

引用格式: 刘小虎, 王新宇, 肖昌浩, 等, 2024. 桂西隆林-西林锑金矿集区成矿控制因素探讨 [J]. 地质力学学报, 30 (3): 427-442.

DOI: [10.12090/j.issn.1006-6616.2023120](https://doi.org/10.12090/j.issn.1006-6616.2023120)

Citation: LIU X H, WANG X Y, XIAO C H, et al., 2024. Discussion on the ore-controlling factors in the Longlin-Xilin Sb-Au mining district of western Guangxi, South China [J]. Journal of Geomechanics, 30 (3): 427-442. DOI: [10.12090/j.issn.1006-6616.2023120](https://doi.org/10.12090/j.issn.1006-6616.2023120)

桂西隆林-西林锑金矿集区成矿控制因素探讨

刘小虎^{1,2}, 王新宇^{3,4}, 肖昌浩^{2,5,6}, 张文高^{2,5,6}, 刘向冲^{2,5}, 于萍萍^{2,5}, 毛承安⁷,
付伟^{1,3}

LIU Xiaohu^{1,2}, WANG Xinyu^{3,4}, XIAO Changhao^{2,5,6}, ZHANG Wengao^{2,5,6}, LIU Xiangchong^{2,5}, YU Pingping^{2,5},
MAO Cheng'an⁷, FU Wei^{1,3}

1. 桂林理工大学地球科学学院, 广西 桂林 541004;
2. 中国地质科学院地质力学研究所动力成岩成矿实验室, 北京 100081;
3. 有色金属矿产勘查与资源高效利用省部共建协同创新中心, 广西 桂林 541004;
4. 广西壮族自治区地质调查院, 广西南宁 530023;
5. 自然资源部古地磁与古构造重建重点实验室, 北京 100081;
6. 自然资源部深地科学与探测技术实验室, 北京 100094;
7. 广西壮族自治区第四地质队, 广西南宁 530031

1. *Department of Earth Sciences, Guilin University of Technology, Guilin 541004, Guangxi, China;*
2. *Laboratory of Dynamic Diagenesis and Metallogenesis, Institute of Geomechanics, Chinese Academy of Geological Sciences, Beijing 100081, China;*
3. *Collaborative Innovation Center for Exploration of Nonferrous Metal Deposits and Efficient Utilization of Resources in Guangxi, Guilin 541004, Guangxi, China;*
4. *Guangxi Institute of Geological Survey, Nanning 530023, Guangxi, China;*
5. *Key Laboratory of Paleomagnetism and Tectonic Reconstruction, Ministry of Natural Resources, Beijing 100081, China;*
6. *SinoProbe Laboratory, Institute of Geomechanics, Chinese Academy of Geological Sciences, Beijing 100094, China;*
7. *Geological Team No. 4 of Guangxi Zhuang Autonomous Region, Nanning 530031, Guangxi, China*

Discussion on the ore-controlling factors in the Longlin-Xilin Sb-Au mining district of western Guangxi, South China

Abstract: [Objective] Sb deposits are characterized by simple mineral assemblage. The ore-forming ages, sources of ore-forming materials, and genesis of Sb deposits are controversial owing to the absence of suitable minerals for analysis. Sb resources in the South China Sb metallogenic region account for over 83% of the national total, with the Dian-Qian-Gui Sb belt in the southwest being a significant component of this region. [Methods] Taking the Longlin-Xilin Sb-Au mining district of western Guixi in the central part of the Dian-Qian-Gui Sb belt as an example, this paper systematically summarizes the ore-bearing strata, lithology of ore-bearing wall rocks, ore-bearing structures, and the coexistence relationship of Au and Sb deposits in 86 ore deposits (points) in the area. Combined with the geological characteristics of

基金项目: 中国地质调查局地质调查项目 (DD20240127, DD20230344, DD20230293); 广西地矿局部门前期找矿选点项目 (桂地矿地 [2021] 68 号-8); 中国地质科学院地质力学研究所基本科研业务费项目 (DZLXJK202203)

This research is financially supported by the Geological Survey Project of the China Geological Survey (Grants No. DD20240127, DD20230344, and DD20230293), the Preliminary Prospecting and Site Selection Project of the Guangxi Bureau of Geology and Mineral Resources (Grant No. 2021-68-8), and the CGS Research Fund (Grant No. DZLXJK202203).

第一作者: 刘小虎 (1998-), 男, 在读硕士, 主要从事锑矿成矿作用研究。Email: liuxiaohu0120@126.com

通讯作者: 肖昌浩 (1986-), 男, 博士, 副研究员, 主要从事矿田构造与成矿规律研究。Email: xiaochanghao1986@126.com

收稿日期: 2023-07-19; 修回日期: 2024-03-05; 录用日期: 2024-03-20; 网络出版日期: 2024-03-28; 责任编辑: 王婧

three typical deposits (Maxiong, Longtan, and Mahao) and the spatiotemporal distribution of Jurassic felsic intrusions, the inherent connection between Sb mineralization and clastic rocks and felsic intrusions was explored. **[Results]** (1) Statistics and field works show that the most favorable ore-bearing stratum in the Longlin–Xilin mining district is the Lower Devonian Yujian Formation (D_{1y}), followed by the Lower Triassic Luolou Formation (T_1L) and the Middle Triassic Banna Formation (T_2b). The lithologies most conducive to mineralization are carbonaceous shale, pyrite-rich sandstone, and siltstone. The Sb content in these strata or lithologies is tens or even hundreds of times higher than the crustal abundance, which has the potential for Sb mineralization. (2) Within the NWW–SEE trending Nongsang–Shijiazhai fault zone in the Longlin area, the middle and late Jurassic felsic intrusions, which have consistent spatiotemporal occurrences with Sb and Au deposits, can directly contribute to antimony mineralization (as sources of Sb and S) and indirectly influence it (as a heat source), both favoring the formation of antimony deposits. (3) Statistical results show that Sb, Au, and Sb–Au deposits account for 48%, 46%, and 6% in the Longlin–Xilin district, respectively. This suggests that the ore-forming fluids for Sb and Au in the study area may originate from different sources. We also can not rule out the possibility that Sb and Au deposits derive from the same fluid. In the latter case, the precipitation of stibnite consumes H_2S in the ore-forming fluid, destabilizing the Au complex in the solution and resulting in localized Au precipitation. This competition between Sb and Au in the fluid for H_2S leads to a negative correlation in the grades of Sb and Au in coexisting deposits. (4) The study area experienced NS-striking compression in the Indosinian period, followed by the NW–SE shortening in the middle–late Jurassic. The intersection of NWW–SEE and NE–SW faults is the favorable ore-bearing space. The NWW–SEE faults displayed strike-slip movement in response to the NW–SE shortening, whereas the NE–SW faults exhibited transpression. Consequently, the NE–SW faults are less conducive to Sb mineralization compared to the NWW–SEE faults. The distribution direction of the NWW–SEE Douhuang–Xilin fault aligns with the axial direction of the main folds in the area, with most fault planes trending northward, displaying horizontal scratches, silicification, and extensional characteristics. The intersection of the Dohuang–Xilin fault and the NE–SW fracture exhibits significant Sb anomalies. **[Conclusion]** Based on the above studies, the promising areas we propose for Sb prospecting in Longlin–Xilin mining district are (1) Black shale and pyrite-rich siltstones of the Yujiang Formation in the core of the Xinzhou anticline as the key strata; (2) The periphery of the concealed intrusions within the NWW–SEE Nongsang–Shijiazhai fault (Longlin County) and the intersection area of the NWW–SEE Douhuang–Xilin fault and the NE–SW fault as the favorable areas. **[Significance]** The findings provide new insights into the genesis and metallogenic regularities of Sb–Au deposits in the study area, enriching the theoretical understanding of Au mineralization processes.

Keywords: source of antimony deposit; coexistence relationship between Au and Sb; Late Jurassic felsic intrusion; Longlin–Xilin mining district; Dian–Qian–Gui Sb metallogenic belt; South China

摘要: 华南锑成矿省锑资源储量占全国 83% 以上, 位于成矿省西南部的滇黔桂锑矿带是华南锑成矿省的重要组成部分。文章以滇黔桂锑矿带中部桂西隆林–西林锑金矿集区为例, 系统分析了区内 82 个矿床(点)的赋矿层位、赋矿围岩岩性、容矿构造特征及锑、金矿床共生关系, 结合 3 个典型矿床调查及岩浆岩时空分布, 探讨锑成矿作用与碎屑岩、岩浆岩的成因联系。研究表明: 具有高锑背景值的炭质泥页岩和富黄铁矿砂岩是研究区锑成矿的有利岩性, 为锑成矿提供了物质来源。岩浆作用对锑成矿既可以起到直接作用 (Sb 和 S 来源) 也可以起到间接作用 (热源), 两者均有利于锑矿床的形成。容矿构造分析显示研究区经历了印支期南北向挤压, 随后叠加中晚侏罗世北西–南东向挤压。北西西–南东东向和北东–南西向断裂及其交汇处是有利的容矿空间。隆林–西林矿集区锑、金矿床统计显示, 区内以独立的锑、金矿床为主, 暗示研究区锑、金成矿流体可能多为不同来源流体。在上述研究基础上, 文章提出桂西隆林–西林锑金矿集区勘查有利区域: 新州背斜核部下泥盆统郁江组炭质泥页岩和富黄铁矿粉砂岩是锑矿勘查的重点层位; 隆林县弄桑–石家寨北西西–南东东向断裂带内隐伏岩体周边和西林县北西西–南东东向斗皇–西林断裂与北东–南西向断裂的交汇部位是锑矿勘查的有利区域。以上成果为研究区内锑金矿床成因和成矿规律认识提供新的思考, 为区内锑矿床勘查提供方向。

关键词: 锑成矿物质来源; 锑金共存关系; 晚侏罗世长英质岩脉; 隆林–西林矿集区; 滇黔桂锑矿带; 华南中图分类号: P611; P612 文献标识码: A 文章编号: 1006–6616 (2024) 03–0427–16

DOI: [10.12090/j.issn.1006-6616.2023120](https://doi.org/10.12090/j.issn.1006-6616.2023120)

0 引言

锑是一种银白色、性脆、无延展性的不可再生金属,是热和电的不良导体,被广泛用于国防科技领域,是重要的战略资源。相关学者在锑成矿时代、成矿流体来源和成因模式等方面作了大量工作(Nesbitt et al., 1989; Buchholz et al., 2007; 肖宪国, 2014; 陈军等, 2021; Yan et al., 2022; Long et al., 2023),但对锑成矿作用仍存在不同意见,如对成矿物质来源及锑金成矿作用的关系争议较大。由于缺乏直接示踪的方法手段,关于锑矿床成矿锑和硫的来源争议不断。一部分学者认为,锑可能来源于地壳,尤其是碎屑岩地层。Zhou et al.(2018)对吉尔吉斯斯坦南天山造山带 Atebayue 锑矿床 S、Pb 同位素特征的研究表明,成矿元素可能来源于志留系或二叠系砂岩、粉砂岩。张天羽等(2020)认为新元古代氧化事件使华南地区寒武系底部富有机质黑色页岩富集锑($1.0 \times 10^{-6} \sim 34.3 \times 10^{-6}$),中生代岩浆活动驱动了成矿物质的二次富集。另一部分学者则认为,锑来源于深部且主要与中酸性岩浆有关。Guillemette and Williams-Jones(1993)对危地马拉中部的 Sb-W-Au 矿床流体包裹体和稳定同位素研究显示,成矿流体主要来自大气降水,矿床成矿金属元素(Sb、W、As 和 Au)来源于长英质侵入体,S 来源于地层中的黄铁矿。李保亮等(2022)通过辉锑矿 S、Pb 同位素研究,认为西藏哈姆曲 Sb-Au 矿床成矿 S 主要为岩浆来源,成矿金属显示壳幔混合的特征。在锑、金成矿作用的关系方面也存在 2 种不同的观点。一种观点认为,在 Sb-Au 成矿系统中,锑、金矿化存在一定的联系,是同一成矿流体不同演化阶段的产物。如 Xing et al.(2024)通过对东昆仑屈库勒克东 Au-Sb 矿床石英微量元素分析、流体包裹体显微测温和 H-O 同位素分析,认为金、锑矿化来源于同一初始流体,物理化学条件的改变导致金、锑的沉淀。另一种观点认为,在 Sb-Au 成矿系统中,锑、金矿化是独立的,Sb-Au 矿床形成于不同矿化作用的叠加。如 Bortnikov et al.(2010)通过对成矿阶段硫化物化学组成、流体包裹体、硫化物 S 同位素和石英 O 同位素的研究,认为俄罗斯 Maiskoe Au-Sb 矿床叠加了 3 种不同年龄、不同成因的矿化作用,这些矿化作用形成于不同的地质构造环境和物理化学条件下,由不同来源的流体上升而成。

