯 冲环境下熔融,使得Re在局部发生富集作用。这些 富含Re的岩浆或熔体在后期地质作用下参与了斑 岩型铜(钼)矿床的形成,则辉钼矿中Re含量较高。 李聪颖等(2020)认为,在500 Ma以前没有形成斑岩 型Mo矿,也与这一时期的氧化事件有关联。揭示了 岩浆缺氧在一定程度上影响了斑岩型铜矿中Re的 含量。

总体来说,矿床形成时代越老,其辉钼矿中Re 含量越低,Re属于变价元素,对氧化还原环境较为 敏感。不同时代辉钼矿Re含量的变化可能由成矿 系统的氧逸度控制。

2.5 不同区域成矿带

中国的斑岩型铜(钼)矿主要分布在冈底斯成矿 带、中亚成矿带和长江中下游成矿带。本文主要探 讨冈底斯、中亚和长江中下游3个成矿带的斑岩型 矿床中辉钼矿平均Re含量的变化规律及其控制 因素。

选取冈底斯成矿带中驱龙、朱诺、吉如、冲江、岗 江、厅宫、南木、达布、帮浦、拉抗俄、尕尔穷、冲木 达、汤不拉和沙让斑岩型矿床,来揭示这一成矿区 辉钼矿中Re含量的变化及其控制因素。统计结果 如图5所示,在冈底斯成矿带,多数矿床形成于新 生代,少量形成于中生代。其中,新近纪形成的斑 岩矿床,辉钼矿平均Re含量变化较大(最高的拉抗 俄矿床中w(Re)为558 µg/g,最低的沙让矿床中辉钼 矿w(Re)为54 µg/g),且多数含量较为集中。

张泽明等(2019)和Zhu等(2017a)研究表明,冈 底斯成矿带的岩浆作用是幕式的,具有3个明显的 峰期:晚白垩世(95~90 Ma)、早始新世(52~48 Ma) 和早-中中新世(18~14 Ma),第二个峰期为大陆碰撞 阶段(即65~48 Ma)。冈底斯成矿带斑岩型矿床主 要形成于21~12 Ma,属于后碰撞阶段,此阶段大量 的中酸性岩(如二长花岗斑岩、二长斑岩、英安岩和 流纹岩等)形成,伴随少量的基性岩。这些具有埃达 克质岩地球化学特征的中酸性岩石被认为是冈底斯 弧新生的加厚下地壳部分熔融产物(Zhang et al., 2015; Yang et al., 2016a; Zeng et al., 2017)。但也有 部分研究者认为这些具有埃达克质岩地球化学特征



图5 冈底斯成矿带、中亚成矿带、长江中下游成矿带不同时 代辉钼矿 Re含量变化图解

Fig. 5 Correlation diagram of the Gangdise metallogenic belt, the Central Asian metallogenic belt and the Middle and Lower Yangtze River metallogenic belt with the changes of Re content in molybdenite of different ages 的岩石来源于俯冲板块熔体交代地幔楔(Qu et al., 2004),或幔源超钾质岩浆与壳源岩浆的混合产物 (Yang et al., 2015; Wang et al., 2015; 2016),表明冈 底斯成矿带中大量斑岩型铜(钼)矿床形成于大陆后 碰撞阶段,形成的辉钼矿以Re平均含量高、变化大 且成矿期较为集中为特点。

中亚成矿带在中国主要包括新疆、甘肃北部和 内蒙等地区,此矿带内发育有多处大型和超大型的 斑岩型铜(钼)矿床。本次研究选取土屋-延东、包古 图、蒙西云影山、白乃庙、莱历斯高尔、卡拉塔格、玉 勒肯哈腊苏、多宝山、乌奴格吐山、布敦花和八大关 等斑岩矿床,来探讨中亚成矿带斑岩型矿床中辉钼 矿Re含量的变化规律及其控制因素。如图4所 示,中亚成矿域斑岩型矿床的成矿期主要有早古生 代、晚古生代、中生代和新生代。其中,二叠纪和志 留纪没有形成储量较大的斑岩型矿床。而泥盆纪 斑岩型矿床的辉钼矿中Re含量最高且差异较大, 石炭纪、奥陶纪和寒武纪次之,中生代含量最少。 另外,此成矿带斑岩型矿床的成矿高峰期为泥盆纪 和石炭纪。中亚成矿域斑岩铜(钼)矿床的成矿构 造地质背景主要为岛弧环境(朱永峰等,2007;申萍 等,2015)。随着冈瓦那大陆的裂解,板块碎片逐渐 形成了多数前寒武纪地质单元,然后漂过古亚洲 洋,与东欧和西伯利亚板块拼合形成了中亚造山 带。朱永峰等(2007)认为,中亚成矿域是由古特提 斯洋俯冲消减造成的。从奥陶纪晚期到早二叠世, 西伯利亚板块发生顺时针旋转,期间引起多期岩浆 活动。加里东构造作用使得区域内大部分地区在 晚古生代经受了不同的隆起和剥蚀,二叠纪时期大 量地层处于抬升,造成中亚成矿带在这一时期没有 斑岩型矿床的形成。结合图5,说明中亚成矿带内 斑岩型铜(钼)矿床的成矿期较为分散,辉钼矿中 Re含量差异大。

长江中下游成矿带作为为中国东部重要的斑岩型成矿带,其内有多个重要的斑岩型矿床,如:城门山铜-钼矿床、丰山洞铜-金矿床、沙溪铜-金矿床、铜山口铜-钼矿床、舒家店铜矿床、安基山铜矿床、马头钼-铜矿床和宝山铜多金属矿床。本次选取以上矿床来探讨本区域辉钼矿中Re的特征。统计结果如图5所示,长江中下游成矿带斑岩型铜矿主要形成于白垩纪,由燕山期陆内造山作用主导。各矿体间Re含量差异较大。周涛发等(2016)认为,该区域内与斑岩型矿床有关的岩浆活动主要发生于149~108

Ma,可以进一步分为早期(149~134 Ma)、中期(133~ 130 Ma)和晚期(120~108 Ma)三个阶段。其中,早 期和晚期以斑岩-砂卡岩型矿化为主,中期以斑岩型 矿化为主。常印佛等(2019)对长江中下游成矿带研 究发现,本区自中侏罗世开始,由古太平洋板块向华 南板块之下俯冲,使得该区域发生强烈的陆内造山 运动,同时受华北板块和大别地块的影响,造成长江 中下游成矿带内地层严重变形,岩石圈加厚。早白 垩世开始,受太平洋板块俯冲的影响,导致岩石圈发 生熔融,引发了岩浆活动且伴随一系列的成矿作用。 因此,周涛发等(2016)认为,太平洋板块的俯冲作用 是导致长江中下游成矿带在燕山期形成一系列斑岩 型矿床的根本原因。长江中下游成矿带内斑岩型铜 (钼)矿床主要形成于以下的地质过程,自燕山期开 始,受太平洋板块俯冲的影响,使得该区域内地壳加 厚(厚度 > 100 km),之后发生岩石圈的熔融、熔体上 升和结晶分异等过程,成矿物质最后储存在地壳深 部,并参与了斑岩型矿床的形成。该区域形成的斑 岩型铜矿以成矿期较为集中,辉钼矿Re含量差异大 为特征。

综上所述(图5),不同的地质构造背景可能会影 响辉钼矿中Re的含量。

2.6 成矿母岩浆的演化程度(SiO₂含量)

由图6可以看出,随着含矿斑岩体中w(SiO₂)的 增加,辉钼矿中Re含量下降,w(SiO₂)与Re含量呈 负相关。说明成岩母岩浆演化程度越高,形成的斑 岩型铜(钼)中辉钼矿Re含量越低。其中,w(SiO₂) 在 52%~65% 之间, 有几个矿区 Re 含量是最高的, 这可能说明含矿斑岩的岩性在一定程度上也会 影响Re在辉钼矿中的含量。Sillitoe(2010)研究 表明与铜矿化有关的斑岩主要为中-酸性钙碱性 岩浆,岩性变化于石英闪长岩与花岗岩之间。当 $w(SiO_2) > 65\% 时, 斑岩型铜矿床的数量最多, 而辉$ 钼矿中Re含量则减少,说明:①参与形成斑岩型 铜矿床的地壳物质越多,越不利于Re在斑岩型矿 床中富集;② 硅酸盐体系贫 Re 且不利于 Re 迁移。 Re为不相融元素,一般在岩浆演化的晚期富集,即 热液流体中大量参与形成辉钼矿,基本上由硫化物 控制,说明成矿母岩浆的演化程度可能会影响辉钼 矿中的Re含量。

2.7 辉钼矿产状及成矿阶段

本次研究选取内蒙古东部白土营子钼-铜矿,探 讨其不同成矿阶段形成的辉钼矿 Re含量的规律及





数据来源:Leng et al., 2013; Li et al., 2005; Ouyang et al., 2014; Wang et al., 2016; Zeng et al., 2004; 陈超等, 2013; 陈文明等, 1998; 高永宝等, 2018; 郭保健等, 2006; 郝金华等, 2012; 康永建等, 2014; 冷成彪等, 2007; 冷秋锋等, 2015; 李志军等, 2011; 林涛等, 2017; 孟祥金等, 2003b; 任涛等, 2014; 芮宗瑶等, 2002; 佘宏全等, 2009; 谭钢等, 2010; 王保弟等, 2010; 王登红等, 2004; 王世伟等, 2012; 王召林等, 2008; 杨富全等, 2012; 杨震等, 2017; 袁顺达等, 2013; 张达玉等, 2010; 赵晓燕等, 2017; 赵云等, 2013; 郑有业等, 2004; 2007; 朱明田等, 2010; 祝向平等, 2011; 2015b

Fig. 6 Correlation diagrams of SiO₂ content in magmatic rocks with the average Re content of molybdenite
The data source: Leng et al., 2013; Li et al., 2005; Ouyang et al., 2014; Wang et al., 2016; Zeng et al., 2004; Chen C et al., 2013; Chen W et al., 1998;
Gao et al., 2018; Guo et al., 2006; Hao et al., 2012; Kang et al., 2014; Leng C et al., 2007; Leng Q et al., 2015; Li et al., 2011; Lin et al., 2017; Meng et al., 2003b; Ren et al., 2014; Rui et al., 2009; Tan et al., 2010; Wang B et al., 2010; Wang D et al., 2004; Wang S et al., 2012; Wang Z et al., 2008; Yang F Q et al., 2012; Yang Z et al., 2017; Yuan et al., 2013; Zhang et al., 2010; Zhao X et al., 2017;

Zhao Y et al., 2013; Zheng et al., 2004; 2007; Zhu et al., 2010; Zhu et al., 2011; 2015b

其影响因素。在B脉石英期(主成矿期),以辉钼矿-黄铜矿发育,见有少量黄铁矿及斑铜矿为特征。D 脉硫化物期(成矿晚期)黄铁矿绝对占优,常见黄铜 矿、石英,有时可见少量的辉钼矿及其他硫化物为 主。B脉石英期形成的辉钼矿相对于D脉硫化物 期的辉钼矿 Re含量较低。在主矿化期(即B脉 期),大量的辉钼矿形成,熔体中大量的 Re进入辉 钼矿晶体,占据 Mo 的晶格位置。D脉硫化物期,仅 有少量的辉钼矿生成,残余熔体中剩余的少量 Re 进入有限的辉钼矿晶体,使得 Re含量高于B脉石 英期(Austen et al., 2010; Shafiei et al., 2015; Ren et al., 2018).

