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赣南石雷钨锡矿云英岩型锂矿找矿新发现及其区域成矿潜力分析

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提要:近年来,随着赣西北云母型锂矿的大规模开发利用,华南云英岩型、蚀变花岗岩型等岩体型锂矿逐渐受到关注。赣南是世界著名石英脉型黑钨矿集区和生产基地,以往勘查研究工作多集中在钨锡矿。**【研究目的】**为进一步了解石英脉型钨锡矿中是否存在锂矿化及其地质特征。**【研究方法】**本次研究通过系统的岩矿鉴定和激光剥蚀电感耦合等离子体质谱仪(LA−ICP−MS)分析,查明了在赣南崇余犹矿集区章源钨业石雷钨锡矿深部存在云英岩型锂矿。**【研究结果】**研究表明,锂矿体产于石雷矿区深部隐伏花岗岩体的顶部,分布于含钨锡石英脉和长石石英脉的两侧,锂元素主要赋存在白云母—多硅白云母之中。产于角岩化砂岩中的云英岩的Li_2O含量平均为0.25%,二云母花岗岩中石英(长石)脉—云英岩Li_2O含量平均为0.21%,二云母花岗岩中发育的含云母脉云英岩Li_2O平均为0.22%,具有潜在的综合利用价值。**【结论】**本次研究查明了石雷石英脉型钨锡矿中存在工业意义的云英岩型锂矿化,进一步丰富了赣南石英脉型钨锡矿的成矿理论,拓宽了崇余犹地区云英岩型锂矿的找矿勘查思路,并为进一步拓展华南地区岩体型锂矿的找矿空间提供了依据。

关 键 词:云英岩型锂矿;石英脉型钨锡矿床;找矿潜力;矿产勘查工程;石雷;赣南

创 新 点:查明了石雷石英脉型钨锡矿中存在工业意义的锂矿化;探讨了赣南地区云英岩型锂矿成矿潜力及找矿发向。

中图分类号: P612 **文献标志码**: A **文章编号**: 1000−3657(2022)06−1834−11

New discovery and regional prospecting potentiality of greisen−type lithium mineralization in the Shilei tungsten and tin deposit, Southern Jiangxi Province

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Abstract: This paper is the result of mineral exploration engineering.

In recent years, with the large-scale exploitation of mica-type lithium deposits in the Northwest of Jiangxi Province, hard-rock-type lithium deposits, such as greisen-type and altered granite-type in south China block, have gradually attracted more and more attention. Southern Jiangxi Province is a world-famous quartz vein-type wolframite mining district and producing base. In the past, exploration and research work mainly focused on the tungsten and tin deposits. **[Objective]**In order to further understand whether lithium mineralization exists in quartz vein type tungsten tin ore and its geological characteristics. **[Methods]**This study was conducted through systematic microscope identification and laser ablation inductively coupled plasma mass spectrometer (LA-ICP-MS) analysis. **[Results]**Greisen-type lithium ore was found in the deep part of Shilei tungsten and tin deposit in Chongyuyou Ore cluster located in the Southern Jiangxi Province. The lithium ore body occurred at the top of the deep concealed granite body, and distributed on two sides of W-Sn-bearing quartz-vein and feldspar quartz-vein. Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analysis and microscope identification show that lithium mainly found in muscovite-phengite. The average Li_2O content of greisen in hornfelsic sandstone is 0.25%, the average Li_2O content of quartz (feldspar) vein greisen in mica granite is 0.21%, and the average Li_2O content of mica vein-bearing greisen developed in mica granite is 0.22%, which shows potential comprehensive utilization value. **[Conclusions]**In this study, lithium mineralization of industrial significance is identified in Shilei quartz vein-type tungsten tin deposit. The discovery enriched the metallogenic theory of tungsten and tin deposits in the Southern Jiangxi Province, broadened the prospecting and exploration ideas of greisen-type lithium deposits in Chongyuyou ore cluster, and provided a basis for further expanding the prospecting space of hard-rock-type lithium deposit in South China Block.