华南锑成矿省位于扬子板块与华夏板块的交

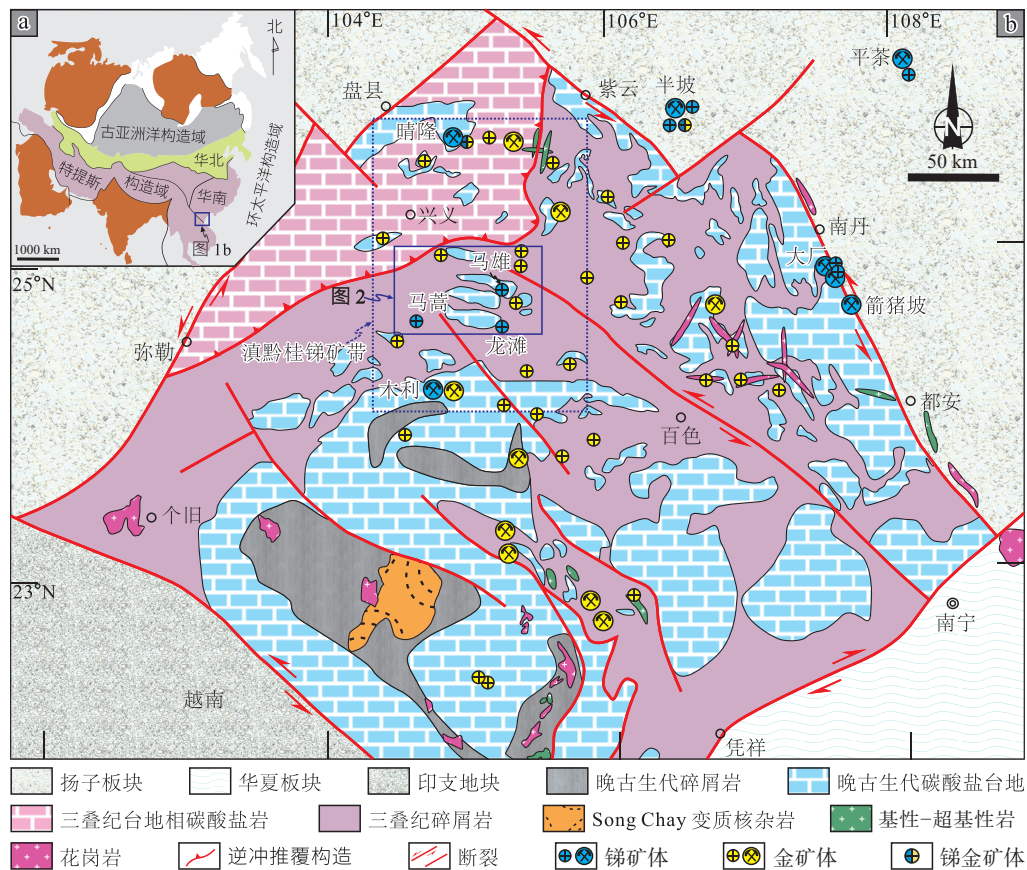
汇处,锑资源储量占全国总储量的 83% 以上(Yan et al., 2022)。滇黔桂锑矿带位于华南锑成矿省的西南部,是华南锑成矿省的重要组成部分。滇黔桂锑矿带产出大量锑、金矿床且锑、金共伴生分异特征显著,直接影响了锑、金矿床找矿勘探。文章以滇黔桂锑矿带中段桂西隆林-西林锑金矿集区为例,基于对研究区锑、金矿床赋矿地层时代和岩性、赋矿构造特征的统计分析,对 3 个典型锑矿床进行了精细解析和矿相学研究,探讨了矿化和同矿化期酸性岩脉的空间分布关系,试图揭示锑成矿作用与长英质岩脉、赋矿围岩以及金、锑成矿作用的相互关系,以期为研究区锑金矿床成因和成矿规律认识提供新的思考,为区域锑、金勘查提供方向。

1 地质背景

1.1 区域地质演化

右江盆地处在特提斯构造域和环太平洋构造域的交汇部位,自古生代以来经历了多期构造-岩浆活动(李三忠等, 2022; 胡利娟等, 2023; 图 1)。

寒武系以台地相碳酸盐岩为主夹少量砂泥岩。经广西运动改造形成褶皱基底被泥盆系碎屑岩角度不整合覆盖(杜远生和徐亚军, 2012)。早泥盆世开始受特提斯构造域影响,随着哀牢山洋盆的打开,在右江地区形成了多条北西-南东向的裂谷带(Gan et al., 2021),逐渐演变为台盆分割的被动大陆边缘裂谷盆地,同时形成台盆相间的古构造地理格局,台地主要为浅水碳酸盐岩沉积,盆地主要为深水泥质岩和硅质岩沉积(Wang et al., 2003; Li et al., 2017)。晚泥盆世-中二叠世,海盆持续扩展加深,形成许多小洋盆(Huang et al., 2013),碳酸盐岩台地经历多次间歇抬升,形成多个平行不整合,期间以深水相沉积为主(Yang et al., 2012)。中一晚二叠世,受峨眉山幔柱的影响,区内发生基性岩浆的侵入或喷发。沿断裂带喷发的凝灰质物质在盆地深水相沉积中形成了一套具有鲍马序列的火山碎屑浊积岩(侯方浩和黄继祥, 1984)。晚二叠世-中三叠世,印支板块与华南板块拼合,弧后盆地转化为前陆盆地(Jiang et al., 2019)。晚三叠世,印支运动导致的右江盆地内部由南往北逐步的造山运动标志着三叠系碎屑沉积的结束,该造山运动以上三叠统不整合和褶皱断裂为主要特征(Qiu et al., 2017)。晚三叠世-晚白垩世,受太平洋板块俯冲的影响,右江盆地发生了 2 次规模较大的花岗岩岩



a—研究区大地构造位置图(据胡丽娟等, 2023 修改); b—右江盆地锑、金矿床分布图(据 Xiao et al., 2022 修改)

图 1 右江盆地区域地质图

Fig. 1 Regional geological map of the Youjiang basin

(a) Tectonic map of Asia showing continental blocks and bounding sutures (modified after Hu et al., 2023); (b) Distribution map of Sb-Au deposits in the Youjiang basin (modified after Xiao et al., 2022)

浆活动,晚侏罗世—早白垩世花岗岩主要分布于盆地东南部,晚白垩世花岗岩主要分布于盆地西部和东部(Gan et al., 2020, 2022)。晚侏罗世—晚白垩世,整个华南地区存在多次锑矿化,最终造就了中国最大的锑矿省——华南锑矿省(彭建堂和胡瑞忠, 2001)。新生代地壳抬升,右江盆地受到西部青藏高原抬升和菲律宾海板块向西俯冲的影响,造成了盆地西高东低的地势(乔龙, 2016)。

1.2 隆林-西林地区地质特征

隆林-西林锑金矿集区位于滇黔桂锑矿带的中段,褶皱和断裂构造发育。从北往南分布有安然、新州、德峨、蛇场 4 个大型背斜和隆或、朝阳 2 个穹窿构造(图 2)。

区内发育北西西—南东东向、北西—南东向、北东—南西向和北东东—南西西向 4 组断裂。以北西西—南东东向、北西—南东向为主,为区域性主干断裂,具有控岩、控矿的特征。区内大面积分布

三叠系,古生界仅在几个背斜和穹窿构造中有出露。寒武系出露于背斜核部,岩性为白云岩夹砂岩。下泥盆统底部以砂泥岩为主,向上逐渐过渡为碳酸盐岩。石炭系下部为薄层硅质岩向上过渡为碳酸盐岩建造。二叠系下部为碳酸盐岩夹碎屑岩,上部为硅质岩、粉砂岩、微晶灰岩。三叠系下部为粉砂岩、泥岩,向上过渡为钙质砂岩、泥岩。区内岩浆岩均出露于背斜核部,主要是辉绿岩和玄武岩,偶见长英质岩脉。辉绿岩呈脉状或不规则状侵入石炭系和二叠系中,玄武岩呈层状、似层状于石炭系中顺层产出。区内矿产资源以锑、金矿床为主,目前已发现的锑、金矿床(点)达 82 个。中型矿床有马雄锑矿床、龙滩锑矿床和马蒿锑矿床(图 2)。

1.3 典型锑矿床地质特征

1.3.1 马雄锑矿床

马雄锑矿床位于隆林新州背斜南翼(图 2)。矿区出露地层自下而上有:上寒武统、下泥盆统、中

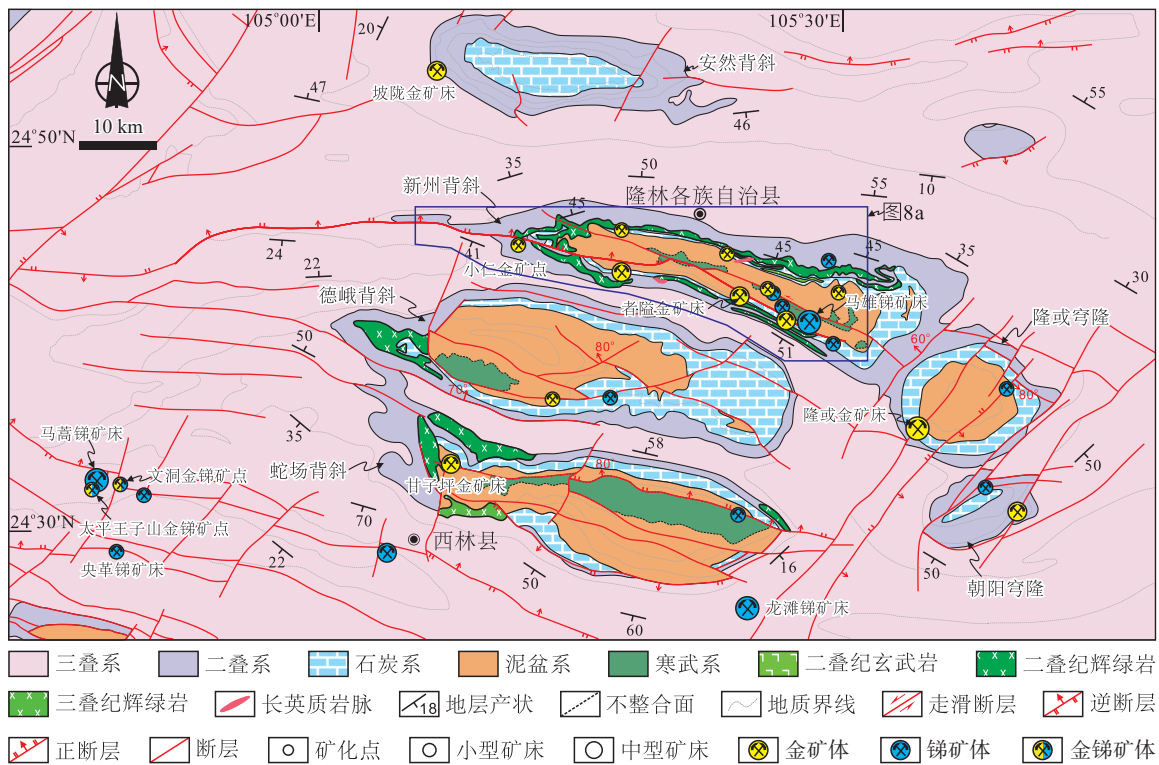


图 2 桂西隆林-西林锑金矿集区地质图

Fig. 2 Geological map of the Longlin-Xilin Sb-Au district in western Guangxi

泥盆统、上泥盆统、石炭系、二叠系、下三叠统。赋矿围岩主要是下泥盆统郁江组富黄铁矿砂岩、炭质泥页岩(图 3a、3b)。北西西-南东东向马雄-岩浪断裂是矿床主容矿断裂,为右行走滑,形成于近南北向挤压构造背景(图 3c)。矿区出露岩浆岩主要为辉绿岩,分布在矿区西南侧,辉绿岩脉沿泥盆系与石炭系、二叠系与三叠系 2 个接触面侵入。