驱龙铜-钼矿位于西藏冈底斯成矿带,属于超 大型斑岩铜-钼矿床。本次利用前人(孟祥金等, 2003b)对西藏冈底斯成矿带驱龙铜-钼矿床(表1) 研究结果,来探讨辉钼矿产状(细脉状、浸染状)是 否会影响Re在其中的含量。以浸染状产出的辉钼 矿,w(Re)为334~466 μg/g,平均为450 μg/g。以细脉 状产出的辉钼矿,w(Re)为307~1218 μg/g,平均值为 724 μg/g。结果表明,以浸染状产出的辉钼矿 Re的 含量高于细脉状的辉钼矿,说明辉钼矿的产状可能 会影响Re的含量。

表1 驱龙斑岩型铜-钼矿床中不同产状辉钼矿的Re含量(据孟祥金等,20

Table 1	Re content of molybdenite of	different modes of occurrence	e in the Qulong	g copper-molybdenum	porphyry deposit
---------	------------------------------	-------------------------------	-----------------	---------------------	------------------

(after Meng et al., 2003a)								
样品编号	$w(\text{Re})/(\mu g/g)$	模式年龄/Ma	样品描述					
QK03	615.4	16.21	含浸染状辉钼矿、黄铜矿的二长花岗斑岩					
QK06	333.9	15.99	浸染状辉钼矿化、黄铜矿化黑云母花岗岩					
QK07	1218.2	16.17	含辉钼矿、黄铜矿的花岗闪长岩					
QK09	465.7	16.11	浸染状辉钼矿化、黄铜矿化黑云母花岗岩					
QK46	757.0	16.74	含浸染状辉钼矿、黄铜矿的二长花岗斑岩					
QK52	306.7	16.42	含辉钼矿的石英细脉					

3 结 论

(1) Re 主要以类质同象的形式赋存在辉钼矿中。当成矿物质来源于地幔时,形成的辉钼矿中 Re 含量最高,来源于壳幔混合源的辉钼矿次之,来源于壳源的辉钼矿 Re 含量最低。

(2)中国斑岩型铜(钼)矿床主要形成于新近 纪、古近纪、白垩纪、侏罗纪、三叠纪、泥盆纪、志留 纪、奥陶纪和寒武纪,且年代越新,辉钼矿中Re含量 越高。

(3) 斑岩型矿床中辉钼矿常以浸染状、细脉状和网脉状为主, 一般 w(Re)由 n µg/g~n×100 µg/g, 且 以浸染状产出的辉钼矿 Re含量往往高于细脉状的 辉钼矿 Re含量。

(4) 冈底斯、中亚及长江中下游3个成矿带中, 辉钼矿Re含量差异较大,说明不同区域及不同地质 构造背景可能会影响辉钼矿中Re含量。

致 谢 对几位审稿专家及编辑提出的宝贵意 见及建议,在此致以诚挚的感谢!

References

- Austen G and Ballantyne G. 2010. Geology and geochemistry of deep molybdenum mineralization at the Bingham Canyon mine, Utah, USA[J]. Society of Economic Geologists Guidebook Series, 41: 35-49.
- Berry A J, Harris A C, Kamenetsky V S, Newville M and Sutton S R. 2009. The speciation of copper in natural fluid inclusions at temperatures up to 700°C[J]. Chemical Geology, 259(1-2): 2-7.
- Berzina A N, Sotnikov V I, Economou-Eliopoulos M and Eliopoulos D G. 2005. Distribution of rhenium in molybdenite from porphyry Cu-Mo and Mo-Cu deposits of Russia (Siberia) and Mongolia[J]. Ore Geology Reviews, 26(1-2): 91-113.
- Chang Y F, Li J H and Song C Z. 2019. The regional tectonic framework and some new understandings of the Middle-Lower Yangtze River valley metallogenic belt[J]. Acta Petrologica Sinica, 35(12): 3579-3591(in Chinese with English abstract).
- Chen C, Wang B D, Niu S G, Ma G X, Zhang J Z, Sun A Q, Ma B J, Chen Z K, Zhang F X and Wang Z L. 2013. Re-Os dating of molybdenite from the Mujicun Cu (-Mo) deposit in Hebei Province and characteristics of the ore-forming fluids[J]. Geology in China, 40(6): 1889-1901(in Chinese with English abstract).
- Chen H A, Zhu X P, Ma D F, Huang H X, Li G M, Li Y B, Li Y C, Wei L J and Liu C Q. 2013. Geochronology and geochemistry of the

Bolong porphyry Cu-Au deposit, Tibet and its mineralizing significance[J]. Acta Geologica Sinica, 87(10): 1593-1611(in Chinese with English abstract).

- Chen R, Liu Y, Guo L, Wang Z, Liu H, Xu K and Zhang J. 2014. Geochronology and geochemistry of the Tinggong porphyry copper ore deposit, Tibet[J]. Acta Geologica Sinica(English Edition), 88 (3): 780-800.
- Chen W M and Li S P. 1998. Rhenkrn-osmium isotopic ages of sulfides from the tongkuang porphyry copper deposit in the Zhongtiao Mountain[J]. Mineral Deposits, 17(3): 224-228(in Chinese with English abstract).
- Colodner D, Sachs J, Ravizza G, Turekian K, Edmond J and Boyle E. 1993. The geochemical cycle of rhenium: A reconnaissance[J]. Earth and Planetary Science Letters, 117(1-2): 205-221.
- Crusius J, Calvert S, Pedersen T and Sage D. 1996. Rhenium and molybdenum enrichments in sediments as indicators of oxic, suboxic and sulfidic conditions of deposition[J]. Earth and Planetary Science Letters, 145(1-4): 65-78.
- Dai P, Wu S H and Ding C W. 2018. Zircon U-Pb dating of granite porphyry and Re-Os isotopic dating of molybdenite from Wangwu porphyry Mo-Cu deposit, Jiangxi Province, and their geological significance[J]. Acta Petrologica Sinica, 34(9): 100-116(in Chinese with English abstract).
- Duan J, Tang J, Mason R, Zheng W and Ying L. 2014. Zircon U-Pb age and deformation characteristics of the Jiama porphyry copper deposit, Tibet: Implications for relationships between mineralization, structure and alteration[J]. Resource Geology, 64(4): 316-331.
- Gao X, Zhou Z H, Che H W, Ma X H, Ouyang H G, Chen B Q and Liu G D. 2018. Origin of intrusive rock and surrounding rock in Bainaimiao Cu-Au-Mo deposit, Inner Mongolia: Evidences from geochemistry and Hf isotope characteristics[J]. Mineral Deposits, 37(2): 420-440(in Chinese with English abstract).
- Gao Y B, Li K, Qian B, Li W Y, Li D S, Su S S, Zhang C G, Zhang D M and Wang S M. 2015. The genesis of granodiorites and dark enclaves from the Kaerqueka deposit in east Kunlun belt: Evidence from zircon U-Pb dating, geochemistry and Sr-Nd-Hf isotopic compositions[J]. Geology in China, 42(3): 646-662(in Chinese with English abstract).
- Gao Y B, Li K, Qian B, Li W Y, He S Y, Zhang D M and Wang S M. 2018. The metallogenic chronology of kaerqueka deposit in eastern Kunlun: Evidences from molybdenite Re-Os and phlogopite Ar-Ar ages[J]. Geotectonica et Metallogenia, 42(1): 96-107(in Chinese with English abstract).
- Gao Y M, Chen Y C, Tang J X, Luo M C, Leng Q F, Wang L Q, Yang H R and Phurbu T R. 2012. A study of diagenetic and metallogenic geochronology of the dagbo Cu (Mo) deposit in quxur county of Tibet and its geological implications[J]. Acta Geoscientia Sinica, 33(4): 613-623(in Chinese with English abstract).
- Golden J, McMillan M, Downs R T, Hystad G, Goldstein I, Stein H J, Zimmerman A, Sverjensky D A, Armstrong J T and Hazen R M.

2013. Rhenium variations in molybdenite(MoS₂): Evidence for progressive subsurface oxidation[J]. Earth Planetary Science Letters. 366: 1-5.

- Gong F Z, Zheng Y Y, Zhang G Y and Qu W J. 2008. The first discovery of porphyry copper deposits formed during the main Indian-Tibetan collision in gangdise, Tibet: Constraints from Re-Os ages for molybdenite from the Jiru porphyry copper deposit[J]. Acta Geologica Sichuan, 28(4): 296-299(in Chinese with English abstract).
- Guo B J, Mao J W, Li H M, Qu W J, Qiu J J, Ye H S, Li M W and Zhu X L. 2006. Re-Os dating of the molybdenite from the Qiushuwan Cu-Mo deposit in the East Qinling and its geological significance[J]. Acta Petrologica Sinica, 22(9): 2341-2348(in Chinese with English abstract).
- Guo S, Zhao Y Y, Qu H C, Wu D X, Xu H, Li C, Liu Y, Zhu X Y and Wang Z K. 2012. Geological characteristics and ore-forming time of the Dexing porphyry copper ore mine in Jiangxi Province[J]. Acta Geologica Sinica(English Edition), 86(3): 691-699.
- Guo Z L, Li J X, Qin K Z, Dong L H, Guo X J, Tang D M and Du X W. 2010. Zircon U-Pb geochronology and geochemistry of Hanzheganeng Cu-Au deposit in West Junggar, Xinjiang: Implications for magma source and metallogenic tectonic setting[J]. Acta Petrologica Sinica, 22(9): 2341-2348(in Chinese with English abstract).
- Guo Z P, Zhao X M, Bai Y, Zhang J W and Kong H L. 2015. Zircon U-Pb and molybdenite Re-Os dating of the Langlike copper deposit in North Qilian mountain and its geological implications[J]. Geology in China, 42(3): 691-701(in Chinese with English abstract).
- Hao J H, Chen J P, Dong Q J, Tian Y G, Li Y L and Chen D. 2012. Zircon LA-ICP-MS U-Pb dating for Narigongma porphyry molybdenum-copper deposit in southern Qinghai Province and its geological implication[J]. Geoscience, 26(1): 45-53(in Chinese with English abstract).
- He S Y, Li D S, Li L L, Qi L Y and He S F. 2009. Re-Os age of molybdenite from the Yazigou copper (molybdenum) mineralized area in Eastern Kunlun of Qinghai Province, and its geological significance[J]. Geotectonica et Metallogenia, 33(2): 236-242(in Chinese with English abstract).
- He W Y, Mo X X, Yu X H, He Z H, Dong G C, Liu X B, Su G S and Huang X F. 2013. Zircon U-Pb and molybdenite Re-Os dating for the Beiya gold-polymetallic deposit in the western Yunnan Province and its geological significance[J]. Acta Petrologica Sinica, 29(4): 205-214(in Chinese with English abstract).
- Hildreth W and Moorbath S. 1988.Crustal contributions to arc magmatism in the Andes of central Chile[J]. Contributions to Mineralogy and Petrology, 98: 455-489.
- Hou Z Q, Mo X X, Gao Y F, Qu X M and Meng X J. 2003. Adakite, a possible host rock for porphyry copper deposits: Case studies of porphyry copper belts in Tibetan plateau and in northern Chile[J]. Mineral Deposits, 22(1): 1-12(in Chinese with English abstract).
- Hou Z Q, Pan X F, Yang Z M and Qu X M. 2007. Porphyry Cu-(Mo-Au) deposits no related to oceanic-slab subduction: Examples

from Chinese porphyry deposits in continental settings[J]. Geoscience, 21(2): 332-351(in Chinese with English abstract).