Key words: greisen-type lithium ore; quartz vein type wolframite; prospecting potentiality; mineral exploration engineering engineering; Shi Lei; Southern Jiangxi Province

Highlights: Lithium mineralization of industrial significance is identified in Shilei quartz vein type tungsten tin mining area. The metallogenic potential and prospecting direction of greisen type lithium mineralization in southern Jiangxi has been discussed.

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1 引 言

赣南地区位于南岭成矿带的东段,享有“世界钨都”之称,分布有包括西华山、漂塘、大吉山、画眉坳、盘古山等在内的与燕山期花岗岩有密切成因联系的钨锡多金属矿床(陈毓川等,1989;陈郑辉等,2006;毛景文等,2007;郭春丽等,2007;许建祥等,2008;刘善宝等,2010;方桂聪等,2014;刘丽君等,2017)。与石英脉型钨锡矿床有成因联系的花岗岩大多属于富含Li、F的高分异花岗岩(陈毓川等,1989;张文兰等,2006;王登红,2019;杨斌等,2021;秦拯纬等,2022),且通常伴有铍铌钽等稀有金属矿产,如大吉山矿区69号钽矿体(袁忠信等,1981)、画眉坳钨铍矿床、淘锡坑烂梗子区段的钨铍矿体等(刘善宝,2008)。这些高分异花岗岩与中国西部伟晶岩型锂铍稀有金属成矿花岗岩属于同一成因类

型(袁忠信等,1981;李建康,2012;李建康等,2014;王登红等,2017;王成辉等,2019;Wang et al., 2020),但赣南地区石英脉型钨锡矿床是否共伴生有锂金属矿产却鲜有报道。本次工作在南岭东段赣南石雷矿区深部发现了云英岩型锂矿,证实了赣南石英脉型钨锡矿集区也有找锂矿的巨大潜力,这为进一步丰富研究赣南地区钨锡锂矿成矿理论研究和拓展岩体型锂矿找矿勘查空间提供了新思路。

2 矿区地质特征

赣南位于南岭成矿带的东段,东邻武夷山成矿带,西接南北向的诸广山—万洋山岩浆岩带,由崇义—大余—上犹、于都—赣县、全南—定南—龙南等5个矿集区组成(图1a)。石雷矿区位于赣南的西南部崇义—大余—上犹钨锡矿集区东段,北北东向的西华山—漂塘—茅坪矿田的中部(图1b)。整个矿田长度约30 km,十余个矿床呈等间距分布(间距3~5 km),致矿花岗岩具有多阶段演化分异、多阶段侵入和多阶段成矿特征(毛景文等,1998,2007;裴荣富和熊群尧,1999;刘善宝等,2010)。

石雷矿区主要出露古生代碎屑岩地层。其中,寒武系类复理石建造分布广泛,且遭受了加里东期强烈褶皱,形成了西部正常东部倒转的复式向斜。泥盆系灰白色巨厚层状砾岩夹紫红色含砾砂岩及石英砂岩层零星分布,与下伏寒武系呈角度不整合接触。矿区中部地表主要出露加里东期石英闪长岩,呈北西展布,形成于434~439 Ma(He et al., 2010)。花岗岩是石雷矿区的主要致矿和赋矿地质体,侵入于石英闪长岩之中,并在接触带形成矽卡岩和似伟晶岩壳。花岗岩为隐伏岩体,钻孔揭露到花岗岩顶面最低标高为−52.93 m (ZK4901),最高标高162.87 m (ZK1107),与漂塘矿区的隐伏花岗岩体(岩凸最高标高为300 m)连为一体。岩相由早到晚依次是黑云母花岗岩((160±0.7) Ma)→二云母花岗岩((159.6±0.7) Ma)→白云母花岗岩((159.9±0.4) Ma),呈逐渐过渡关系,没有明显侵入界限(Zhang et al., 2017)。