矿床主矿脉沿寒武系与泥盆系不整合面及其附近的破碎带充填,走向 300°~320°,倾向南西,倾角 55°~85°(图 3a)。矿石有辉锑矿-石英脉和辉锑矿-方解石脉 2 种类型。前者金属矿物主要有辉锑矿,少量黄铁矿、毒砂、磁黄铁矿、白钨矿等(图 3d);脉石矿物主要是石英和少量白云石、白云母、绢云母、钠长石、萤石等。后者金属矿物主要是辉锑矿和少量黄铁矿、毒砂等;脉石矿物主要是方解石、白云石、白云母等。矿石构造包括块状构造、角砾状构造、脉状构造和浸染状构造。岩矿学研究显示矿床成矿阶段划分为辉锑矿-石英阶段(主成矿阶段)和辉锑矿-碳酸盐岩阶段(图 3d、3e)。矿区热液蚀变包括硅化、黄铁矿化、毒砂化、碳酸盐化、绢云母化等。

1.3.2 龙滩锑矿床

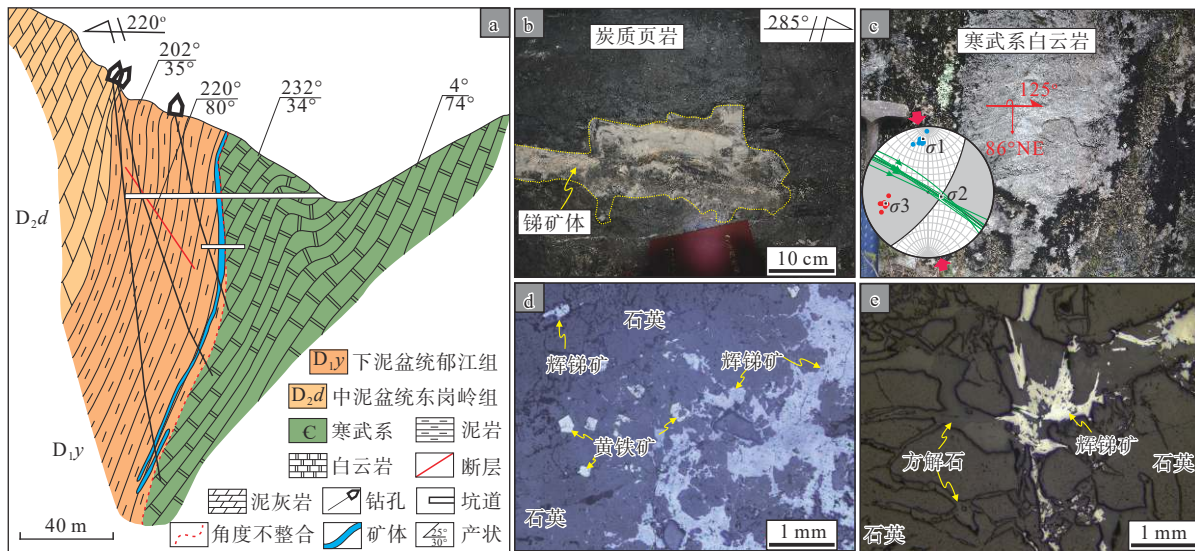
龙滩锑矿床位于蛇场背斜东南部(图 2)。矿区出露地层包括下三叠统罗楼组、中三叠统板纳组。

赋矿围岩主要是下三叠统罗楼组第三段粉砂岩、泥岩。北东-南西向高角度走滑断裂次级北东东-南西西向断裂是矿床主容矿断裂,为右行走滑,形成于北西-南东向挤压(图 4)。矿区西北部出露少量辉绿岩。

龙滩锑矿床主要发育似层状和脉状 2 种类型矿体(图 4a-4c)。似层状矿体主要呈扁豆状产于层间剪切带,走向 270°~280°,倾向南西,倾角 5°~12°。脉状矿体受高角度断层控制,反向切割中一薄层砂岩地层,呈板状、长扁豆状雁列产出,走向 60°~70°,倾向北西,倾角 70°~85°。2 类矿体在空间上组成“非”字型。金属矿物主要有辉锑矿和少量黄铁矿、磁黄铁矿、赤铁矿;脉石矿物主要是方解石、白云石、石英,局部有绿泥石、钙长石等(图 4d)。辉锑矿通常呈放射状、针状、柱状等与方解石共生(图 4e)。矿石构造包括块状构造、角砾状构造、脉状构造和浸染状构造。矿区热液蚀变主要是硅化、碳酸盐化,零星有黄铁矿化和绿泥石化。

1.3.3 马蒿锑矿床

马蒿锑矿床位于隆林-西林矿集区西南部(图 2)。矿区出露中三叠统板纳组、兰木组,两者呈整合接触。赋矿围岩主要是板纳组二段薄-中层钙质泥岩夹粉砂岩,矿体顶底板均为泥岩、钙

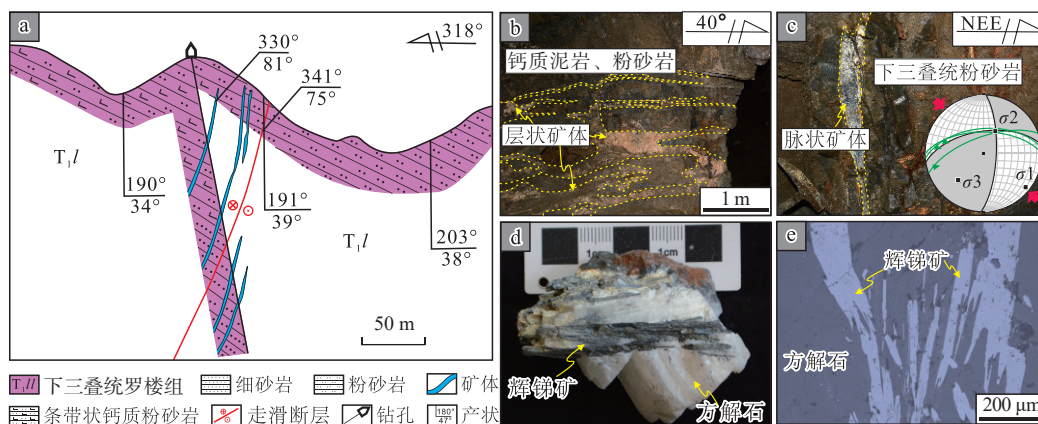


a—0号勘探线剖面图(据 Yan et al., 2022 修改); b—主矿体顶部为炭质页岩; c—容矿北西西—南东东向走滑断裂底面水平擦痕产状特征(走滑断裂底面水平擦痕矢量数据反演显示三轴主应力方向 σ_1 为 $351^\circ/12^\circ$ 、 σ_2 为 $110^\circ/67^\circ$ 、 σ_3 为 $256^\circ/20^\circ$, 指示近南北向挤压应力场); d—脉状矿化的辉锑矿、石英和蚀变围岩中的黄铁矿; e—脉状矿化的辉锑矿、方解石、石英

图3 马雄锑矿床矿体及矿物特征

Fig. 3 Ore body and mineral characteristics of the Maxiong antimony deposit

(a) Geological cross-section along the exploration line 0 (modified after Yan et al., 2022); (b) The hanging wall of the main ore body composed of carbonaceous shales; (c) Occurrence characteristics of horizontal scratches on the bottom surface of NWW–SEE strike-slip ore-bearing fault (Inversion of horizontal scratches vector data on the bottom surface of strike-slip fault shows that the triaxial principal stress directions σ_1 is $351^\circ/12^\circ$, σ_2 is $110^\circ/67^\circ$ and σ_3 is $256^\circ/20^\circ$, indicating the near NS compressive stress field); (d) Stibnite–quartz vein mineralization and pyrite in altered wall rocks; (e) Stibnite–quartz–calcite vein mineralization



a—A12勘探线地质剖面图(据广西壮族自治区二七四地质队, 1990 修改); b—层状矿体; c—脉状矿体产于北东东—南西西向高角度走滑断裂中(高角度走滑断裂层面擦痕矢量数据反演显示三轴主应力方向 σ_1 为 $129^\circ/9^\circ$ 、 σ_2 为 $28^\circ/53^\circ$ 、 σ_3 为 $226^\circ/36^\circ$, 指示北西—南东向挤压应力场); d—方解石—辉锑矿矿石手标本; e—脉状矿化的辉锑矿、方解石