- Hou Z Q, Pan X F, Li Q Y, Yang Z M and Song Y C. 2013. The giant Dexing porphyry Cu-Mo-Au deposit in East China: Product of melting of juvenile lower crust in an intracontinental setting[J]. Mineralium Deposita, 48(8): 1019-1045.
- Hou Z Q and Wang R. 2019. Fingerprinting metal transfer from mantle[J]. Nature Communications, 10(1): 3510.
- Huang Y, Ding J, Li G M, Dong S L, Huang H X, Cui X L, Dai J and Yan G Q. 2015. Petrogenesis of intrusions in Tinggong copper deposit, Gangdese, Xizang(Tibet): Evidence from LA-ICP-MS zircon U-Pb dating, petrogeochemical and Sr-Nd-Pb isotopic composition[J]. Geological Review, (3): 664-680(in Chinese with English abstract).
- Huang Y, Li G M, Ding J, Dai J, Yan G Q, Dong S L and Huang H X. 2017. Origin of the newly discovered Zhunuo porphyry Cu-Mo-Au deposit in the western part of the Gangdese porphyry copper belt in the southern Tibetan plateau, SW China[J]. Acta Geologica Sinica(English Edition), 91(1): 109-134.
- Jia L Q, Mo X X, Dong G C, Xu W Y, Wang L, Guo X D, Wang Z H and Wei S G. 2013. Genesis of lamprophyres from Machangqing, western Yunnan: Constraints from geochemistry, geochronology and Sr-Nd-Pb-Hf isotopes[J]. Acta Petrologica Sinica, (4): 1247-1260(in Chinese with English abstract).
- Jia L Q, Xu W Y, Yang D, Yang Z S and Wang L. 2015. Zircon U-Pb and molybdenite Re-Os dating of Baoshan porphyry Cu polymetallic deposit in Jiujiang-Ruichang ore concentration area of Jiangxi Province and its geological significance[J]. Mineral Deposits, 34(1): 63-80(in Chinese with English abstract).
- Kang Y J, Wang Y J, Huang G J, She H Q, Xiang A P, Tian J, Guo Z J and Dong X Z. 2014. Study of rock-forming and ore-forming ages of Badaguan prophypy Cu-Mo deposit in Inner Mongolia[J]. Mineral Deposits, 33(4): 795-806(in Chinese with English abstract).
- Klemm L M, Pettke T and Heinrich C A. 2008. Fluid and source magma evolution of the Questa porphyry Mo deposit, New Mexico, USA[J]. Mineralium Deposita, 43: 533-552.
- Lang X H, Tang J X, Chen Y C, Li Z J, Huang Y, Wang C H, Chen Y and Zhang L. 2010. Re-Os dating of molybdenite from orebody No.II of the Xiongcun porphyry copper-gold metallogenic district, Xietongmen, Tibet and its geological significance[J]. Journal of Mineralogy and Petrology, (4): 57-63(in Chinese with English abstract).
- Lang X H, Tang J X and Xie F W. 2014. Elements spatial distribution and ore prospecting of the No. II porphyry copper-gold deposit in the Xiongcun district, Tibet[J]. Advanced Materials Research, 962-965:1136-1142.
- Leng C B, Zhang X C, Wang S X, Qin C J and Gou T Z. 2007. Geochemical characteristic of porphyry copper deposits in the Zhongdian area, Yunnan as exemplified by the Xuejiping and Pulang porphyry copper deposits[J]. Acta Mineralogica Sinica, 27(3): 414-422(in Chinese with English abstract).

- Leng C B, Zhang X C, Hu R Z, Wang S X, Zhong H, Wang W Q and Bi X W. 2012. Zircon U-Pb and molybdenite Re-Os geochronology and Sr-Nd-Pb-Hf isotopic constraints on the genesis of the Xuejiping porphyry copper deposit in Zhongdian, northwest Yunnan, China[J]. Journal of Asian Earth Sciences, 60: 31-48.
- Leng C B, Zhang X C, Zhong H, Hu R Z, Zhou W D and Li C. 2013. Re-Os molybdenite ages and zircon Hf isotopes of the Gangjiang porphyry Cu-Mo deposit in the Tibetan orogen[J]. Mineralium Deposita, 48(5): 585-602.
- Leng Q F, Tang J X, Zheng W B, Zhang J S, Tang P, Yan G and Dong Y. 2015. Re-Os dating of molybdenite from the Lakange porphyry Cu-Mo deposit in Tibet and its geological significance[J]. Geology in China, 42(2): 570-584(in Chinese with English abstract).
- Leng Q F, Tang J X, Zheng W B, Wang B H, Tang P and Wang H. 2016. Geochronology, geochemistry and Zircon Hf isotopic compositions of the ore-bearing porphyry in the Lakang'e porphyry Cu-Mo deposit, Tibet[J]. Earth Science-Journal of China University of Geosciences, 41(6): 999-1015(in Chinese with English abstract).
- Li C, Qu W J, Du A D and Zhou L M. 2011. Study on Re-Os isotope in molybdenite containing common Os[J]. Acta Petrologica Sinica, 28(2): 702-708(in Chinese with English abstract).
- Li C Y and Liao R Q. 2020. Formation mechanism and geochemical process of porphyry molybdenum deposits[J]. Acta Petrologica Sinica, 36(1): 77-84(in Chinese with English abstract).
- Li G M, Liu B, Qu W J, Lin F C, She H Q and Feng C Y. 2005. The porphyry-skarn ore-forming system in Gangdese metallogenic belt, southern Xizang: Evidence from molybdenite Re-Os age of porphyry-type copper deposits and skarn-type copper polymetallic deposits[J]. Geotectonica et Metallogenia, (4): 482-490(in Chinese with English abstract).
- Li G M, Liu B, Qi H Q, Feng C Y and Qu W J. 2006. Early Himalayan mineralization on the southern margin of the Gangdise metallogenic belt, Tibet, China: Evidence from Re-Os ages of the Chongmuda skarn-type Cu-Au deposit[J]. Geological Bulletin of China, (12): 1481-1486(in Chinese with English abstract).
- Li J J, Zhi C, Zhao Z L, Shi Y R, Dun Y, Li C, Qu W J, Wang C X, Fu C, Tang W L, Zhang T, Wang S G, Zhou H Y, Zhao L J and Liu X X. 2015. The metallogenic epochs of Bainaimiao copper deposit in Inner Mongolia[J]. Acta Geologica Sinica, 89(8): 1448-1457(in Chinese with English abstract).
- Li L, Ni P, Wang G G and Zhu A D. 2018. Re-Os isotopic dating of pyrite from Dexing porphyry copper orefield and its geological significance[J]. Mineral Deposits, 37(6): 25-35(in Chinese with English abstract).
- Li Z J, Tang J X, Yao X F, Deng S L and Wang Y. 2011. Re-Os isotope age and geological significance of molybdenite in the Gaerqiong Cu-Au deposit of Geji, Tibet, China[J]. Journal of Chengdu University of Technology(Science & Technology Edition), 38(6): 678-683(in Chinese with English abstract).

Liang H Y, Mo J H, Sun W D, Zhang Y Q, Zeng T, Hu G Q and Charl-

lote M A. 2009. Study on geochemical composition and isotope ages of the Malasongduo porphyry associated with Cu-Mo mineralization[J]. Acta Petrologica Sinica, 25(2): 385-392(in Chinese with English abstract).

- Liang Q L, Jiang S H, Wang S H, Li C and Zeng F G. 2012. Re-Os dating of molybdenite from the Luoboling porphyry Cu-Mo deposit in the Zijinshan ore field of Fujian Province and its geological significance[J]. Acta Geologica Sinica, 86(7): 1113-1118(in Chinese with English abstract).
- Lin T, Deng Y F, Qu W J, Zhou T F, Yuan F and Deng G. 2017. The gensis, petrology, chronology and geochemical evidence of the Sanchakou copper deposit in the East Tianshan area, Xinjiang[J]. Journal of Mineralogy and Petrology, 37(4): 47-61(in Chinese with English abstract).
- Lipinski M, Warning B and Brumsack H J. 2003. Trace metal signatures of jurassic/cretaceous black shales from the Norwegian shelf and the Barents sea[J]. Palaeogeography Palaeoclimatology Palaeoecology, 190(1): 459-475.
- Lü B, Meng G X, Yang Y Q, Yan J Y, Zhao J H, Deng Z and Li C. 2014. Discover of Layikeleke insidious porphyry deposit in Xinjiang, Re-Os isotope dating and its geological implications[J]. Acta Petrologica Sinica, 30(4): 1168-1178(in Chinese with English abstract).
- Mao J W, Zhang Z C, Zhang Z H and Du A D. 1999. Re-Os isotopic dating of molybdenites in the Xiaoliugou W (Mo) deposit in the northern Qilian mountains and its geological significance[J]. Geochimica et Cosmochimica Acta, 63(11-12): 1815-1818.
- Meng X J, Hou Z Q, Gao Y F, Huang W, Qu X M and Qu W J. 2003a.
 Development of porphyry copper-molybdenum-lead-zinc oreforming system in east Gangdese belt, Tibet: Evidence from Re-Os age of molybdenite in Bangpu copper polymetallic deposit[J].
 Mineral Deposits, 22(3): 246-252(in Chinese with English abstract).
- Meng X J, Hou Z Q, Gao Y F, Huang W, Qu X M and Qu W J. 2003b. Re-Os dating for molybdenite from Qulong porphyry copper deposit in Gangdese metallogenic belt, Xizang and its metallogenic significance[J]. Geological Review, 49(6): 660-666(in Chinese with English abstract).
- Mi K F, Liu Z J, Li C F, Liu R B, Wang J P and Peng R M. 2017. Origin of the Badaguan porphyry Cu single bond Mo deposit, Inner Mongolia, northeast China: Constraints from geology, isotope geochemistry and geochronology[J]. Ore Geology Reviews, 81(1): 154-172.
- Millensifer T A, Sinclair W D, Jonasson I R and Lipmann A. 2013. Rhenium[A]. In: Gunn A G, ed. Critical metals handbook: American Geophysical Union[M]. 340-360.
- Ouyang H Y, Wu X L, Mao J W, Su H M, Santosh M, Zhou Z H and Li C. 2014. The nature and timing of ore formation in the budunhua copper deposit, southern great Xing'an range: Evidence from geology, fluid inclusions, and U-Pb and Re-Os geochronology[J]. Ore Geology Reviews, 63: 238-251.