矿区共发育7个脉带组,呈北东东走向,倾向北北西,倾角变化在69°~85°,矿脉带长度变化在500~1700 m,宽度变化在100~300 m,最大深度超过700 m;除中带脉带组产于加里东期石英闪长岩外,其余脉带均产于寒武系砂岩中,自上而下具有典型的"五层楼"分带特征。本次工作在对矿区11勘探线钻孔进行系统编录过程中,发现深部隐伏花岗岩顶部存在广泛的云英岩带。对钻孔ZKn11−11部分云英岩进行采样测试分析,其中的Li_2O变化于0.204%~0.514%(表1)。根据其产状和矿物组成,含锂云英岩可以划分为石英脉(±钾长石)+云英岩、云母脉+云英岩等两种类型。

(1)石英脉(±钾长石)+云英岩复合型锂矿化体:该类型的矿化广泛分布于花岗岩体和围岩(角岩带)中(图2)。产于角岩带中的石英脉+云英岩复合脉位于隐伏花岗岩体的上部,主要由早期的角岩化、黑云母化和晚期的石英脉复合叠加而成,上部石英呈团块状,下部石英呈脉状穿插于角岩之中(图2a)。产于花岗岩内接触带二云母花岗岩内石英(±钾长石)+云英岩型锂矿化体以石英脉为中心,其两侧围岩发生云英岩化蚀变,云英岩与二云母花岗岩呈逐渐过渡关系(图2b)。

(2)云母脉+云英岩复合型钨锡锂矿体:产于花岗岩体内接触带的二云母花岗岩中(图2c),含钨锡石英脉穿插于云英岩中,脉两侧的云英岩中也有浸染状的细粒黑钨矿和锡石产出。

3 含锂云母成分分析和初步认识

本次研究对11号勘探线两个坑内钻孔ZK11−09、ZK11−10(图3)中的3件样品进行了分析。将钻孔样品制备为为厚度为30 μm的探针片,然后在国家地质测试实验中心,通过激光剥蚀电感耦合等离子体质谱仪(LA−ICP−MS)分析出云母的成分。分析结果见于表2。石雷矿区云英岩中的云母中Li_2O的含量介于0.18%~0.89%。其中,ZK11−10−B2样品中Li_2O的平均含量为0.30%;ZK11−10−B4样品中Li_2O的平均含量为0.43%;ZK11−09−B9样品中Li_2O的平均含量为0.52%。根据云母的Fe_{tot}+Mn+Ti−Al^{VI}−Mg−Li图解(图4),石雷矿区云英岩中的云母应属于白云母—多硅白云母(Guggenhim and Bailey, 1977; Tischendorf et al., 1977; Brigatti et al., 2001)。