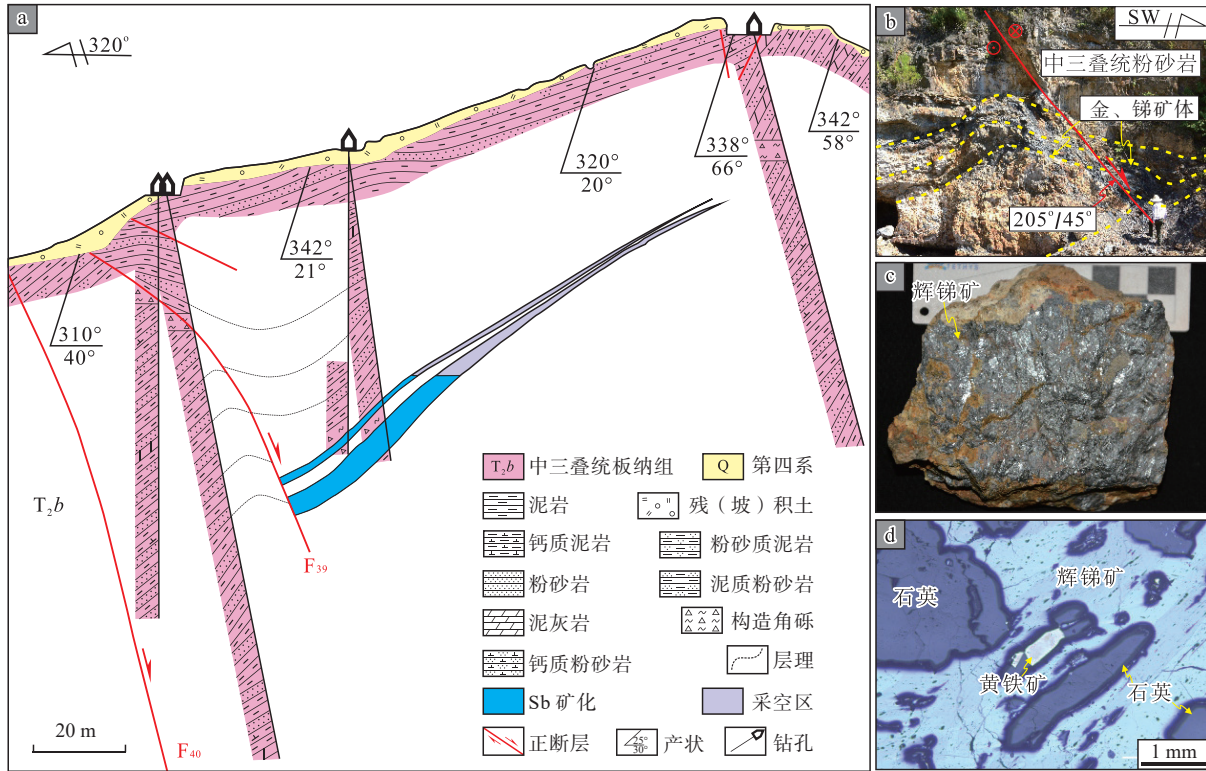
图4 龙滩锑矿床矿体及矿物特征

Fig. 4 Ore body and mineral characteristics of the Longtan Sb deposit

(a) Geological cross-section along the exploration line A12 (modified after No.274 Team of Guangxi Bureau of Geology, 1990); (b) Stratiform ore body in Luolou Formation sandstones; (c) Vein ore bodies occur in NEE–SWW high angle strike-slip faults (Inversion of the vector data of scratches on the fault plane of high-angle strike-slip fault shows that the triaxial principal stress directions σ_1 is $129^\circ/9^\circ$, σ_2 is $28^\circ/53^\circ$ and σ_3 is $226^\circ/36^\circ$, indicating that it was formed in the NW–SE compressive stress field); (d) Calcite–stibnite hand specimen; (e) Stibnite–calcite vein mineralization

质泥岩。矿床产于北西西—南东东向斗皇-西林断裂和北东—南西向平佑断裂的交汇部位, 矿体呈似层状赋存于北东—南西向断裂旁侧牵引褶皱核部

虚脱空间及层间破碎带中, 走向 $15^{\circ}\sim 30^{\circ}$, 倾向北西, 倾角 $18^{\circ}\sim 32^{\circ}$, 锑矿体远离断裂逐渐减薄(图 5a、5b)。矿区未见岩浆岩出露。



a—6号勘探线地质剖面图(据广西金果子矿业有限公司, 2011 修改); b—马蒿锑矿床文洞矿段容矿断裂具有右行正断特征, 金、锑矿体产在断裂下盘牵引褶皱核部虚脱空间; c—辉锑矿矿石手标本; d—辉锑矿-石英脉中石英与辉锑矿、黄铁矿共生

图 5 马蒿锑矿床矿体及矿物特征

Fig. 5 Ore body and mineral characteristics of the Mahao Sb deposit

(a) Geological cross-section along the exploration line 6 (modified after Guangxi Jinguozhi Mining Co., Ltd, 2011); (b) The ore-bearing fault in Wendong ore segment of Mahao Sb deposit characterized by right-lateral normal faulting, with the Au (Sb) ore bodies occurring in the core space of traction folds formed by footwall of faults; (c) Stibnite hand specimen; (d) Stibnite coexisting with quartz and pyrite

矿石发育有辉锑矿-石英脉和辉锑矿-碳酸盐岩脉 2 种类型。前者金属矿物主要是辉锑矿和少量黄铁矿、磁黄铁矿、毒砂等; 非金属矿物有石英及少量白云母、高岭石、磷灰石、钠长石等(图 5c、5d)。后者金属矿物主要是辉锑矿及少量黄铁矿、磁黄铁矿、毒砂等; 非金属矿物为方解石、铁白云石等。矿石构造主要有块状构造、角砾状构造、脉状构造等。矿区热液蚀变主要是硅化、碳酸盐化、黄铁矿化、毒砂化、高岭石化等。

2 成矿特征统计

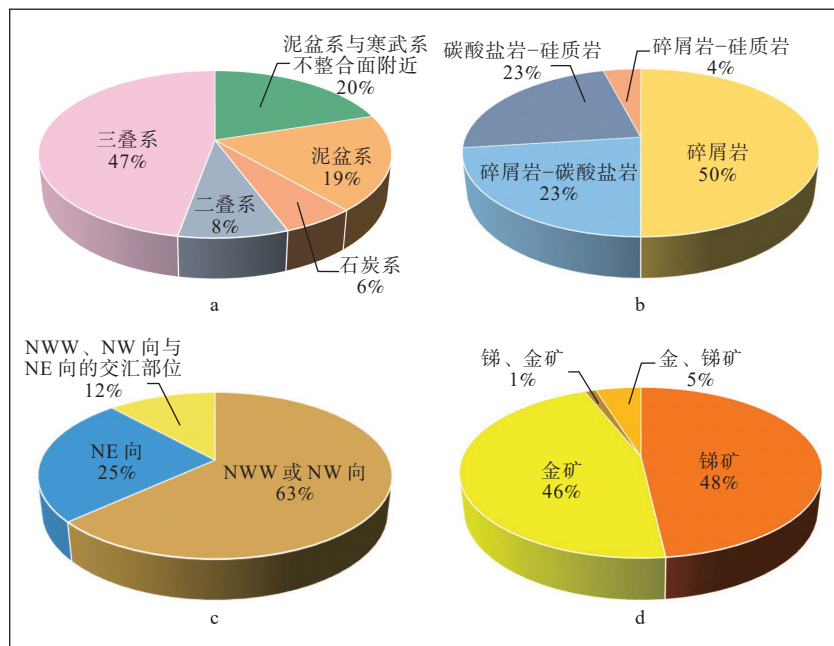
2.1 赋矿地层

据隆林-西林锑金矿集区 82 份锑、金矿勘查报

告统计显示, 隆林-西林锑金矿集区锑、金矿床的赋矿层位主要有泥盆系与寒武系不整合面、泥盆系、石炭系、二叠系和三叠系。上述地层赋存锑、金矿床数量分别占比 20%、19%、6%、8% 和 47%(图 6a)。

产于泥盆系与寒武系不整合面及附近破碎带中的锑、金矿床包括马雄中型锑矿床和岩浪锑矿床、洞等金矿床等小型锑、金矿床。这些矿床受泥盆系与寒武系不整合面及北西向陡倾角断裂控制, 矿体主要赋存于下泥盆统郁江组的泥页岩、砂岩中, 部分矿体延伸至寒武系白云岩和中泥盆统东岗岭组灰岩中。

产于泥盆系的锑、金矿床包括六隆金矿床、者隘金矿床、唐皇锑矿床等小型锑、金矿床。六隆金



a—主要赋矿地层占比图; b—赋矿围岩岩性占比图; c—容矿断裂走向占比图; d—金、锑共生组合占比图

图 6 桂西隆林-西林锑金矿床特征饼图

Fig. 6 Pie charts of Sb-Au deposit in the Longlin-Xinlin mining district, western Guangxi

(a) Ore-bearing strata; (b) Lithologies of ore-bearing rocks; (c) Ore-bearing faults; (d) Au and Sb co-existing assemblages

矿床矿体赋存于下泥盆统郁江组的砂岩、泥岩中;者隘金矿床矿体赋存于上泥盆统榴江组的钙质砂岩、粉砂岩中;唐皇锑矿床矿体赋存于下泥盆统郁江组粉砂岩中。

产于石炭系的锑、金矿床包括隆或中型金矿床、克保小型金矿床和一些锑、金矿点。隆或金矿床似层状矿体赋存于下石炭统英塘组硅质岩、硅质灰岩、硅质泥岩中;克保金矿床赋存于石炭系白云质灰岩中。

产于二叠系的锑、金矿床目前仅发现包括小仁金矿点在内的一些锑金矿点。小仁金矿点赋存于上二叠统领好组凝灰质砂岩中。

产于三叠系的锑、金矿床包括龙滩锑矿床、马蒿锑金矿床 2 个中型锑矿床和央革锑矿床等小型锑矿床。龙滩锑矿床赋存于下三叠统罗楼组粉砂岩、泥岩中;马蒿锑金矿床赋存于中三叠统板纳组粉砂岩、泥岩中;央革锑矿床赋存于中三叠统兰木组泥岩、粉砂岩中。

2.2 赋矿围岩岩性

隆林-西林锑金矿集区锑、金矿床的赋矿围岩主要有泥岩、砂岩、粉砂岩等碎屑岩及少量碳酸盐岩、硅质岩。通过此次数据统计分析,研究区锑金矿床赋矿围岩岩性组合包括以下 4 类(图 6b)。

赋存于碎屑岩中的矿床,以马蒿锑矿床、龙滩锑矿床、六隆金矿床为代表。马蒿锑矿床的赋矿围岩为中三叠统板纳组第二段钙质泥岩、泥岩、粉砂岩,矿体顶板为泥岩、钙质泥岩,底板为钙质泥岩;龙滩锑矿床赋矿围岩为下三叠统罗楼组第三段粉砂岩、泥岩,局部夹泥灰岩和灰岩;六隆金矿床赋矿围岩为下泥盆统郁江组的砂岩、泥岩。

赋存于碎屑岩-碳酸盐岩组合中的矿床,以马雄锑矿床、洞等金矿床为代表。马雄锑矿床赋矿围岩主要是下泥盆统郁江组下部炭质泥页岩、富黄铁矿粉砂岩,其次为中泥盆统东岗岭组泥质灰岩、寒武系白云岩等;洞等金矿床 I 号矿体赋矿围岩为下泥盆统郁江组细砂岩、泥岩及粉砂岩,II 号矿体赋矿围岩为寒武系龙哈组一段砂泥岩,矿体顶底板均为灰岩。

赋存于碳酸盐岩-硅质岩组合中的矿床,以甘子坪金矿床为代表。甘子坪金矿床矿体顶板为上泥盆统榴江组硅质岩,底板为中泥盆统东岗岭组灰岩。

赋存于碎屑岩-硅质岩组合中的矿床,以隆或金矿床、坡陇金矿床等为代表。隆或金矿床 I 号矿体赋矿围岩为下石炭统英塘组薄层硅质岩、硅质灰岩、硅质泥岩、凝灰质泥岩,II 号矿体赋存于上二

叠统底部凝灰质泥岩、凝灰质粉砂岩、粉砂岩、泥岩、硅质岩中, III号矿体赋存于下三叠统凝灰岩、粉砂质泥岩、炭质泥岩中。

2.3 容矿断裂方向

隆林-西林锑金矿集区容矿断裂以北西西-南东东、北西-南东向为主, 其次为北东-南西向及其与前两者的交汇部位(图6c)。

(1)受北西西-南东东、北西-南东向断裂控制的锑、金矿床, 主要分布于新州背斜核部的马雄-岩浪断裂和西林县城南部的斗皇-西林断裂附近, 如马雄锑矿床、六隆金矿床、央革锑矿床等。马雄锑矿床主要的控矿构造为北西西-南东东向马雄-岩浪断裂, 矿脉沿该断裂及两侧层间破碎带充填产出。六隆金矿床主要的控矿构造为北西西-南东东向断裂, 金矿体主要赋存在寒武系与泥盆系不整合面附近发育的断层破碎带中。北西西-南东东向斗皇-西林断裂为央革锑矿床主要的控矿构造, 断裂破碎带为主要容矿构造。