- Pokrovski G S, Roux J and Harrichoury J C. 2005. Fluid density control on vapor—liquid partitioning of metals in hydrothermal systems[J]. Earth Planetary Science Letters, 266(3-4): 345-362.
- Qu K, Dong G C, Li S R, Shen J F, Wang Y J, Wang X and Luo W. 2014. Lithogeochemistry and Sr-Nd-Pb isotopic characteristics of Mujicun porphyry Cu-Mo deposit in Taihang mountains and their significances[J]. Geoscience, 28(3): 449-460(in Chinese with English abstract).
- Qu X, Xu X W, Liang G L, Qu W J, Du S J, Jiang N, Wu H P, Zhang Y, Xiao H and Dong L H. 2009. Geological and geochemical characteristics of the Mengxi Cu-Mo deposit and its constraint to tectonic setting of the Qiongheba magmatic arc in eastern Junggar, Xinjiang[J]. Acta Petrologica Sinica, 25(4): 765-776(in Chinese with English abstract).
- Qu X M, Hou Z Q and Li Y G. 2004. Melt components derived from a subducted slab in late orogenic ore-bearing porphyries in the Gangdese copper belt, southern Tibetan Plateau[J]. Lithos, 74(3-4): 131-148.
- Reinhard C T, Planavsky N J, Gill B C, Ozaki K, Robbins L J, Lyons T W, Fischer W W, Wang C J, Cole D B and Konhauser K O. 2017. Evolution of the global phosphorus cycle[J]. Nature, 541(7637): 386-389.
- Ren J B, Xu J F, Chen J L, Zhang S Q and Liang H Y. 2011. Geochemistry and petrogenesis of Pulang porphyries in Sanjiang region[J]. Acta Petrologica et Mineralogica, 30(4): 581-592(in Chinese with English abstract).
- Ren T, Wang R T, Xie G Q, Li J B, Dai J Z, Guo Y H, Dang K F and Wu X Q. 2014. Geochemistry and rock-forming and ore-forming epochs of Chigou Cu porphyry deposit in Shaanxi Province, and their implications[J]. Mineral Deposits, 33(4): 807-820(in Chinese with English abstract).
- Ren Z, Zhou T, Hollings P, White N C, Wang F and Yuan F. 2018. Trace element geochemistry of molybdenite from the Shapinggou super-large porphyry Mo deposit, China[J]. Ore Geology Reviews, 95: 1049-1065.
- Richards J P and Şengör A M C. 2017. Did Paleo-Tethyan Anoxia kill arc magma fertility for porphyry copper formation[J]? Geology, 45: 591-594.
- Righter K, Chesley J T, Geist D and Ruiz J. 1998. Behavior of Re during magma fractionation: An example from volcán alcedo, galápagos[J]. Journal of Petrology, 39(4): 785-795.
- Rowins S M. 2000. Reduced porphyry copper-gold deposits: A new variation on an old theme[J]. Geology, 28(6): 491-494.
- Rui Z Y, Wang L S, Wang Y H and Liu Y L. 2002. Discussion on metallogenic epoch of Tuwu and Yandong porphyry copper deposits in eastern Tianshan mountains, Xinjiang[J]. Mineral Deposits, 21(1): 16-22(in Chinese with English abstract).
- Shafiei B, Shamanian G, Mathur R and Mirnejad H. 2015. Mo isotope fractionation during hydrothermal evolution of porphyry Cu systems[J]. Mineralium Deposita, 50(3): 281-291.
- She H Q, Zhang D Q, Jing X Y, Guan J, Zhu H P, Feng C Y and Li D

X. 2007. Geological characteristics and genesis of the Ulan Uzhur porphyry copper deposit in Qinghai[J]. Geology in China, (2): 306-314(in Chinese with English abstract).

- She H Q, Li J W, Ma D F, Li G M, Zhang D Q, Feng C Y, Qu W J and Pan G T. 2009. Molybdenite Re-Os and SHRIMP zircon U-Pb dating of Duobuza porphyry copper deposit in Tibet and its geological implications[J]. Mineral Deposits, 28(6): 737-746(in Chinese with English abstract).
- Shen P, Pan H, Zhou T and Wang J. 2014. Petrography, geochemistry and geochronology of the host porphyries and associated alteration at the Tuwu Cu deposit, NW China: A case for increased depositional efficiency by reaction with mafic hostrock[J]? Mineralium Deposita, 49(6): 709-731.
- Shen P, Pan H D and Seitmuratova E. 2015. Characteristics of the porphyry Cu deposits in the Central Asia metallogenic domain[J]. Acta Petrologica Sinica, 31(2): 315-332(in Chinese with English abstract).
- Shen P, Pan H D and Seitmuratova E. 2017. Petrogenesis of the mineralized granitoids from the Kounrad and Borly porphyry Cu deposits and the east Kounrad porphyry Mo deposit in Kazakhstan: Implication for tectonic evolution and mineralization of the western part of the Central Asian Orogenic Belt[J]. Lithos, 286/287: 53-74.
- Sillitoe R H. 2010. Porphyry copper systems[J]. Econ. Geol., 105(1): 3-41.
- Stein H J, Markey R J, Morgan J W, Hannah J L and Scherstén A. 2001. The remarkable Re-Os chronometer in molybdenite: How and why it works[J]. Terra Nova, 13(6): 479-486.
- Stein H J, Schersten A, Hannah J and Markey R. 2003. Subgrain-scale decoupling of Re and 187Os and assessment of laser ablation ICP-MS spot dating in molybdenite[J]. Geochimica et Cosmochimica Acta, 67(19): 3673-3686.
- Sun W D , Bennett V C, Eggins S M, Kamenetsky V S and Arculus R J. 2003. Enhanced mantle-to-crust rhenium transfer in undegassed arc magmas[J]. Nature, 422(6929): 294.
- Sun W D, Arculus R J, Kamenetsky V S and Binns R A. 2004. Release of gold-bearing fluids in convergent margin magmas prompted by magnetite crystallization[J]. Nature, 431(7011): 975-978.
- Sun W D, Liang H Y, Ling M X, Zhan M Z, Ding X, Zhang H, Yang X Y, Li Y L, Trevor R I, Wei Q R and Fan W M. 2013. The link between reduced porphyry copper deposits and oxidized magmas[J]. Geochimica et Cosmochimica Acta, 103: 263-275.
- Sun W D, Huang R F, Li H, Hu Y B, Zhang C C, Sun S J, Zhang L P, Ding X, Li C Y, Robert E Z and Li M X. 2015. Porphyry deposits and oxidized magmas[J]. Ore Geology Reviews, 65: 97-131.
- Sun Y, Liu J M, Zeng Q J, Chu S X, Zhou L L, Wu G B, Gao Y Y and Shen W J. 2013. Geological characteristics and molybdenite Re-Os ages of the Baituyingzi Mo-Cu field, eastern Inner Mongolia and their geological implications[J]. Acta Petrologica Sinica, 29 (1): 241-254(in Chinese with English abstract).
- Tan G, Chang G X, Qi H Q, Li J W, Zhang D Q, Yang Y C, Zhang B, Xiang A P and Dong Y J. 2010. The Re-Os isotope dating of the

molybdenum deposit in the W unugetushan porphyry Cu-Mo deposit, Inner Mongolia, and its geological significance[J]. Mineral Deposits, 29 (S1): 506-508(in Chinese with English abstract).

- Tang J X, Huang Y, Li Z J, Deng Q, Lang X H, Chen Y and Zhang L. 2009a. Element geochemical characteristics of Xiongcun Cu-Au deposit in Xaitongmoin County, Tibet[J]. Mineral Deposits, 28(1): 15-28(in Chinese with English abstract).
- Tang J X, Wang C H, Qu W J, Du A D, Ying L J and Gao Y M. 2009b. Re-Os isotopic dating of molybdenite from the Yulong porphyry copper-molybdenum deposit in Tibet and its metallogenic significance[J]. Rock and Mineral Analysis, 28(3): 215-218(in Chinese with English abstract).
- Tang J X, Chen Y C, Wang D H, Wang C H, Xu Y P, Qu W J, Huang W and Huang Y. 2009c. Re-Os dating of molybdenite from the Sharang porphyry molybdenum deposit in Gongbo'gyamda county, Tibet and its geological significance[J]. Acta Geologica Sinica, 83 (5): 698-704(in Chinese with English abstract).
- Tang J X, Li F J, Li Z J, Zhang L, Tang X Q, Deng Q, Lang X H, Huang Y, Yao X F and Wang Y. 2010. Time limit for formation of main geological bodies in Xiongcun copper-gold deposit, Xietongmen County, Tibet: Evidence from zircon U-Pb ages and Re-Os age of molybdenite[J]. Mineral Deposits, 29(3): 461-475(in Chinese with English abstract).
- Tang J X, Zheng W B, Chen Y C, Wang D H, Ying L J and Qin Z P. 2013. Prospecting breakthrough of the deep porphyry ore body and its significance in Jiama copper polymetallic deposit, Tibet, China[J]. Journal of Jilin University(Earth Science Edition), 43 (4): 1100-1110(in Chinese with English abstract).
- Tatsumoto M, Basu A R, Wankang H, Junwen W and Guanghong X. 1992. Sr, Nd, and Pb isotopes of ultramafic xenoliths in volcanic rocks of Eastern China: Enriched components EMI and EMII in subcontinental lithosphere[J]. Earth and Planetary Science Letters, 113(1-2): 107-128.
- Taylor S R and Mclennan S M. 1995. The geochemical evolution of the continental crust[J]. Reviews of Geophysics, 33(2): 241-265.
- Terada K, Osaki S, Ishihara S and Kiba T. 2008. Distribution of rheniumin molybdenites from Japan[J]. Geochemical Journal, 4(3): 123-141.
- Turner E C and Bekker A. 2015. Thick sulfate evaporite accumulations marking a Mid-Neoproterozoic oxygenation event (Ten Stone Formation, Northwest Territories, Canada) [J]. Geological Society of America Bulletin, 128(1-2): 203-222.
- Ulrich T and Mavrogenes J. 2008. An experimental study of the solubility of molybdenum in H₂O and KCl-H₂O solutions from 500°C to 800°C, and 150 to 300 MPa[J]. Geochimica et Cosmochimica Acta, 72: 2316-2330.
- Wang B D, Xu J F, Chen J L, Zhang X G, Wang L Q and Xia B B. 2010. Petrogenesis and geochronology of the ore-beating porphyritic rocks in Tangbula porphyry molybdenum-copper deposit in the eastern segment of the Gangdese metalloganic belt[J]. Acta Petrologica Sinica, 26(6): 1820-1832(in Chinese with English ab-

stract).