云英岩是由花岗岩经高温热液作用形成的蚀变岩石,作为钨锡矿重要找矿标志,广泛发育于南岭钨锡矿床之中(陈毓川等,1989)。近年来,关于

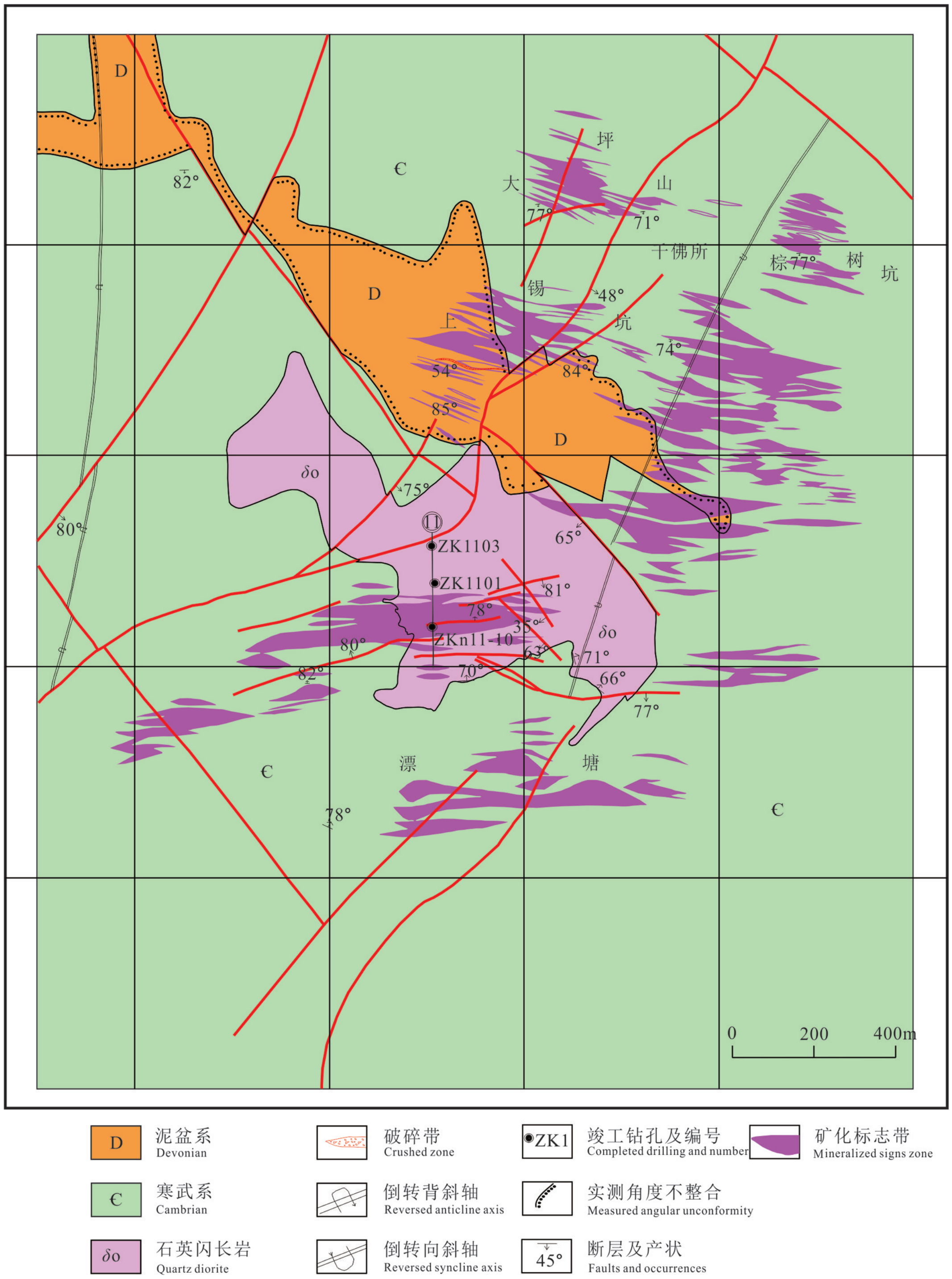

图1 赣南石雷钨锡矿地质简图

Fig.1 Simplified geological map of Shilei tungsten and tin deposits in the Southern Jiangxi Province

南岭成矿带及其邻区的钨锡矿床中云英岩带中富锂云母发现的报道陆续出现。不少的研究认为伴生于该类型的锂矿化主要赋存于铁锂云母−锂云母之中,例如栗木矿区的锂云母(李胜虎等,2015),大湖塘、香花岭、茅坪、漂塘、大厂矿区的铁锂云母(Legros et al., 2016, 2018;王正军等,2018;张勇等,2020;Guo et al., 2022)。石雷矿区云英岩中云母类型主要为Li含量较低的白云母—多硅白云母。根

表1 ZKn11−11云英岩W、Sn、Li测试分析结果

Table 1 The W, Sn, Li analysis results of greisen samples of ZKn11−11

序号	钻孔编号	样品编号	样长/m	岩性	含量/%		
					WO_3	Sn	Li_2O
1	ZKn 11-11	H22	1.43	云英岩夹石英脉	0.012	0.028	0.326
2		H23	0.40	黑钨矿化石英脉	0.392	0.036	0.028
3		H24	0.99	云英岩	0.012	3.16	0.514
4		H25	1.26	云英岩	0.012	0.028	0.304
5		H26	0.38	云英岩夹石英脉	0.012	0.020	0.215
6		H27	0.26	石英脉	0.012	0.010	0.041
7		H28	0.99	云英岩夹石英脉	0.012	0.068	0.274
8		H29	1.03	云英岩夹石英脉	0.012	0.028	0.284
9		H30	0.11	云英岩	0.012	0.020	0.264
10		H39	0.63	云英岩夹石英脉	0.012	0.020	0.215
11		H40	1.11	云英岩夹石英脉	0.012	0.024	0.185
12		H41	1.08	云英岩	0.032	0.028	0.215
13		H42	0.71	云英岩夹石英脉	0.012	0.020	0.204