(2)受北东-南西向断裂控制的锑、金矿床, 主要分布于北东-南西向隆或-岩茶断裂一带, 如龙滩锑矿床、隆或金矿床等。

(3)受北西西-南东东与北东-南西向断裂共同控制的锑、金矿床, 主要分布于北西西-南东东向斗皇-西林断裂与北东-南西向断裂的交汇部位, 如马蒿锑金矿床等。

2.4 金、锑共生组合特征

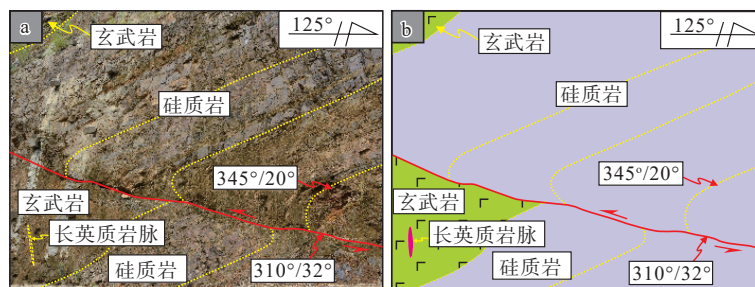
隆林-西林矿集区锑、金矿床按共生组合可分为4种类型, 分别为锑矿床、金矿床、锑金矿床和金锑矿床。在已收集的锑金矿床资料中, 锑矿床占48%, 金矿床占46%, 锑、金共伴生的矿床只占6%

(图6d)。锑矿床分布广泛, 规模上以小型锑矿床为主, 中型锑矿床目前只有马雄锑矿床、马蒿锑矿床和龙滩锑矿床。金矿床数量众多, 几乎都是小型矿床或矿点, 中型金矿床只有隆或金矿床。锑、金共生的矿床规模都很小, 以矿点为主。总体来说, 隆林-西林地区的锑、金矿床以独立的锑矿床或金矿床为主, 锑、金共生的矿床占少数。

3 讨论

3.1 锑成矿控制因素探讨

对研究区锑金矿床赋矿地层时代和岩性、赋矿构造特征的统计分析及3个典型矿床的地质特征野外调查表明, 隆林-西林锑金矿集区锑成矿作用与富黄铁矿砂岩及黑色页岩、中晚侏罗世长英质岩脉及中生代以来构造演化关系密切。研究区中生代以来构造-岩浆-锑成矿过程概括如下: 受印支期扬子板块与印支板块拼合碰撞造山的影响, 研究区经历了近南北向缩短变形(Yang et al., 2012; 吴玉等, 2019), 表现为形成近东西向冲断褶皱体系及一系列北东-南西向区域调节断裂, 以高角度走滑断裂为主。如隆林大树脚近南北向构造剖面可以清晰观察到下泥盆统郁江组至上二叠统领好组卷入断裂-褶皱变形体系(图7), 通过卷入变形的中晚二叠世基性岩可以推测南北向挤压可能发生在二叠纪之后。对野外马雄和龙滩锑矿床容矿构造几何学、运动学及动力学调查分析显示, 马雄锑矿床北西西-南东东向容矿构造和龙滩锑矿床北东-南西向容矿构造均经历了印支期南北向挤压(图3b, 图4c)。



a—剖面图; b—素描图

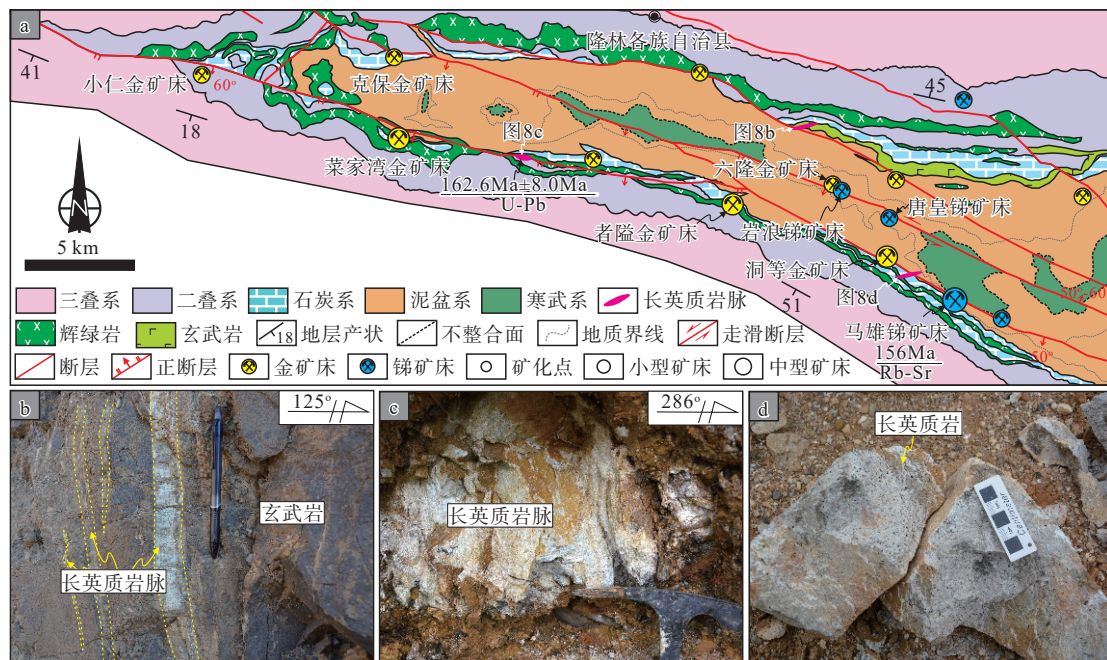
图7 隆林县大树脚北西西-南东东向逆冲断层错断中二叠世玄武岩露头剖面及素描图

Fig. 7 The Outcrop profile and geologic sketch of Middle Permian basalt staggered by the NWW-SEE thrust fault in Dashujiao, Longlin County

(a) Outcrop profile; (b) Geologic sketch

以往岩浆岩研究显示,研究区随后经历了早侏罗世印支期造山后伸展,沿着早期近东西向断裂及褶皱倾伏端侵入基性岩(Qiu et al., 2019)。中晚侏罗世受太平洋板片向华南板块俯冲影响,研究区经历了北西—南东向缩短变形,导致印支期构造再活化。如新州背斜及核部的马雄—岩浪断裂普遍发育早期高角度倾向擦痕并叠加晚期水平擦痕(图 3b)。矿区容矿的北西西—南东东向和北东—南西向断

裂晚期水平擦痕古应力方向反演显示,二者均形成于北西—南东向挤压,表明北西—南东向和北东—南西向容矿构造均经历了后期北西—南东向缩短变形的叠加(图 3b, 图 4c)。中晚侏罗世,伴随着太平洋板块的俯冲,研究区发育少量长英质岩脉沿着走滑断裂侵位。如隆林马雄—岩浪断裂带内发育弄桑、石家寨和大树脚长英质岩脉(图 8)。



a—隆林北西西—南东东向含矿断裂中锑、金矿床及晚侏罗世长英质岩脉分布图; b—大树脚长英质岩脉侵入中二叠世玄武岩; c—弄桑长英质岩脉; d—石家寨长英质岩

图 8 隆林北西西—南东东向含矿断裂中锑、金矿床及长英质岩脉分布图

Fig. 8 Distribution map of antimony deposits, gold deposits, and felsic dikes in NW-SE striking faults in Longlin Country

(a) Distribution map of Sb deposit, Au deposits, and Late Jurassic felsic dikes in NW-SE ore-bearing faults; (b) Felsic dyke intruded into the Middle Permian basalt at Dashujiao, Longlin Country; (c) Felsic dyke occurred at Nongsang, Longlin Country; (d) Felsic rock occurred at Shijiazhai, Longlin Country

已有研究获得马雄—岩浪断裂内的弄桑长英质岩脉锆石 U-Pb 年龄为 162.6 ± 8.0 Ma (广西壮族自治区地质调查院, 2019)与马雄辉锑矿石英脉中石英流体包裹体 Rb-Sr 年龄 (156 Ma) 基本一致(韦文灼, 1993; 图 8a)。鉴于两者具有一致的时空关系,长英质岩脉对锑成矿可能具有重要贡献。伴随着中晚侏罗世岩浆侵位,构造活动热和岩浆热可能为研究区 S 从富黄铁矿的砂岩及 Sb 从炭质页岩中的活化迁移提供有利条件。以往研究显示碎屑岩地层往往因具有较高的 Sb 元素丰度(如页岩中的锑丰度为 1.5×10^{-6} , 黑色页岩中的锑丰度达到了 5.0×10^{-6} , 是

锑在地壳中丰度 (0.2×10^{-6}) 的数十倍) 而成为矿源层 (Ketris and Yudovich, 2009)。如文中统计的世界大型锑矿床有 75% 赋存于碎屑岩中(表 1)。研究区泥盆系郁江组、三叠系罗楼组和板纳组粉砂岩、泥岩 Sb 元素丰度达到地壳丰度的 150~200 倍,可能是成矿 Sb 元素的主要来源(图 9a)。此次统计的 82 个锑、金矿床(点)中有 50% 矿体产在碎屑岩(主要是下泥盆统郁江组砂岩、页岩,中三叠统板纳组泥岩、粉砂岩,下三叠统罗楼组粉砂岩、泥岩)中也验证了上述假设。此外,富黄铁矿的砂岩可能是辉锑矿形成硫的主要来源。如马雄锑矿床主矿体产于

下泥盆统郁江组黑色富炭质的泥页岩和下覆富黄铁矿砂岩层间破碎带中(图3c)。上述认识也被国内外同类型锑矿床同位素研究所证实。如德国Rhenish地块北部的Arnsberg锑矿床的辉锑矿和黄铁矿S同位素研究显示赋矿围岩富黄铁矿的黑色页岩可能是矿床成矿金属和S的重要来源(Wagner and Boyce, 2003)。湖南锡矿山锑矿床矿区页岩中锑的含量是地壳丰度的200倍以上,可能是成矿Sb元素的重要来源(Hu and Peng, 2018)。Fu et al.(2023)通过研究湖南锡矿山锑矿床成矿流体氦/热比值($^3\text{He}/\text{Q}$),认为是深部花岗质岩浆加热的地下水在新元古代基底中循环和萃取成矿物质,形成的成矿流体沿断裂上升,在有利位置沉淀成矿。然而由于此

次工作野外调查新发现的长英质岩脉风化程度较强,无法准确获得长英质岩中Sb的含量,因此不排除长英质岩脉为锑成矿提供物质的可能。尽管已有的数值模拟研究结果显示岩浆出溶到流体中的锑是有限的,不足以形成大型锑矿床(Fu et al., 2020),但是已有研究显示温度是影响热液流体中辉锑矿溶解度最显著的因素,当温度高于300℃时辉锑矿溶解度呈指数倍增加(Sośnicka et al., 2022)。这就意味着中晚侏罗世长英质岩脉即使不提供成矿物质,其提供的热也有利于加热的流体萃取地层中的Sb,并在断裂带内活化迁移,运移至有利的部位成矿。若上述假设成立,那么层间剪切摩擦生热对研究区锑成矿作用也不容忽视。