- Wang D H, Qu W J, Li Z W, Yin H L and Chen Y C. 2005. Mineralization episode of porphyry copper deposits in the Jinshajiang-Red river mineralization belt: Re-Os dating[J]. Science in China Series D: Earth Sciences, 48(2): 50-56.
- Wang H, Feng C, Li D, Li C, Ding T and Liao F. 2016. Geology, geochronology and geochemistry of the Saishitang Cu deposit, East Kunlun Mountains, NW China: Constraints on ore genesis and tectonic setting[J]. Ore Geology Reviews, 72: 43-59.
- Wang L B and Chen D. 1997. Re-Os isotope ages of Molybdenite from the Anjishan copper deposit and the Tongshan copper molybdenum deposit and their implications[J]. Acta Petrologica et Mineralogica, 16(2): 154-159(in Chinese with English abstract).
- Wang R, Richards J P, Hou Z Q, Yang Z M, Gou Z B and Dufrane S A. 2014. Increasing magmatic oxidation state from Paleocene to Miocene in the eastern Tibetan Gangdese belt: Implication for collision-related porphyry Cu-Mo±Au mineralization[J]. Econ. Geol., 195 (7): 1943-1965.
- Wang R, Wang J P, Zhou L M, Hou Z Q, Stern R A, Creaser R A and Zhu J J. 2015. The Role of Indian and Tibetan lithosphere in spatial distribution of Cenozoic magmatism and porphyry Cu-Mo± Au deposits in the Gangdese belt, southern Tibet[J]. Earth-Science Reviews, 150: 68-94.
- Wang R, Collins W J, Weinberg R F, Li J X, Li Q Y, He W Y, Richards J P, Hou Z Q and Zhou L M. 2016. Xenoliths in ultrapotassic volcanic rocks in the Lhasa Block: Direct evidence for crust-mantle mixing and metamorphism in the deep crust[J]. Contributions to Mineralogy and Petrology, 172: 62.
- Wang R, Weinberg R F, Collins W J, Richards J P and Zhu D C. 2018. Origin of post-collisional magmas and formation of porphyry Cu deposits in southern Tibet[J]. Earth-Science Reviews, 181: 122-143.
- Wang R, Zhu D C, Wang Q, Hou Z Q, Yang Z M, Zhao Z D and Mo X X. 2020. Porphyry mineralization in the Tethyan orogen[J]. Scientia Sinica(Terrae), 50: 1919-1946(in Chinese).
- Wang S W, Zhou T F, Yuan F, Fan Y, Cao X S and Wang B. 2012. Re-Os and 40Ar/39Ar dating of the Shujiadian copper deposit in Tongling, China: Implications for regional metallogenesis[J]. Acta Petrologica Sinica, 28(10): 3170-3180(in Chinese with English abstract).
- Wang S W, Zhou T F, Yuan F, Fan Y, Yu C H, Ge L H, Shi C and Chi Y Y. 2014. Emplacement sequences and geochronology of the Shaxi porphyry copper-gold deposit, Anhui Province, East China[J]. Acta Petrologica Sinica, 30(4): 979-994(in Chinese with English abstract).
- Wang Z L, Yang Z M, Yang Z S, Tian S H, Liu Y C, Ma Y Q, Wang G R and Qu W J. 2008. Narigongma porphery molybdenite copper deposit, northern extension of Yulong copper belt: Evidence from the age of Re-Os isotope[J]. Acta Petrologica Sinica, 24(3): 503-510(in Chinese with English abstract).

Webster J D and Botcharnikov R E. 2011. Distribution of sulfur be-

tween melt and fluid in S-O-C-Cl-bearing magmatic systems at shallow crustal pressures and temperatures[J]. Reviews in Mineralogy and Geochemistry, 73(1): 247-283.

- Wilkinson J J. 2013. Triggers for the formation of porphyry ore deposits in magmatic arcs[J]. Nature Geoscience, 6(11): 917-925.
- Wu L S and Zou X Q. 1997. Re-Os isotopic age study of the Chengmenshan copper deposit, Jiangxi Province[J]. Mineral Deposits, 16(4): 376-381(in Chinese with English abstract).
- Wu W Z, Xia B, Zhang Y Q, Dong B H and Xia Z X. 2013. Geochemical characteristics and metallogenic mechanism of the porphyry Cu-Mo deposits in the Yulong ore belt, eastern Tibet: A case study of the Yulong and Duoxiasongduo porphyries[J]. Geotectonica et Metallogenia, (3): 440-454(in Chinese with English abstract).
- Wu Y H, Xiong X L, Zhao T P, Zhu Z M and Li L. 2013. Zircon U-Pb age of the ore-bearing granite and molybdenite Re-Os isotopic age of the Donggebi Mo deposit, Xinjiang and their geological significance[J]. Geotectonica et Metallogenia, 37(4): 743-753(in Chinese with English abstract).
- Xiao B, Chen H Y, Wang Y F and Yang J T. 2017. Zircon U-Pb and molybdenite Re-Os dating of the Tuwu-Yandong Cu deposit belt of the eastern Tianshan mountains and its geological significance[J]. Geotectonica et Metallogenia, 41(1): 145-156(in Chinese with English abstract).
- Xie G Q, Mao J W, Li R L, Zhang Z S, Zhao W C, Qu W J, Zhao C S and Wei S K. 2006. Metallogenic epoch and geodynamic framework of Cu-Au-Mo-(W) deposits in southeastern Hubei Province: Constraints from Re-Os molybdenite ages[J]. Mineral Deposits, 25 (1): 43-52(in Chinese with English abstract).
- Xie G Q, Mao J W, Li R L, Qu W J, Pirajno F and Du A D. 2007. Re-Os molybdenite and Ar-Ar phlogopite dating of Cu-Fe-Au-Mo (W) deposits in southeastern Hubei, China[J]. Minralogy and Petrology, 90: 249-270.
- Xin H B, Qu X M, Wang R J, Liu H F, Zhao Y Y and Huang W. 2009. Geochemistry and Pb, Sr, Nd isotopic features of ore-bearing porphyries in Bangong Lake porphyry copper belt, western Tibet[J]. Mineral Deposits, 28(6): 785-792(in Chinese with English abstract).
- Xing J B, Guo X D, Qu W J, Wang Z H and Li H G. 2009. Molybdenite Re-Os age and other geological meaning of Machangqing porphyry copper, molybdenum deposit[J]. Gold Science and Technology, (5): 24-29(in Chinese with English abstract).
- Xue C J, Chen B, Jia Z Y, Zhang B and Wan Y. 2011. Geology, geochemistry and chronology of Lailisigao'er-3571 porphyry Cu-Mo ore-field, western Tianshan, Xinjiang[J]. Earth Science Frontiers, 18(1): 149-165(in Chinese with English abstract).
- Yang F Q, Zhang Z X, Liu G R, Qu W J, Zhang L W, Wei G Z, Liu F and Chai F M. 2012. Geochronology of Yulekenhalasu porphyry copper deposit in northtern Junggar area, Xinjiang, China[J]. Acta Petrologica Sinica, 28(7): 85-98(in Chinese with English abstract).
- Yang G C, Ge L S, Lu Y C, Zou Y L, Xing J B, Zhang F and Yuan S S. 2014. Re-Os isotopic dating of molybdenite from the Matou mo-

lybdenum deposit from Chizhou area in the south of Anhui Province and its geological implications[J]. Journal of Mineralogy and Petrology, 34(1): 30-35(in Chinese with English abstract).

- Yang J H, Wu F Y, Chung S L, Wilde S A and Chu M F. 2006. A hybrid origin for the Qianshan a-type granite, northeast China: Geochemical and Sr-Nd-Hf isotopic evidence[J]. Lithos, 89(1-2): 89-106.
- Yang Z F, Luo Z H, Lu X X, Cheng L L, Huang F. 2011. Discussion on significance of Re content of molybdenite in tracing source of metallogenic materials[J]. Mineral Deposits, 30(4): 654-674(in Chinese with English abstract).
- Yang Z M, Hou Z Q, White N C, Chang Z S, Li Z Q and Song Y C. 2009. Geology of post-collisional porphyry copper-molybdenum deposit at Qulong, Tibet[J]. Ore Geology Review, 36: 133-159.
- Yang Z M, Hou Z Q, Jiang Y F, Zhang H R and Song Y C. 2011. Sr-Nd-Pb and zircon Hf isotopic constraints on petrogenesis of the Late Jurassic granitic porphyry at Qulong, Tibet[J]. Acta Petrologica Sinica, 27(7): 2003-2010(in Chinese with English abstract).
- Yang Z M, Lu Y J, Hou Z Q and Chang Z S. 2015. High-Mg diorite from Qulong in southern Tibet: Implications for the genesis of Adakite-like intrusions and associated porphyry Cu deposits in collisional orogens[J]. Journal of Petrology, 56(2): 227-254.
- Yang Z M, Goldfarb R and Chang Z S. 2016a. Generation of post-collisional porphyry copper deposits in southern Tibert triggered by subduction of the Indian continental plate[A]. In: Richards J P, ed. Tectonics and metallogeny of the Tethyan orogenic belt[C]. Society of Economic Geologists Special Publication. 19: 279-300.
- Yang Z M and Cooke D R. 2019. Porphyry copper deposits in China, Mineral deposits of China[C]. Chang Z S, Goldfarb R J, ed. Society of Economic Geologists, Special Publication, United States. 133-187.
- Yang Z M, Hou Z Q, Zhou L M and Zhou Y W. 2020. Critical elements in porphyry copper deposits of China[J]. Chinese Science Bulletin, 65(33): 9-20(in Chinese).
- Yang Z, Jiang H, Yang M G, Mei H B, Hu G D, Zhang L L and Zhang P P. 2017. Zircon U-Pb and molybdenite Re-Os dating of the Gangjiang porphyry Cu-Mo deposit in central Gangdese and its geological significance[J]. Editorial Committee of Earth Science-Journal of China University of Geosciences, 42(3): 339-356(in Chinese with English abstract).
- Yuan S D. 2013. Molybdenite Re-Os dating for the Yulong skarn molybdenum deposit in Tongshanling orefield, southern Hunan Province[J]. Geological Review, 59 (Suppl.): 393-394(in Chinese with English abstract).
- Zeng P S, Hou Z Q, Wang H P, Qu W J, Meng Y F, Yang Z S and Li W C. 2004. Re-Os dating of the Pulang porphyry copper deposit in Zhongdian, NW Yunnan, and its geological significance[J]. Acta Geologica Sinica(English Edition), 78(2): 604-609.
- Zeng P S, Wang H P, Mo X X, Yu X H, Li W C, Li T G, Li H and Yang C Z. 2004. Tectonic setting and prospects of porphyry copper deposits in Zhongdian island arc belt[J]. Acta Geoscientica Sinica, 25(5): 535-540(in Chinese with English abstract).