据矿山提供的钻孔样品测试分析结果，矿区深部、隐伏岩体顶部的云英岩化具有普遍性，其中仅中矿带角岩化砂岩中的云英岩的Li_2O含量可达0.25%（视厚度为2.3 m）；二云母花岗岩中发育视厚度为3.08 m，Li_2O含量为0.15%~0.27%（平均0.21%）的石英（长石）脉—云英岩复合型锂矿化体；二云母花岗岩中发育的含云母脉云英岩连续4个样品（视厚度为3.08 m）的WO_3含量为0.022%~2.61%，Sn为0.013%~0.93%；Li_2O为0.14%~0.33%（平均0.22%），均达到共伴生品位要求，具有潜在的综合利用价值。该类型伴生的锂矿化的发现证实，钨锡矿中低锂含量云母的大量富集也可形成具有工业价值的锂矿体。此外，富锂云英岩主要发育于晚期的二云母花岗岩之中，其成矿来源显然不可能来自于稍早形成的黑云

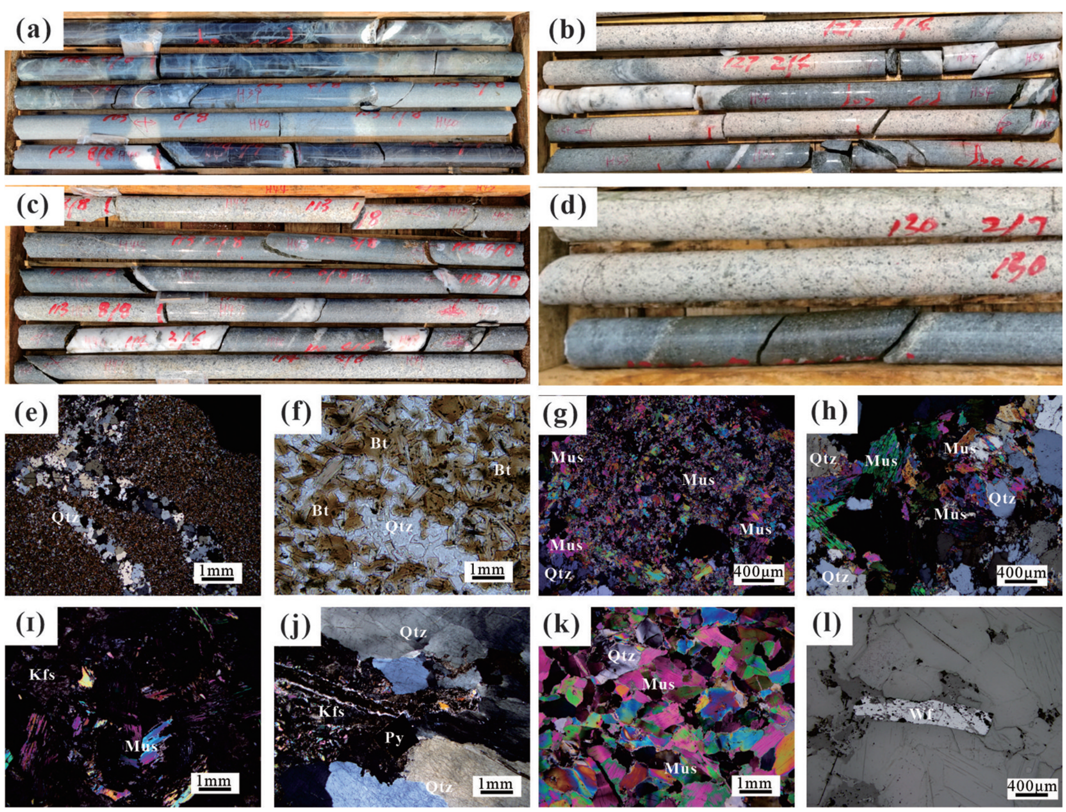

图2 石雷矿区钨锡锂多金属矿体特征

a、e、f—产于角岩化砂岩中的石英脉与黑云母石英复合脉；b、c、g、h—产于二云母花岗岩中的石英脉+云英岩复合脉复合型钨锡锂矿体；i、j—产于二云母花岗岩中的长石石英脉；d、k、l—产于二云母花岗岩中云母脉+云英岩（含钨锡矿化）复合脉；Bt—黑云母；Qtz—石英；Mus—白云母；Kfs—钾长石；Wf—黑钨矿；Py—黄铁矿