表1 国内外典型锑矿床赋矿围岩岩性

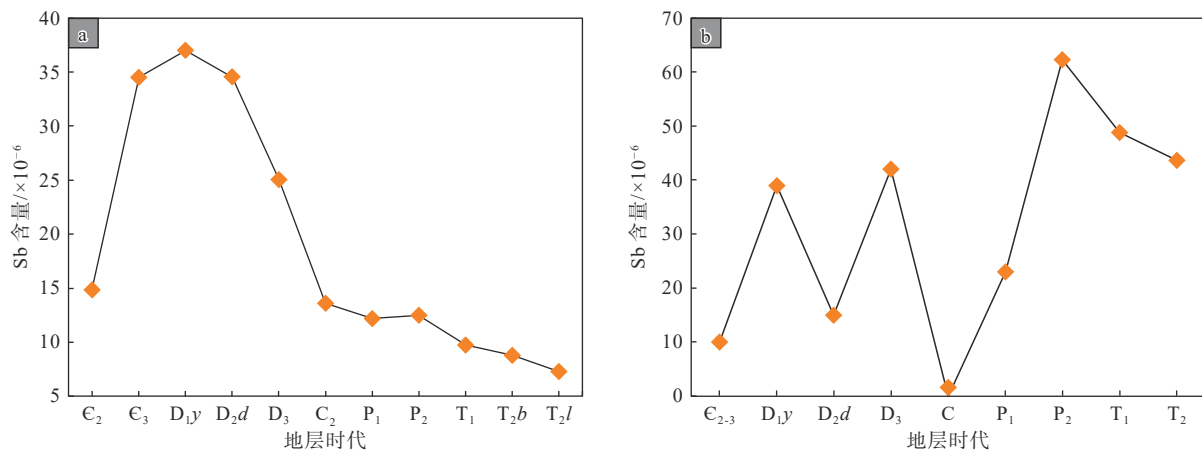
Table 1 Lithology of the surrounding rocks of typical antimony deposits at home and abroad

国家	地区	矿床名称	赋矿围岩主要岩性	参考文献
中国	湖南	锡矿山锑矿床	灰岩、黑色页岩、砂岩	Hu and Peng, 2018
	贵州	半坡锑矿床	石英砂岩、砂质泥岩、页岩	肖宪国, 2014
	云南	木利锑矿床	硅质岩、黑色页岩	韩江, 2020
	西藏	扎西康Sb-Pb-Zn矿床	灰黑色页岩、泥质和钙质页岩	Liang et al., 2018
澳大利亚	Victoria	Costerfield Sb-Au矿床	富黄铁矿粉砂岩、炭质页岩	Wilson et al., 2017
	New England Orogen	Hillgrove锑矿床	页岩、石英砂岩、灰岩	Boyle and Hill, 1988
加拿大	New Brunswick	The Lake George锑矿床	砂岩、泥岩	Scratch et al., 1984
	Newfoundland	Beaver Brook锑矿床	黑色页岩、砂岩、砾岩	Lake and Wilton, 2006
俄罗斯	The kolyvan-tomsk folded area	Semiluzhinskoe Au-Sb矿床	炭质页岩、钙质页岩	Kalinin et al., 2015
美国	California	McLaughlin锑矿床	泥岩、粉砂岩、灰岩、砾岩	Sherlock et al., 1995
吉尔吉斯斯坦	—	Kadamzhai and Khaidarkan锑矿床	灰岩、灰绿色页岩、黑色页岩	Hnylko et al., 2019
	—	Atebayue锑矿床	砂岩、粉砂岩	Zhou et al., 2018
西班牙	SAN Antonio, Badajoz	Alburquerqu锑矿床	角砾岩、钙质页岩组、硅质层	
	Ciudad Real	San Felipe锑矿床	砂质页岩、石英岩	Gumiel and Vindel, 1983
	Ciudad Real	Nazarena 锑矿床	砂质页岩、石英岩	
葡萄牙	Braganca	Braganca锑矿床	砾岩、石英岩、黑色板岩	Neiva et al., 2008
	Porto	Alto do Sobrido锑矿床	黑色泥页岩、砂岩、黑色泥质片岩	Simoës, 1997
德国	Rhenish地块北部	Arnsberg锑矿床	富黄铁矿的黑色页岩和硅质灰岩	Wagner and Boyce, 2003

3.2 锑金成矿作用的关系

隆林-西林矿集区锑、金矿床统计显示,区内以独立的锑、金矿床为主,少量锑、金共伴生矿床(图6d)。暗示研究区锑、金成矿流体可能为不同来源流体,少部分矿床可能为同一流体的演化分带。上述认识有别于以往对右江成矿带锑金成矿作用的认知。如Li et al.(2020)通过分析右江盆地Sb-Au矿

床石英原位氧同位素和微量元素,认为锑金成矿作用来自同一成矿流体,赋矿围岩的差异和流体混合导致了卡林型金矿和锑矿成矿作用的分异。部分学者提出辉锑矿的沉淀需要消耗流体中的 H_2S ,可以触发其他以硫氢络合物迁移的金属(如Au、Hg)共同沉淀(Krupp, 1988);另一部分学者认为断裂活动引起的循环压力释放导致温度降低,使辉锑矿发



C₂—中寒武统; E₃—上寒武统; D₃—上泥盆统; D_{1y}—下泥盆统郁江组; D_{2d}—中泥盆统东岗岭组; C—石炭系; C₂—中石炭统; P₁—下二叠统; P₂—上二叠统; T₁—下三叠统; T₂—中三叠统; T_{2b}—中三叠统板纳组; T_{2l}—中三叠统兰木组

a—隆林地区不同时代地层锑丰度(数据引自杨怀顺, 2007); b—三林地区不同时代地层锑丰度(数据引自韦文灼, 1993)

图9 隆林-西林地区不同时代地层锑丰度

Fig. 9 Sb abundance in different strata in the Longlin-Xilin area

(a) Sb abundance in stratigraphic units of different ages in the Longlin area (data from Yang, 2007); (b) Sb abundance stratigraphic units of different ages in the Sanlin area (data from Wei, 1993)

C₂—the Middle Cambrian; E₃—the Upper Cambrian; D₃—the Upper Devonian; D_{1y}—the Yujiang Formation of the Lower Devonian; D_{2d}—the Donggangling Formation of the Middle Devonian; C—the Carboniferous; C₂—the Middle Carboniferous; P₁—the Lower Permian; P₂—the Upper Permian; T₁—the Lower Triassic; T₂—the Middle Triassic; T_{2b}—the Banna Formation of the Middle Triassic; T_{2l}—the Mulan Formation of the Middle Triassic

生沉淀, 辉锑矿的沉淀降低了流体的 H₂S 浓度, 从而使溶液中的 Au 络合物不稳定, 导致了 Au 的局部沉淀 (Hagemann and Lüders, 2003)。由于 Sb、Au 对硫氢络合物的竞争关系, 使得锑金矿床中两者的品位往往呈负相关(表 2)。隆林-西林矿集区太平王子山金、锑矿点 Au 平均品位 1.61×10^{-6} , Sb 平均品位 0.83% (广西西林县恒源矿业开发有限责任公司, 2017); 文洞锑、金矿点 Au 平均品位 0.063×10^{-6} , Sb 平均品位 2.05% (广西西林县恒源矿业开发有限

责任公司, 2015)。研究区锑、金品位的这种负相关可能是由成矿过程中 Sb、Au 元素对 H₂S 的竞争关系造成的。然而, 此次统计显示, 94% 的矿床是以独立的矿床产出, 因此很难用金锑同源成矿流体解释这一现象。已有研究显示锑在成矿流体中除了可以以硫氢络合物的形式迁移外, 还可以以羟基络合物的形式迁移。因此, 对于锑金成矿作用的关系, 还需加强成矿流体性质的研究。

表 2 国内外典型锑-金矿床 Au-Sb 品位

Table 2 Au-Sb ore grade of typical antimony gold deposits at home and abroad

国家	矿床名称	Au品位/ $\times 10^{-6}$	Sb品位/%	参考文献
中国	湘中沃溪Sb-Au-W矿床	8.1	3.50	陈明辉, 2016
	湘中龙山Au-Sb矿床	2.51~5.91	1.93~6.63	文琴和刘涛, 2019
	西藏马扎拉Au-Sb矿床	2~18.6	3.16~41.67	莫儒伟等, 2013
	西秦岭早子沟Au-Sb矿床	3.34	1.34	耿建珍等, 2019
捷克	Krásná Hora Sb-Au矿床	3~5	1.5~3	Němec and Zachariáš, 2018
俄罗斯	Sarylakh and Sentachan Au-Sb矿床	8~35	20~30	Bortnikov et al., 2010
俄罗斯	Semiluzhinskoe Au-Sb矿床	2	0.1~21	Kalinin et al., 2015
澳大利亚	Hillgrove Au-Sb 矿床	4~5	3~4	Ashley et al., 2000

3.3 桂西隆林-西林锑矿勘查方向

上述统计显示炭质泥页岩、富黄铁矿砂岩、粉砂岩是成矿的有利岩性,长英质岩脉有利于锑矿床的形成,北西西-南东东向和北东-南西向断裂及其交汇部位是有利的容矿构造。基于上述认识,认为以下几个方面是隆林-西林地区锑矿床勘查的有利方向。

首先,砂岩、粉砂岩、泥岩或泥页岩与富黄铁矿砂岩组合是锑矿勘查有利层位。以往研究表明,隆林-西林地区泥盆系与三叠系砂岩、粉砂岩、泥岩锑含量是地壳丰度的数十甚至数百倍(图7)。下泥盆统郁江组砂岩、泥岩、页岩交互的岩性组合既能成为矿源层,又能成为遮挡层。同时,软硬相间的岩性易发生断裂和破碎,成为矿液运移和沉淀的有利场所(肖宪国,2014),是区内有利的赋矿岩性。如新州背斜核部沿北西西-南东东向马雄-岩浪断裂带两侧地层具有富黄铁矿粉砂岩和黑色炭质泥页岩岩性组合。在该位置上,目前已发现的锑矿床有马雄锑矿床、岩浪锑矿床等,可以作为区内下一步锑矿勘查方向。

其次,长英质岩脉周边可以作为第二个有利找矿部位。据广西壮族自治区地球物理勘察院前期重力反演显示,弄桑长英质岩脉可能是隆林隐伏岩体西侧的岩突,因此弄桑-石家寨北西西-南东东向断裂带内隐伏岩体周边锑矿勘查可以作为区内下一步锑矿的勘查方向。

正如前面讨论所述,研究区容矿构造整体形成于印支期北东-南西向缩短变形,随后叠加了晚侏罗世北西-南东向缩短变形。鉴于前面讨论中所论述的成矿时代为中晚侏罗世,北西西-南东东向与北东-南西向断裂交汇处是有利的容矿空间之一。成矿期,容矿构造经历了北西-南东向缩短变形,北西西-南东东向断裂表现为走滑为主,而北东-南西向断裂表现为压扭性特征。因此,相比较而言,北东-南西向断裂含矿性稍差于北西西-南东东向断裂。最后提出北西西-南东东向与北东-南西向断裂的交汇部位可以作为第三个有利的找矿部位。如北西西-南东东向斗皇-西林断裂展布方向与区内主要褶皱的轴向保持一致,断层面多数倾向北,具水平擦痕和硅化,显张性特征。斗皇-西林断裂与北东-南西向断裂的交汇部位易形成有利的容矿空间。区域化探资料显示,沿斗皇-西林断裂与北东-南西向断裂交汇部位具有明显Sb异