- Zeng P S, Hou Z Q, Gao Y F and Du A D. 2012. The Himalayan Cu-Mo-Au mineralization in the Eastern Indo-Asian collision zone: Constraints from Re-Os dating of molybdenite[J]. Geological Review, 52(1): 72-84(in Chinese with English abstract).
- Zeng Y C, Chen J L, Xu J F, Lei M and Xiong Q W. 2017. Origin of Miocene Cu-bearing porphyries in the Zhunuo region of the Southern Lhasa subterrane: Constraints from geochronology and geochemistry[J]. Gondwana Research, 41: 51-64.
- Zhang D Y, Zhou T F, Yuan F, Fan Y, Liu S and Peng M X. 2010. Geochemical characters, metallogenic chronology and geological significance of the Yanxi copper deposit in eastern Tianshan, Xinjiang[J]. Acta Petrologica Sinica, 26(11): 3327-3338(in Chinese with English abstract).
- Zhang G Y, Zheng Y Y, Gong F Z, Gao S B, Qu W J, Pang Y C, Shi Y R and Yin S Y. 2008. Geochronologic constraints on magmatic intrusions and mineralization of the Jiru porphyry copper deposit, Tibet associated with continent-continent collisional process[J]. Acta Petrologica Sinica, 24(3): 75-81(in Chinese with English abstract).
- Zhang H F, Sun M, Zhou X H, Fan W M, Zhai M G and Yin J F. 2002. Mesozoic lithosphere destruction beneath the north China Craton: Evidence from major, trace-element and Sr-Nd-Pb isotope studies of Fangcheng basalts[J]. Contributions to Mineralogy and Petrology, 144(2): 241-254.
- Zhang L C, Xiang P, Jin X D, Li W J and Xu X W. 2013. Re-Os isotopic geochronology of superimposed reworked porphyry Cu-Mo deposit in the eastern quasi Kalasinger metallogenic belt[A]. The 10th National Symposium on Isotope Geochronology and Isotope Geochemistry[C]. 88-88.
- Zhang Q, Wang Y, Qian Q, Yang J H, Wang Y L, Zhao T P and Guo G J. 2001. The characteristics and tectonic-metallogenic significances of the Adakites in Yanshan period from eastern China[J]. Acta Petrologica Sinica, 17(2): 236-244(in Chinese with English abstract).
- Zhang T, Zhang D H, Yang B, Zhang H and Yu X. 2015. Re-Os dating of molybdenite from the Jiangligou porphyry-skarn Cu-W-Mo deposit in Tongren, Qinghai Province and its metallogenic significance[J]. Acta Geologica Sinica, 89(2): 355-364(in Chinese with English abstract).
- Zhang Y Q, Xie Y W, Qiu H N and Li X H. 1998. Shoshonitic series: Sr, Nd, and Pb isotopic compositions of ore-bearing porphyry for Yulong copper ore belt in the eastern Xizang(Tibet)[J]. Scientia Geologica Sinica, 33(3): 359-366(in Chinese with English abstract).
- Zhang Z, Dong X, Xiang H, Ding H, He Z and Liou J G. 2015. Reworking of the Gangdese magmatic arc, southeastern Tibet: Postcollisional metamorphism and anatexis[J]. Journal of Metamorphic Geology, 33(1): 1-21.
- Zhang Z H, Mao J W, Wang Z L, Du A D, Zuo G C, Wang L S, Wang J W and Qu W J. 2006. Geology and metallogenetic epoch of the Dabate porphyry copper deposit in west Tianshan mountains, Xin-

jiang[J]. Geological Review, 52(5): 683-689(in Chinese with English abstract).

- Zhang Z M, Ding H X, Dong X and Tian Z L. 2019. Formation and evolution of the Gangdese magmatic arc, southern Tibet[J]. Acta Petrologica Sinica, 35(2):275-294(in Chinese with English abstract).
- Zhang Z X, Yang F Q, Yan S H, Zhang R, Chai F M, Liu F and Geng X X. 2009. Sources of ore-forming fluids and materials of the Baogutu porphyry copper deposit in Xinjiang: Constraints from sulfur-hydrogen-oxygen isotopes geochemistry[J]. Acta Petrologica Sinca, 26(3): 707-716(in Chinese with English abstract).
- Zhao B S. 2018. Sulfide Re-Os isochron and discussions in pyrites from Meiling Cu deposit in the eastern Tianshan (The degree of Master)[D]. Supervisor: Yuan C and Long X P. Beijing: Chinese Academy of Science (Guangzhou Institute of Geochemistry). 110p (in Chinese with English abstract).
- Zhao J X, Qin K Z, Li G M, Li J X, Xiao B, Chen L, Yang Y H, Li C and Liu Y S. 2014. Collision-related genesis of the sharang porphyry molybdenum deposit, Tibet: Evidence from zircon U-Pb ages, Re-Os ages and Lu-Hf isotopes[J]. Ore Geology Reviews, 56: 312-326.
- Zhao X Y, Yang Z S, Zhang X and Lu S Y. 2017. Geochronology and geochemistry characteristics of the biotite monzonite in the Bangpu porphyry deposit, Tibet[J]. Bulletin of Mineralogy, Petrology and Geochemistry, 36(5): 786-796(in Chinese with English abstract).
- Zhao Y, Wang J P, Ynag Z H, Zhang J X, Wang S G, Shang H S, Zuo H Y and Zhang C X. 2013. Re-Os isotopic dating of molybdenite separated from the Bainaimiao copper deposit, Inner Mongolia and its geological significance[J]. Earth Science Frontiers, 20(4): 361-368(in Chinese with English abstract).
- Zhao Y M, Bi C S, Zou X Q, Sun Y L, Du A D and Zhao Y M. 1997. The Re-Os isotopic age of molybdenite from Duobaoshan and Tongshan porphyry copper(molybdenum) deposits[J]. Acta Geoscientica Sinica, 27(1): 61-67(in Chinese with English abstract).
- Zhao Y Y, Song L, Fan X T, Shi D H, Zhang T P, Chen H Q and Qu W J. 2009. Re-Os dating of molybdenite from the Shesuo copper polymetallic ore in Shenzha County, Tibet and its geological significance[J]. Acta Geologica Sinica, 83(8): 1150-1158(in Chinese with English abstract).
- Zheng W, Ouyang H G, Zhao H J, Zhao C S, Yu X F, Luo D L, Huang H G and Ouyang Z X. 2017. Re-Os dating for the molybdenite from the Xiping Mo-Cu polymetallic deposit in Guangdong Province and its geological significance[J]. Acta Petrologica Sinica, 33(3): 843-858(in Chinese with English abstract).
- Zheng Y Y, Gao S B, Chen L J, Li G L, Feng N P, Fan Z J, Zhang H P, Guo J C and Zhang G Y. 2004. Finding and significances of Chongjiangporphyrycopper(molybdenum, aurum) deposit, Tibet[J]. Earth Science-Journal of China University of Geosciences, 29(3): 333-339(in Chinese with English abstract).
- Zheng Y Y, Zhang G Y, Xu R K, Gao S B, Pang Y C, Cao L, Du A D and Shi Y R. 2007. Geochronologic constraints on magmatic intru-

sions and mineralization of the Zhunuo porphyry copper deposit in Gangdese, Tibet[J]. Chinese Science Bulletin (22): 3139-3147.

- Zhong J, Chen Y J and Pirajno F. 2017. Geology, geochemistry and tectonic settings of the molybdenum deposits in south China: A review[J]. Ore Geology Reviews, 81: 829-855.
- Zhou T F, Wang S W, Yuan F, Fan Y, Zhang D Y, Chang Y F and Noel C W. 2016. Magmatism and related mineralization of the intracontinental porphyry deposits in the Middle-Lower Yangtze River valley metallogenic belt[J]. Acta Petrologica Sinica, 32(2): 271-288 (in Chinese with English abstract).
- Zhou X, Wen Q Q, Zhang Y, Zhou Y, Fei G C and Zhang X Q. 2013. Re-Os dating of molybdenite from the Bangpu polymetallic deposit of Tibet, and its geological significance[J]. Journal of Mineralogy and Petrology, 33(2): 59-64(in Chinese with English abstract).
- Zhu D C, Wang Q, Cawood P A, Zhao Z D and Mo X X. 2017a. Raising the Gangdese mountains in southern Tibet[J]. Journal of Geophysical Research: Solid Earth, 122(1): 214-223.
- Zhu M T, Wu G, Xie H J, Wan Y, Zhong W, Mei M and Liu J. 2010. Re-Os isotopic geochronology and fluid inclusion study of the Lailisigao'er porphyry Cu-Mo deposit in western Tianshan, Xinjiang, NW China[J]. Acta Petrologica Sinca, 26(12): 3667-3682(in Chinese with English abstract).
- Zhu X, Li G, Chen H, Ma D and Huang H. 2015. Zircon U-Pb, molybdenite Re-Os and K-feldspar ⁴⁰Ar/³⁹Ar dating of the bolong porphyry Cu-Au deposit, Tibet, China[J]. Resource Geology, 65(2): 122-135.
- Zhu X P, Chen H A, Ma D F, Huang H X, Li G M, Li Y B and Li Y C.
 2011. Re-Os dating for the molybdenite from Bolong porphyry copper-gold deposit in Tibet, China and its geological significance[J].
 Acta Petrologica Sinica, 27(7): 2159-2164(in Chinese with English abstract).
- Zhu X P, Chen H A, Liu H F, Ma D F, Li G M, Zhang H, Liu C Q and Wei L J. 2015a. Geochronology and geochemistry of porphyries from the Naruo porphyry copper deposit, Tibet and their metallogenic significance[J]. Acta Geologica Sinica, 89(1): 109-128(in Chinese with English abstract).
- Zhu X P, Chen H A, Liu H F, Ma D F, Li G M, Huang H X, Zhang H, Liu C Q and Wei L J. 2015b. Zircon U-Pb ages, geochemistry of the porphyries from the Duobuza porphyry Cu-Au deposit, Tibet and their metallogenic significance[J]. Acta Geologica Sinica, 89 (3): 534-548(in Chinese with English abstract).
- Zhu Y F, He G Q and An F. 2007. Geological evolution and metallogeny in the core part of the central Asian metallogenic domain[J]. Geological Bulletin of China, 26(9): 1167-1177(in Chinese with English abstract).

附中文参考文献

常印佛,李加好,宋传中.2019.长江中下游成矿带区域构造格局的

新认识[J]. 岩石学报, 35(12): 3579-3591.

- 陈超,王宝德,牛树银,马国玺,张建珍,孙爱群,马宝军,陈志宽,张 福祥,王自力.2013.河北木吉村铜(钼)矿床辉钼矿 Re-Os 年龄 及成矿流体特征[J].中国地质,40(6):1889-1901.
- 陈华安,祝向平,马东方,黄瀚霄,李光明,李玉彬,李玉昌,卫鲁杰, 刘朝强.2013 西藏波龙斑岩铜金矿床成矿斑岩年代学、岩石化 学特征及其成矿意义[J].地质学报,87(10):1593-1611.
- 陈文明,李树屏.1998. 中条山铜矿峪斑岩铜矿金属硫化物的铼-锇 同位素年龄及地质意义[J]. 矿床地质,17(3): 224-228.
- 戴盼,吴胜华,丁成武.2018. 江西王坞斑岩型 Mo-Cu 矿床花岗斑岩 锆石 U-Pb 和辉钼矿 Re-Os 同位素测年及地质意义[J]. 岩石学 报,34(9): 100-116.
- 高旭,周振华,车合伟,马星华,欧阳荷根,陈宝全,刘国东.2018.内 蒙古白乃庙铜-金-钼矿床侵入岩和围岩成因:岩石地球化学和 Hf同位素的证据[J].矿床地质,37(2):420-440.
- 高一鸣,陈毓川,唐菊兴,罗茂澄,冷秋锋,王立强,杨海锐,普布次 仁.2012. 西藏曲水县达布斑岩铜(钼)矿床成岩成矿年代学研 究[J]. 地球学报,33(4):613-623.
- 高永宝,李侃,钱兵,李文渊,李东生,苏生顺,Zhang C G,张大民,王 生明.2015. 东昆仑卡而却卡铜矿区花岗闪长岩及其暗色微粒 包体成因:锆石 U-Pb 年龄、岩石地球化学及 Sr-Nd-Hf 同位素证 据[J]. 中国地质,42(3): 646-662.
- 高永宝,李侃,钱兵,李文渊,何书跃,张大民,王生明.2018. 东昆仑 卡而却卡铜钼铁多金属矿床成矿年代学:辉钼矿 Re-Os 和金云 母 Ar-Ar 同位素定年约束[J]. 大地构造与成矿学,42(1): 96-107.
- 龚福志,郑有业,张刚阳,屈文俊.2008. 首次在冈底斯发现主碰撞期 斑岩铜矿——来自西藏吉如斑岩铜矿辉钼矿 Re-Os 同位素年龄 的证据[J]. 四川地质学报, 28(4): 296-299.
- 郭保健,毛景文,李厚民,屈文俊,仇建军,叶会寿,李蒙文,竹学丽. 2006. 秦岭造山带秋树湾铜钼矿床辉钼矿 Re-Os 定年及其地质 意义[J]. 岩石学报,22(9): 2341-2348.
- 郭正林,李金祥,秦克章,董连慧,郭旭吉,唐冬梅,杜兴旺.2010.新 疆西准噶尔罕哲尕能Cu-Au矿床的锆石U-Pb年代学和岩石地 球化学特征:对源区和成矿构造背景的指示[J].岩石学报,26 (12):3563-3578.
- 郭周平,赵辛敏,白赟,张江伟,孔会磊.2015.北祁连浪力克铜矿床 锆石 U-Pb 和辉钼矿 Re-Os 年龄及其地质意义[J].中国地质,42 (3):691-701.
- 郝金华,陈建平,董庆吉,田永革,李玉龙,陈冬.2012. 青海省纳日贡 玛斑岩钼铜矿床成矿花岗斑岩锆石 LA-ICP-MS U-Pb 定年及地 质意义[J]. 现代地质,26(1): 45-53.
- 何书跃,李东生,李良林,祁兰英,何寿福.2009.青海东昆仑鸭子沟 斑岩型铜(钼)矿区辉钼矿铼-锇同位素年龄及地质意义[J].大地 构造与成矿学,33(2):236-242.
- 和文言,莫宣学,喻学惠,和中华,董国臣,刘晓波,苏纲生,黄雄飞. 2013. 滇西北衙金多金属矿床锆石 U-Pb和辉钼矿 Re-Os年龄及 其地质意义[J]. 岩石学报,29(4): 205-214.
- 侯增谦,莫宣学,高永丰,曲晓明,孟祥金.2003. 埃达克岩:斑岩铜矿 的一种可能的重要含矿母岩——以西藏和智利斑岩铜矿为例[J].

矿床地质,22(1):1-12.

- 侯增谦,潘小菲,杨志明,曲晓明.2007.初论大陆环境斑岩铜矿[J]. 现代地质,21(2):332-351.
- 黄勇,丁俊,李光明,董随亮,黄瀚霄,崔晓亮,戴婕,闫国强.2015.西藏冈底斯厅宫铜矿侵入岩成因:LA-ICP-MS 锆石 U-Pb 年龄,地球化学及 Sr-Nd-Pb 同位素证据[J].地质论评,(3):664-680.
- 贾丽琼,莫宣学,董国臣,徐文艺,王梁,郭晓东,王治华,韦少港. 2013. 滇西马厂箐煌斑岩成因:地球化学、年代学及 Sr-Nd-Pb-Hf 同位素约束[J]. 岩石学报,(4): 1247-1260.
- 贾丽琼,徐文艺,杨丹,杨竹森,王粱.2015. 江西九瑞地区宝山斑岩 型铜多金属矿床锆石 U-Pb 和辉钼矿 Re-Os 年龄及其地质意 义[J]. 矿床地质,34(1): 63-80.
- 康永建,王亚君,黄光杰,佘宏全,向安平,田京,郭志军,董旭舟. 2014. 内蒙古八大关斑岩型铜钼矿床成岩成矿年代学研究[J]. 矿床地质,33(4): 795-806.
- 郎兴海,唐菊兴,陈毓川,李志军,黄勇,王成辉,陈渊,张丽.2010.西 藏谢通门县雄村斑岩型铜金矿集区II号矿体中辉钼矿 Re-Os年 代学及地质意义[J].矿物岩石,(4):57-63.
- 冷成彪,张兴春,王守旭,秦朝建,荀体忠.2007. 云南中甸地区两个 斑岩铜矿容矿斑岩的地球化学特征——以雪鸡坪和普朗斑岩 铜矿床为例[J]. 矿物学报,27(3):414-422.
- 冷秋锋,唐菊兴,郑文宝,张金树,唐攀,严刚,董宇.2015. 西藏拉抗 俄斑岩铜钼矿床辉钼矿 Re-Os 同位素测年及其地质意义[J]. 中 国地质,42(2): 570-584.
- 冷秋锋,唐菊兴,郑文宝,王保宏,唐攀,王豪.2016.西藏拉抗俄斑岩 Cu-Mo矿床含矿斑岩地球化学、锆石U-Pb年代学及Hf同位素 组成[J].地球科学-中国地质大学学报,41(6):999-1015.
- 李超,屈文俊,杜安道,周利敏.2011.含有普通锇的辉钼矿 Re-Os 同 位素定年研究[J]. 岩石学报,28(2):702-708.
- 李聪颖,廖仁强.2020. 斑岩型钼矿床的形成机制与地球化学过程[J]. 岩石学报,36(1):77-84.
- 李光明,刘波,屈文俊,林方成,佘宏全,丰成友.2005.西藏冈底斯成 矿带的斑岩-砂卡岩成矿系统——来自斑岩矿床和砂卡岩型铜 多金属矿床的Re-Os同位素年龄证据[J].大地构造与成矿学, (4):482-490.
- 李光明,刘波,佘宏全,丰成友,屈文俊.2006. 西藏冈底斯成矿带南 缘喜马拉雅早期成矿作用——来自冲木达铜金矿床的Re-Os同 位素年龄证据[J]. 地质通报,(12): 1481-1486.
- 李俊建,党智财,赵泽霖,石玉若,刘敦一,李超,屈文俊,王存贤,付 超,唐文龙,张彤,王守光,周红英,赵丽君,刘晓雪.2015.内蒙 古白乃庙铜矿床成矿时代的研究[J].地质学报,89(8):1448-1457.
- 李利,倪培,王国光,朱安冬.2018. 德兴斑岩铜矿田黄铁矿 Re-Os 同 位素定年及其地质意义[J]. 矿床地质,37(6): 25-35.
- 李志军,唐菊兴,姚晓峰,邓世林,王友.2011. 班公湖-怒江成矿带西 段尕尔穷铜金矿床辉钼矿 Re-Os 年龄及其地质意义[J]. 成都理 工大学学报(自然科学版),38(6): 678-683.
- 梁华英,莫济海,孙卫东,张玉泉,曾提,胡光黔,Charllote M A. 2009. 玉龙铜矿带马拉松多斑岩体岩石学及成岩成矿系统年代学分 析[J]. 岩石学报,25(2): 385-392.

梁清玲,江思宏,王少怀,李超,曾法刚.2012.福建紫金山矿田罗卜

岭斑岩型铜钼矿床辉钼矿 Re-Os 定年及地质意义[J]. 地质学报,86(7): 1113-1118.

- 林涛,邓宇峰,屈文俊,周涛发,袁峰,邓刚.2017.新疆东天山地区三 岔口铜矿床的成因:岩石学,年代学和地球化学证据[J].矿物岩 石,37(4):47-61.
- 吕博,孟贵祥,杨岳清,严加永,赵金花,邓震,李超.2014. 新疆拉依 克勒克隐伏斑岩矿床的发现、Re-Os同位素定年及地质意义[J]. 岩石学报,30(4):1168-1178.
- 孟祥金,侯增谦,高永丰,黄卫,曲晓明,屈文俊.2003a.西藏冈底斯 东段斑岩铜钼铅锌成矿系统的发育时限:帮浦铜多金属矿床辉 钼矿 Re-Os年龄证据[J].矿床地质,22(3):246-252.
- 孟祥金,侯增谦,高永丰,黄卫,曲晓明,屈文俊.2003b.西藏冈底斯 成矿带驱龙铜矿 Re-Os年龄及成矿学意义[J].地质论评,49(6): 660-666.
- 曲凯,董国臣,李胜荣,申俊峰,王艳娟,王霞,罗薇.2014.太行山木 吉村斑岩铜(钼)矿床岩石地球化学, Sr-Nd-Pb 同位素特征及其 地质意义[J].现代地质,28(3):449-460.
- 屈迅,徐兴旺,梁广林,屈文俊,杜世俊,姜能,吴惠平,张永,肖鸿,董 连慧.2009.蒙西斑岩型铜钼矿地质地球化学特征及其对东准 噶尔琼河坝岩浆岛弧构造属性的制约[J].岩石学报,25(4):765-776.
- 任江波,许继峰,陈建林,张世权,梁华英.2011."三江"地区中甸弧 普朗成矿斑岩地球化学特征及其成因[J]. 岩石矿物学杂志,30 (4):581-592.
- 任涛,王瑞廷,谢桂青,李剑斌,代军治,郭延辉,党勘峰,武晓琴. 2014.陕西池沟斑岩型铜矿床含矿岩体地球化学特征,成岩成矿 时代及其意义[J].矿床地质,33(4):807-820.
- 芮宗瑶,王龙生,王义天,刘玉琳.2002.东天山土屋和延东斑岩铜矿 床时代讨论[J].矿床地质,21(1):16-22.
- 余宏全,张德全,景向阳,关军,朱华平,丰成友,李大新.2007.青海 省乌兰乌珠尔斑岩铜矿床地质特征与成因[J].中国地质,(2): 306-314.
- 佘宏全,李进文,马东方,李光明,张德全,丰成友,屈文俊,潘桂棠. 2009. 西藏多不杂斑岩铜矿床辉钼矿 Re-Os 和锆石 U-Pb SHRIMP测年及地质意义[J]. 矿床地质,28(6):737-746.
- 申萍, 潘鸿迪, SEITMURATOVA Eleonora. 2015. 中亚成矿域斑岩铜 矿床基本特征[J]. 岩石学报, 31(2): 315-332.
- 孙燕,刘建明,曾庆栋,褚少雄,周伶俐,吴冠斌,高玉友,沈文君. 2013.内蒙东部白土营子钼铜矿田的矿床地质特征,辉钼矿 Re-Os年龄及其意义[J]. 岩石学报,29(1): 241-254.
- 谭钢,常国雄,佘宏全,李进文,张德全,杨郧城,张斌,向安平,董英 君.2010.内蒙古乌奴格吐山斑岩铜钼矿床辉钼矿铼-锇同位素 定年及其地质意义[J].矿床地质,29(Z8):506-508.
- 唐菊兴,黄勇,李志军,邓起,郎兴海,陈渊,张丽.2009a. 西藏谢通门 县雄村铜金矿床元素地球化学特征[J]. 矿床地质,28(1):15-28.
- 唐菊兴,王成辉,屈文俊,杜安道,应立娟,高一鸣.2009b.西藏玉龙 斑岩铜钼矿辉钼矿铼-锇同位素定年及其成矿学意义[J]. 岩矿 测试,28(3):215-218.
- 唐菊兴,陈毓川,王登红,王成辉,许远平,屈文俊,黄卫,黄勇. 2009c.西藏工布江达县沙让斑岩钼矿床辉钼矿铼-锇同位素年 龄及其地质意义[J].地质学报,83(5):698-704.