常。该部位已发现的锑矿床有马蒿锑矿床、央革锑矿床等。因此,斗皇-西林断裂与北东-南西向断裂的交汇部位可以作为区内下一步锑矿勘查方向。

4 结论

文章以桂西隆林-西林锑金矿集区为例,初步讨论锑、金成矿作用,取得以下认识。

(1)具有高锑背景值的炭质泥页岩,富黄铁矿砂岩、粉砂岩是赋锑有利岩性。岩浆作用对锑成矿既可以起到直接作用(Sb和S来源),也可以起到间接作用(热源),无论是直接还是间接作用均有利于锑矿床的形成。北西西-南东东向和北东-南西向断裂及其交汇部位是有利的容矿空间,且北东-南西向断裂含矿性差于北西西-南东东向断裂。

(2)隆林-西林地区锑、金矿床统计显示,该地区以独立的锑、金矿床为主,少量矿床以共伴生为主,暗示锑、金成矿流体是不同来源流体,少部分矿床为同一流体的演化分带。锑、金同源流体中Sb、Au对H₂S的竞争关系,可能是锑金矿床中两者的品位负相关的重要原因。

(3)初步提出桂西隆林-西林锑金矿集区勘查有利区域:新州背斜核部下泥盆统郁江组炭质泥页岩、富黄铁矿粉砂岩是锑矿勘查的重点部位;隆林县弄桑-石家寨北西西-南东东向断裂带内隐伏岩体周边和西林县北西西-南东东向斗皇-西林断裂与北东-南西向断裂的交汇部位是锑矿勘查的有利区域。

致谢:感谢王宗秀研究员并提出的宝贵建议。野外工作得到了广西百色百金矿业投资集团有限公司、隆林县龙滩锑矿床和马雄锑矿床、西林县马蒿锑矿床和文洞锑矿床、广西壮族自治区二七四地质队、广西壮族自治区第四地质队的帮助;研究生赵圣涛、刘昊、唐一飞、赵裕达共同参与了野外工作,在此一并感谢。

References

- ASHLEY P M, CREAUGH C J, RYAN C G, 2000. Invisible gold in ore and mineral concentrates from the Hillgrove gold-antimony deposits, NSW, Australia[J]. *Mineralium Deposita*, 35(4): 285-301.
- BORTNIKOV N S, GAMYNIN G N, VIKENT'EVA O V, et al, 2010. The Sarylakh and Sentachan gold-antimony deposits, Sakha-Yakutia: a case of combined mesothermal gold-quartz and epithermal stibnite ores[J]. *Geo-*

- logy of Ore Deposits, 52(5): 339-372.
- BOYLE G O, HILL R L, 1988. The Hillgrove antimony-gold field[J]. New England Orogen Tectonics and Metallogensis, 235-239.
- BUCHHOLZ P, OBERTHUR T, LÜDERS V, et al, 2007. Multistage Au-As-Sb mineralization and crustal-scale fluid evolution in the Kwekwe district, Midlands greenstone belt, Zimbabwe: a combined geochemical, mineralogical, stable isotope, and fluid inclusion study[J]. *Economic Geology*, 102(3): 347-378.
- CHEN J, HUANG Z L, YANG R D, et al, 2021. Symbiosis and differentiation mechanism of gold and antimony in Nanpanjiang-Youjiang Basin[C]//Proceedings of the first national mineral exploration conference. Hefei: Chinese Geophysical Society: 1067-1071. (in Chinese)
- CHEN M H, 2016. Pitch of ore bodies and occurrence pattern of the tabular ore body in vein-like W-Tb-Au deposits in western Hunan province[J]. *Contributions to Geology and Mineral Resources Research*, 31(3): 340-345. (in Chinese with English abstract)
- DING J H, ZHANG Y, MA Y B, et al, 2021. Metallogenic characteristics and resource potential of antimony in China[J]. *Journal of Geochemical Exploration*, 230: 106834.
- DU Y S, XU Y J, 2012. A preliminary study on Caledonian event in South China[J]. *Geological Science and Technology Information*, 31(5): 43-49. (in Chinese with English abstract)
- FU S L, ZAJACZ Z, TSAY A, et al, 2020. Can magma degassing at depth donate the metal budget of large hydrothermal Sb deposits?[J]. *Geochimica et Cosmochimica Acta*, 290: 1-15.
- FU S L, HU R Z, PENG J T, et al, 2023. A comprehensive genetic model for the world's largest Sb deposit (Xikuangshan, China)[J]. *GSA Bulletin*, 135(3-4): 1074-1088.
- GAN C S, WANG Y J, BARRY T L, et al, 2020. Late Jurassic high-Mg andesites in the Youjiang Basin and their significance for the southward continuation of the Jiangnan Orogen, South China[J]. *Gondwana Research*, 77: 260-273.
- GAN C S, WANG Y J, ZHANG Y Z, et al, 2021. The assembly of the South China and Indochina blocks: constraints from the Triassic felsic volcanics in the Youjiang Basin[J]. *GSA Bulletin*, 133(9-10): 2097-2112.
- GAN C S, WANG Y J, ZHANG Y Z, et al, 2022. Petrogenesis of Late Cretaceous granites and implications for W-Sn mineralization in the Youjiang Basin, South China[J]. *Ore Geology Reviews*, 144: 104846.
- GENG J Z, HUANG Y Q, JIANG G P, et al, 2019. Zircon U-Pb age and Lu-Hf isotopes of the dacite from Zaozigou Au-Sb deposit, west Qinling, China[J]. *Geological Survey and Research*, 42(3): 166-173. (in Chinese with English abstract)
- Guangxi Jinguozi Mining Co., Ltd, 2011. Geological Profile of No.6 Exploration Line in Mahao Antimony Deposit [R]. Guangxi: Guangxi Jinguozi Mining Co., Ltd. (in Chinese)
- Guangxi Institute of Geological Survey, 2019. Report on actually measured and 1: 50000 regional geological survey of Longlin [R]. Guangxi: Guangxi Institute of Geological Survey. (in Chinese)
- Guangxi Xilin County Hengyuan Mining Development Co., Ltd, 2015. Implementation scheme of gold and antimony exploration in Wendong mining area, Xilin county, Guangxi [R]. Guangxi: Guangxi Xilin County Hengyuan Mining Development Co., Ltd. (in Chinese)
- Guangxi Xilin County Hengyuan Mining Development Co., Ltd, 2017. Implementation scheme of gold and antimony exploration in Taipingwang-zishan mining area, Guzhang Town, Xilin County, Guangxi [R]. Guangxi Xilin County Hengyuan Mining Development Co., Ltd. (in Chinese)
- GUILLEMETTE N, WILLIAMS-JONES A E, 1993. Genesis of the Sb-W-Au deposits at Ixtahuacan, Guatemala: evidence from fluid inclusions and stable isotopes[J]. *Mineralium Deposita*, 28(3): 167-180.
- GUMIEL P, VINDEL E, 1983. Estudio de las mineralizaciones filonianas plomo-antimoníferas de la cobertera en la Sierra de la Demanda. Mina Santa Rufina, Urrez (Burgos)[R]. Madrid: Instituto Geológico y Minero de España.
- HAGEMANN S G, LÜDERS V, 2003. P-T-X conditions of hydrothermal fluids and precipitation mechanism of stibnite-gold mineralization at the Wiluna lode-gold deposits, western Australia: conventional and infrared microthermometric constraints[J]. *Mineralium Deposita*, 38(8): 936-952.
- HAN J, 2020. Discussion on the origin of Muliang deposit in Guangnan County, Yunnan Province[J]. *Gansu Metallurgy*, 42(1): 69-71. (in Chinese with English abstract)
- HNYLKO O, TSUKORNYK I, HENERALOVA L, et al, 2019. A Late Carboniferous olistostrome at the front of the southern Tian Shan nappes (Kadamzhai and Khaidarkan deposits, Kyrgyzstan)[J]. *Geological Quarterly*, 63(2): 407-423.
- HOU F H, HUANG J X, 1984. Research into the Permian and Triassic volcanoclastic turbidite of Nanpan River Sag: a unique turbidite mode without submarine fan[J]. *Acta Sedimentologica Sinica*, 2(4): 19-32. (in Chinese with English abstract)
- HU A X, PENG J T, 2018. Fluid inclusions and ore precipitation mechanism in the giant Xikuangshan mesothermal antimony deposit, South China: conventional and infrared microthermometric constraints[J]. *Ore Geology Reviews*, 95: 49-64.
- HU L J, WU X K, LE X W, et al, 2023. Dating the Deli Pb-Zn deposit, Xidamingshan mining district, South China: implications for regional exploration[J]. *Journal of Geomechanics*, 29(1): 76-86. (in Chinese with English abstract)
- HUANG H, DU Y S, HUANG Z Q, et al, 2013. Depositional chemistry of chert during late Paleozoic from western Guangxi and its implication for the tectonic evolution of the Youjiang Basin[J]. *Science China Earth Sciences*, 56(3): 479-493.
- JIANG W, YAN Q R, DENG L, et al, 2019. Early Jurassic mafic intrusions in the southern Youjiang Basin, SW China: petrogenesis, tectonic and metallogenic implications[J]. *Minerals*, 9(12): 771.
- KALININ Y A, NAUMOV E A, BORISENKO A S, et al, 2015. Spatial-temporal and genetic relationships between gold and antimony mineralization at gold-sulfide deposits of the Ob-Zaisan folded zone[J]. *Geology of Ore Deposits*, 57(3): 157-171.
- KETRIS M P, YUDOVICH Y E, 2009. Estimations of Clarkes for Carbon-

- aceous biolithes: world averages for trace element contents in black shales and coals[J]. *International Journal of Coal Geology*, 78(2): 135-148.
- KRUPP R E, 1988. Solubility of stibnite in hydrogen sulfide solutions, speciation, and equilibrium constants, from 25 to 350°C[J]. *Geochimica et Cosmochimica Acta*, 52(12): 3005-3015.
- LAKE J W L, WILTON D H C, 2006. Structural and stratigraphic controls on mineralization at the Beaver Brook antimony deposit, central Newfoundland[R]. Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report, 6(1): 135-146.
- LI B L, WANG L Q, ZHANG X G, et al, 2022. Sulfur and lead isotope compositions and their geological significances in the Quzhen Sb mineralization section of the Hamuqu Sb-Au Deposit, Tibet[J]. *Acta Geoscientica Sinica*, 43(2): 202-210. (in Chinese with English abstract)
- LI J H, ZHAO G C, JOHNSTON S T, et al, 2017. Permo-Triassic structural evolution of the Shiwandashan and Youjiang structural belts, South China[J]. *Journal of Structural Geology*, 100: 24-44.
- LI J W, HU R Z, XIAO J F, et al, 2020. Genesis of gold and antimony deposits in the Youjiang metallogenic province, SW China: evidence from in situ oxygen isotopic and trace element compositions of quartz[J]. *Ore Geology Reviews*, 116: 103257.
- LI S Z, SUO Y H, ZHOU J, et al, 2022. Tectonic evolution of the South China Ocean-Continent Connection Zone: transition and mechanism of the Tethyan to the Pacific tectonic domains[J]. *Journal of Geomechanics*, 28(5): 683-704. (in Chinese with English abstract)
- LIANG W, HOU Z Q, ZHENG Y C, et al, 2018. The Zhaxikang vein-type Pb-Zn-Ag-Sb deposit in Himalayan Orogen, Tibet: product by overprinting and remobilization processes during post-collisional period[J]. *Acta Geologica Sinica-English Edition*, 92(2): 682-705.
- LONG Z Y, QIU K F, SANTOSH M, et al, 2023. Fingerprinting the metal source and cycling of the world's largest antimony deposit in Xikuangshan, China[J]. *GSA Bulletin*, 135(1-2): 286-294.
- MO R W, SUN X M, ZHAI W, et al, 2013. Ore-forming fluid geochemistry and metallogenic mechanism from Mazhala gold-antimony deposit in southern Tibet, China[J]. *Acta Petrologica Sinica*, 29(4): 1427-1438. (in Chinese with English abstract)
- NEIVA A M R, ANDRÁŠ P, RAMOS J M F, 2008. Antimony quartz and antimony-gold quartz veins from northern Portugal[J]. *Ore Geology Reviews*, 34(4): 533-546.
- NĚMEC M, ZACHARÍÁŠ J, 2018. The Krásná Hora, Milešov, and Příkladov Sb-Au ore deposits, Bohemian Massif: mineralogy, fluid inclusions, and stable isotope constraints on the deposit formation[J]. *Mineralium Deposita*, 53(2): 225-244.
- NESBITT B E, MUEHLENBACHS K, MUROWCHICK J B, 1989. Genetic implications of stable isotope characteristics of mesothermal Au deposits and related Sb and Hg deposits in the Canadian Cordillera[J]. *Economic Geology*, 84(6): 1489-1506.
- No.274 Geological Team of Guangxi Bureau of Geology, 1990. Geological survey report of Longtan antimony mine area in Longlin county [R]. Guangxi: 274 Team of Guangxi Bureau of Geology. (in Chinese)
- PENG J T, HU R Z, 2001. Metallogenic Epoch and metallogenic tectonic environment of antimony deposits, South China[J]. *Geology-Geochemistry*, 29(3): 104-108. (in Chinese with English abstract)
- QIAO L, 2016. Tectonic evolution and bauxite metallogenesis in the Youjiang Basin and Adjacent Area[D]. Beijing: China University of Geosciences (Beijing): 1-165. (in Chinese with English abstract)
- QIU L, YAN D P, YANG W X, et al, 2017. Early to Middle Triassic sedimentary records in the Youjiang Basin, South China: implications for Indosinian orogenesis[J]. *Journal of Asian Earth Sciences*, 141: 125-139.
- QIU L, YANG W X, YAN D P, et al, 2019. Geochronology of early Mesozoic diabase units in southwestern China: metallogenic and tectonic implications[J]. *Geological Magazine*, 156(7): 1141-1156.
- SCRATCH R B, WATSON G P, KERRICH R, et al, 1984. Fracture-controlled antimony-quartz mineralization, Lake George Deposit, New Brunswick; mineralogy, geochemistry, alteration, and hydrothermal regimes[J]. *Economic Geology*, 79(5), 1159-1186.
- SHERLOCK R L, TOSDAL R M, LEHRMAN N J, et al, 1995. Origin of the McLaughlin Mine sheeted vein complex: metal zoning, fluid inclusion, and isotopic evidence[J]. *Economic Geology*, 90(8): 2156-2181.
- SIMOES M C, 1997. Mineralogical and geochemical features of metasedimentary rocks associated to Au-Sb vein mineralization in northern Portugal[J]. *Comunicações do Instituto Geológico e Mineiro*, 83: 29-46.
- SOŠNICKA M, DE GRAAF S, MORTEANI, G, et al, 2022. The Schlaining quartz-stibnite deposit, Eastern Alps, Austria: constraints from conventional and infrared microthermometry and isotope and crush-leach analyses of fluid inclusions[J]. *Mineralium Deposita*, 1-17.
- WAGNER T, BOYCE A J, 2003. Sulphur isotope geochemistry of black shale-hosted antimony mineralization, Arnsberg, northern Rhenish Massif, Germany: implications for late-stage fluid flow during the Variscan orogeny[J]. *Journal of the Geological Society*, 160(2): 299-308.
- WANG G Z, HU R Z, SU W C, et al, 2003. Fluid flow and mineralization of Youjiang Basin in the Yunnan-Guizhou-Guangxi area, China[J]. *Science in China Series D: Earth Sciences*, 46(S1): 99-109.
- WEI W Z, 1993. Geological characteristics of Maxiong antimony deposit[J]. *Southwest Mineral Geology*, 7(2): 8-16. (in Chinese)
- WEN Q, LIU T, 2019. Analysis of geological characteristics and genesis of Longshan gold-antimony deposit[J]. *World Nonferrous Metals*(14): 90-91. (in Chinese with English abstract)
- WILSON C J L, MOORE D H, LUZIN V, et al, 2017. Costerfield antimony-gold deposit, southeast Australia: coupling between brittle deformation and dissolution-precipitation reactions in the Melbourne Zone[J]. *Ore Geology Reviews*, 91: 741-764.
- WU Y, ZHANG S, HUANG Z, et al, 2019. Meso-Cenozoic tectonic evolution of the Nandan-Libo Area, Northwestern Guangxi, China: evidence from Palaeo-tectonic stress fields analyses[J]. *Geotectonica et Metallogenia*, 43(5): 872-893. (in Chinese with English abstract)

- XIAO C H, LI G J, LIU H, et al, 2016. Characteristics of rare earth and trace elements of stibnite from the Bijishan antimony deposit, Southwest Yunnan: implications for ore genesis[J]. *Journal of Geomechanics*, 22(2): 310-324. (in Chinese with English abstract)
- XIAO C H, CHEN Z L, LIU X C, et al, 2022. Structural analysis, mineralogy, and cassiterite U-Pb ages of the Wuxu Sb-Zn-polymetallic district, Danchi Fold-and-Thrust belt, South China[J]. *Ore Geology Reviews*, 150: 105150.
- XIAO X G, 2014. Geochronology, ore geochemistry and genesis of the Banpo antimony deposit, Guizhou Province, China[D]. Kunming: Kunming University of Science and Technology: 1-138. (in Chinese with English abstract)
- XING L, LI W C, ZHAO X B, et al, 2024. Separation of Au and Sb mineralization in the Qukulekedong intrusion-related deposit, East Kunlun Orogen (NW China): evidence from fluid inclusions, H-O isotopes, and quartz geochemistry[J]. *Ore Geology Reviews*, 164: 105828.
- YAN J, FU S L, LIU S, et al, 2022. Giant Sb metallogenic belt in South China: a product of Late Mesozoic flat-slab subduction of paleo-Pacific plate[J]. *Ore Geology Reviews*, 142: 104697.
- YANG H S, 2007. Geological characteristics and ore indicators of antimony deposit in northwestern Guangxi[J]. *Mineral Resources and Geology*, 21(1): 52-55. (in Chinese with English abstract)
- YANG J H, CAWOOD P A, DU Y S, et al, 2012. Detrital record of Indosinian mountain building in SW China: provenance of the Middle Triassic turbidites in the Youjiang Basin[J]. *Tectonophysics*, 574-575: 105-117.
- ZHANG T Y, LI C Y, SUN S J, et al, 2020. Geochemical characteristics of antimony and genesis of antimony deposits in South China[J]. *Acta Petrologica Sinica*, 36(1): 44-54. (in Chinese with English abstract)
- ZHOU Z J, CHEN Z L, HAN F B, et al, 2018. Fluid inclusion and isotope geochemistry of the Atebayue Sb deposit, South Tianshan Orogen, Kyrgyzstan[J]. *Geological Journal*, 53(3): 1050-1060.
- 图[R]. 广西: 广西金果子矿业有限公司.
- 广西西林县恒源矿业开发有限责任公司, 2015. 广西西林县文洞矿区金锑矿勘探实施方案[R]. 广西: 广西西林县恒源矿业开发有限责任公司.
- 广西西林县恒源矿业开发有限责任公司, 2017. 广西西林县古障镇太平王子山矿区金锑矿勘探实施方案[R]. 广西: 广西西林县恒源矿业开发有限责任公司.
- 广西壮族自治区地质调查院, 2019. 实测及 1:5 万区域地质调查隆林幅报告[R]. 广西: 广西壮族自治区地质调查院.
- 广西壮族自治区二七四地质队, 1990. 隆林县龙滩锑矿区地质普查报告[R]. 广西: 广西壮族自治区二七四地质队.
- 韩江. 2020. 云南省广南县木利锑矿成因及控矿因素探讨[J]. *甘肃冶金*, 42(1): 69-71.
- 侯方浩, 黄继祥. 1984. 南盘江断陷区二、三叠系的火山碎屑浊积岩: 一种独特的无海底扇浊流沉积模式[J]. *沉积学报*, 2(4): 19-32.
- 胡利娟, 吴祥珂, 乐兴文, 等. 2023. 广西西大明山矿集区德立铅锌矿床成矿时代及其找矿勘查启示[J]. *地质力学学报*, 29(1): 76-86.
- 李保亮, 王立强, 张相国, 等. 2022. 西藏哈姆曲锑(金)矿床曲珍矿段 S、Pb 同位素组成及意义[J]. *地球学报*, 43(2): 202-210.
- 李三忠, 索艳慧, 周洁, 等. 2022. 华南海陆过渡带构造演化: 特提斯构造域向太平洋构造域的转换过程与机制[J]. *地质力学学报*, 28(5): 683-704.
- 莫儒伟, 孙晓明, 翟伟, 等. 2013. 藏南马扎拉金锑矿床成矿流体地球化学和成矿机制[J]. *岩石学报*, 29(4): 1427-1438.
- 彭建堂, 胡瑞忠. 2001. 华南锑矿带的成矿时代和成矿构造环境[J]. *地质地球化学*, 29(3): 104-108.
- 乔龙. 2016. 右江盆地及其周缘地区构造演化及铝土矿成矿作用[D]. 北京: 中国地质大学(北京): 1-165.
- 韦文灼. 1993. 马雄锑矿床地质特征[J]. *西南矿产地质*, 7(2): 8-16.
- 文琴, 刘涛, 2019. 龙山金锑矿地质特征及成因浅析[J]. *世界有色金属*(14): 90-91.
- 吴玉, 张松, 黄铮, 等. 2019. 桂西北南丹-荔波地区中、新生代构造演化: 来自古构造应力场的证据[J]. *大地构造与成矿学*, 43(5): 872-893.
- 肖昌浩, 李龚健, 刘欢, 等. 2016. 云南巍山笔架山锑矿床辉锑矿稀土微量元素特征及其矿床成因意义[J]. *地质力学学报*, 22(2): 310-324.
- 肖宪国. 2014. 贵州半坡锑矿床年代学、地球化学及成因[D]. 昆明: 昆明理工大学: 1-138.
- 杨怀顺. 2007. 桂西北地区锑矿地质特征及找矿标志探讨[J]. *矿产与地质*, 21(1): 52-55.
- 张天羽, 李聪颖, 孙赛军, 等. 2020. 锑的地球化学性质与华南锑矿带成因初探[J]. *岩石学报*, 36(1): 44-54.

附中文参考文献

- 陈军, 黄智龙, 杨瑞东, 等. 2021. 南盘江-右江盆地金、锑共生分异机制[C]//首届全国矿产勘查大会论文集. 合肥: 中国地球物理学会: 1067-1071.
- 陈明辉. 2016. 湘西地区脉状钨锑金矿床的矿体侧伏与板柱状赋存规律[J]. *地质找矿论丛*, 31(3): 340-345.
- 杜远生, 徐亚军. 2012. 华南加里东运动初探[J]. *地质科技情报*, 31(5): 43-49.
- 耿建珍, 黄雅琪, 姜桂鹏, 等. 2019. 西秦岭早子沟金锑矿床含矿英安斑岩年代学及其成因[J]. *地质调查与研究*, 42(3): 166-173.
- 广西金果子矿业有限公司, 2011. 马蒿锑矿床 6 号勘探线地质剖面