- 唐菊兴,黎风佶,李志军,张丽,唐晓倩,邓起,郎兴海,黄勇,姚晓峰, 王友.2010.西藏谢通门县雄村铜金矿主要地质体形成的时限: 锆石 U-Pb、辉钼矿 Re-Os 年龄的证据[J]. 矿床地质,29(3):461-475.
- 唐菊兴,郑文宝,陈毓川,王登红,应立娟,秦志鹏.2013. 西藏甲玛铜 多金属矿床深部斑岩矿体找矿突破及其意义[J]. 吉林大学学报 (地球科学版),43(4):1100-1110.
- 王保弟,许继峰,陈建林,张兴国,王立全,夏抱本.2010. 冈底斯东段 汤不拉斑岩 Mo-Cu 矿床成岩成矿时代与成因研究[J]. 岩石学 报,26(6): 1820-1832.
- 王立本,陈东.1997.安基山和铜山铜(钼)矿床中辉钼矿的铼-锇同 位素年龄及其意义[J].岩石矿物学杂志,16(2):154-159.
- 王瑞,朱弟成,王青,侯增谦,杨志明,赵志丹,莫宣学.2020.特提斯 带斑岩成矿作用[J].中国科学:地球科学,50:1919-1946.
- 王世伟,周涛发,袁峰,范裕,曹晓生,王彪.2012.铜陵舒家店斑岩铜 矿成矿年代学研究及其成矿意义[J].岩石学报,28(10):3170-3180.
- 王世伟,周涛发,袁峰,范裕,俞沧海,葛岭虹,石诚,池月余.2014.安 徽沙溪斑岩型铜金矿床成岩序列及成岩成矿年代学研究[J].岩 石学报,30(4):979-994.
- 王召林,杨志明,杨竹森,田世洪,刘英超,马彦青,王贵仁,屈文俊. 2008. 纳日贡玛斑岩钼铜矿床:玉龙铜矿带的北延——来自辉钼 矿 Re-Os 同位素年龄的证据[J]. 岩石学报,24(3): 503-510.
- 吴良士,邹晓秋.1997. 江西城门山铜矿铼-锇同位素年龄研究[J]. 矿 床地质,16(4): 376-381.
- 吴伟中,夏斌,张玉泉,董冰华,夏中曦.2013. 西藏玉龙成矿带斑岩 Cu-Mo矿床地质地球化学特征及成矿机制探讨——玉龙和多 霞松多对比研究[J]. 大地构造与成矿学,(3): 440-454.
- 吴云辉,熊小林,赵太平,朱志敏,李立.2013. 新疆东戈壁斑岩型Mo 矿辉钼矿 Re-Os 年龄和成矿岩体锆石 U-Pb 年龄及其地质意 义[J]. 大地构造与成矿学,37(4):743-753.
- 肖兵,陈华勇,王云峰,杨俊弢.2017.东天山土屋-延东铜矿带石英 钠长斑岩与辉钼矿形成年龄及其重要意义[J].大地构造与成矿 学,41(1):145-156.
- 谢桂青,毛景文,李瑞玲,张祖送,赵维超,屈文俊,赵财胜,魏世昆. 2006. 鄂东南地区 Cu-Au-Mo-(W)矿床的成矿时代及其成矿地 球动力学背景探讨:辉钼矿 Re-Os 同位素年龄[J]. 矿床地质,25 (1): 43-52.
- 辛洪波,曲晓明,王瑞江,刘鸿飞,赵元艺,黄玮.2009.藏西班公湖斑 岩铜矿带成矿斑岩地球化学及Pb、Sr、Nd同位素特征[J].矿床 地质,28(6):785-792.
- 邢俊兵,郭晓东,屈文俊,王治华,李汉光.2009.马厂箐斑岩型铜、钼 矿辉钼矿Re-Os年龄及地质意义[J].黄金科学技术,(5):24-29.
- 薛春纪,陈波,贾志业,张兵,万阈.2011.新疆西天山莱历斯高尔-3571 斑岩铜钼矿田地质地球化学和成矿年代[J].地学前缘,18 (1):149-165.
- 杨富全,张志欣,刘国仁,屈文俊,张立武,魏广智,刘锋,柴凤梅. 2012. 新疆准噶尔北缘玉勒肯哈腊苏斑岩铜矿床年代学研究[J]. 岩石学报,28(7): 85-98.
- 杨贵才,葛良胜,路英川,邹依林,邢俊兵,张峰,袁士松.2014.安徽 省池州地区马头钼矿辉钼矿 Re-Os年龄及其地质意义[J].矿物

岩石,34(1):30-35.

- 杨震,姜华,杨明国,梅红波,胡光道,张黎黎,张裴培.2017. 冈底斯 中段岗讲斑岩铜钼矿床锆石 U-Pb 和辉钼矿 Re-Os 年代学及其 地质意义[J]. 地球科学:中国地质大学学报,42(3): 339-356.
- 杨志明,侯增谦,江迎飞,张洪瑞,宋玉财.2011. 西藏驱龙矿区早侏 罗世斑岩的 Sr-Nd-Pb 及锆石 Hf 同位素研究[J]. 岩石学报,27 (7):2003-2010.
- 杨志明,侯增谦,周利敏,周怿惟.2020.中国斑岩铜矿床中的主要关键矿产[J].科学通报,65(33):9-20.
- 杨宗锋,罗照华,卢欣祥,程黎鹿,黄凡.2011.关于辉钼矿中Re含量 示踪来源的讨论[J].矿床地质,30(4):654-674.
- 袁顺达.2013. 湘南铜山岭矿田玉龙砂卡岩型钼矿床辉钼矿 Re-Os 测年[J]. 地质论评,59(z1): 393-394.
- 曾普胜,王海平,莫宣学,喻学惠,李文昌,李体刚,李红,杨朝志. 2004. 中甸岛弧带构造格架及斑岩铜矿前景[J]. 地球学报,25 (5): 535-540.
- 曾普胜,侯增谦,高永峰,杜安道.2012.印度-亚洲碰撞带东段喜马 拉雅期铜-钼-金矿床 Re-Os 年龄及成矿作用[J].地质论评,52 (1):72-84.
- 张达玉,周涛发,袁峰,范裕,刘帅,彭明兴.2010. 新疆东天山地区延 西铜矿床的地球化学,成矿年代学及其地质意义[J]. 岩石学报, 26(11): 3327-3338.
- 张刚阳,郑有业,龚福志,高顺宝,屈文俊,庞迎春,石玉若,殷世艳. 2008. 西藏吉如斑岩铜矿:与陆陆碰撞过程相关的斑岩成岩成矿 时代约束[J]. 岩石学报,24(3): 75-81.
- 张连昌,相鹏,靳新娣,李文君,徐兴旺.2013.东准卡拉先格尔成 矿带叠加改造型斑岩 Cu-Mo 矿床的 Re-Os 同位素年代学制 约[A].第十届全国同位素地质年代与同位素地球化学学术讨 论会[C].88-88.
- 张旗, 王焰, 钱青, 杨进辉, 王元龙, 赵太平, 郭光军. 2001. 中国东部 燕山期埃达克岩的特征及其构造-成矿意义[J]. 岩石学报, 17 (2): 236-244.
- 张涛,张德会,杨兵,张辉,喻晓.2015.青海同仁县江里沟斑岩-矽卡 岩型铜钨钼矿床辉钼矿 Re-Os 同位素年龄及其成矿意义[J].地 质学报,89(2):355-364.
- 张玉泉,谢应雯,邱华宁,李献华.1998.钾玄岩系列:藏东玉龙铜矿 带含矿斑岩Sr,Nd,Pb同位素组成[J].地质科学,33(3):359-366.
- 张泽明,丁慧霞,董昕,田作林.2019. 冈底斯岩浆弧的形成与演化[J]. 岩石学报,35(2): 275-294.
- 张志欣,杨富全,闫升好,张锐,柴凤梅,刘锋,耿新霞.2009.新疆包 古图斑岩铜矿床成矿流体及成矿物质来源——来自硫、氢和氧 同位素证据[J]. 岩石学报,26(3):707-716.
- 张作衡,毛景文,王志良,杜安道,左国朝,王龙生,王见蓶,屈文俊. 2006. 新疆西天山达巴特铜矿床地质特征和成矿时代研究[J]. 地质论评,52(5): 683-689.
- 赵冰爽.2018.硫化物 Re-Os 同位素等时线及其在东天山梅岭铜矿 床黄铁矿中的探讨(硕士学位论文)[D].导师:袁超,龙晓平.北 京:中国科学院大学(中国科学院广州地球化学研究所).110页.
- 赵晓燕,杨竹森,张雄,卢世银.2017. 西藏邦铺斑岩矿床黑云二长花 岗岩的形成时代及地球化学特征[J]. 矿物岩石地球化学通报, 36(5): 786-796.

- 赵一鸣,毕承思,邹晓秋,孙亚莉,杜安道,赵玉明.1997. 黑龙江多宝山、铜山大型斑岩铜(钼)矿床中辉钼矿的铼-锇同位素年龄[J]. 地球学报,27(1):61-67.
- 赵元艺,宋亮,樊兴涛,石登华,张天平,陈红旗,屈文俊.2009. 西藏 申扎县舍索铜多金属矿床辉钼矿Re-Os年代学及地质意义[J]. 地质学报,83(8):1150-1158.
- 赵云,王建平,杨增海,张捷先,王守光,尚恒胜,左海洋,杨光,张彩 霞.2013.内蒙古白乃庙铜矿床辉钼矿铼锇同位素定年及其地 质意义[J].地学前缘,20(4):361-368.
- 郑伟,欧阳荷根,赵海杰,赵财胜,于晓飞,罗大略,黄华谷,欧阳志 侠. 2017. 广东锡坪钼铜多金属矿床辉钼矿 Re-Os 同位素定年 及其地质意义[J]. 岩石学报, 33(3): 843-858.
- 郑有业,高顺宝,程力军,李国梁,冯南平,樊子珲,张华平,郭建慈, 张刚阳.2004.西藏冲江大型斑岩铜(钼金)矿床的发现及意义[J]. 地球科学-中国地质大学学报,29(3):333-339.
- 周涛发,王世伟,袁峰,范裕,张达玉,常印佛,Noel C W. 2016. 长江 中下游成矿带陆内斑岩型矿床的成岩成矿作用[J]. 岩石学报, 32(2): 271-288.

- 周雄,温春齐,张贻,周玉,费光春,张学全.2013. 西藏邦铺钼铜多金 属矿床辉钼矿 Re-Os 年代学及地质意义[J]. 矿物岩石,33(2): 59-64.
- 朱明田,武广,解洪晶,万阈,钟伟,糜梅,刘军.2010. 新疆西天山莱 历斯高尔斑岩型铜钼矿床辉钼矿 Re-Os 同位素年龄及流体包裹 体研究[J]. 岩石学报,26(12): 3667-3682.
- 祝向平,陈华安,马东方,黄瀚霄,李光明,李玉彬,李玉昌.2011.西 藏波龙斑岩铜金矿床的 Re-Os 同位素年龄及其地质意义[J].岩 石学报,27(7):2159-2164.
- 祝向平,陈华安,刘鸿飞,马东方,李光明,张红,刘朝强,卫鲁杰. 2015a.西藏拿若斑岩铜金矿床成矿斑岩年代学、岩石化学特征 及其成矿意义[J].地质学报,89(1):109-128.
- 祝向平,陈华安,刘鸿飞,马东方,李光明,黄瀚霄,张红,刘朝强,卫 鲁杰.2015b.西藏多不杂斑岩铜矿斑岩锆石U-Pb年龄、岩石地 球化学特征及其成矿意义[J].地质学报,89(3):534-548.
- 朱永峰,何国琦,安芳.2007.中亚成矿域核心地区地质演化与成矿 规律[J].地质通报,26(9):1167-1177.