Fig.2 Characteristics of tungsten, tin and lithium polymetallic ore bodies in the Shilei mining area

a, e, f−Quartz vein and biotite quartz composite vein occurring in hornfelized sandstone; b, c, g, h−Composite W−Sn−Li ore body of Quartz vein and greisen composite vein occurring in mica granite; i, j−Feldspar quartz veins occurring in mica granite; d, k, l−Mica vein+greisen (containing tungsten tin mineralization) composite vein occurred in two mica granite; Bt−Biotite; Qtz−Quartz; Mus−Muscovite; Kfs−K−feldspar; Wf−Wolframite; Py−Pyrite

表2 石雷矿区云英岩中云母LA−ICP−MS原位分析结果

Table 2 LA−ICP−MS in−situ analysis results of mica of greisen in the Shilei mining area

样品号		Li_2O/%	Al_2O_3/%	SiO_2/%	K_2O/%	FeO/%	MnO/%	P_2O_5/%	Na_2O/%
ZK11-10-B2 (*n*=10)	极小值	0.20	34.84	31.38	26.24	1.35	0.12	0	0
	上四分位	0.26	35.99	32.40	26.86	1.94	0.38	0.01	0.01
	中位值	0.31	36.26	32.58	27.11	2.00	0.49	0.01	0.09
	下四分位	0.33	36.79	32.70	27.43	2.11	0.54	0.01	0.24
	极大值	0.38	37.88	32.85	27.91	2.50	0.60	0.02	0.35
	平均值	0.30	36.35	32.46	27.10	1.99	0.43	0.01	0.13
ZK11-10-B4 (*n*=10)	极小值	0.34	38.19	28.88	25.93	2.03	0.28	0	0.06
	上四分位	0.39	38.4	29.91	26.27	2.33	0.31	0	0.09
	中位值	0.43	38.88	30.27	26.44	2.55	0.33	0	0.15
	下四分位	0.45	39.20	30.49	26.88	2.72	0.39	0.01	0.17
	极大值	0.50	39.31	30.59	28.13	3.05	0.49	0.02	0.32
	平均值	0.43	38.80	30.12	26.64	2.54	0.36	0	0.15
ZK11-09-B9 (*n*=15)	极小值	0.18	16.27	38.52	6.17	0.57	0.30	0	0
	上四分位	0.39	42.74	39.05	13.09	1.28	0.67	0	0.01
	中位值	0.51	43.38	39.45	13.33	1.41	0.81	0.01	0.05
	下四分位	0.68	43.62	40.10	13.51	1.47	0.86	0.02	0.10
	极大值	0.89	44.51	54.55	13.78	1.74	1.03	0.03	0.24
	平均值	0.52	41.06	40.71	12.76	1.34	0.75	0.01	0.07
样品号		MgO/%	Si	Al(iv)	Al(vi)	Ti	Fe	Mn	Mg
ZK11-10-B2 (*n*=10)	极小值	0.14	4.54	3.00	2.71	0.00	0.16	0.01	0.03
	上四分位	0.16	4.75	3.15	2.89	0.01	0.25	0.05	0.04
	中位值	0.18	4.80	3.20	2.99	0.01	0.28	0.06	0.06
	下四分位	0.30	4.85	3.25	3.04	0.01	0.41	0.07	0.06
	极大值	1.24	5.00	3.46	3.18	0.02	0.86	0.22	0.27
	平均值	0.37	4.79	3.21	2.97	0.01	0.34	0.07	0.07
ZK11-10-B4 (*n*=10)	极小值	0.22	4.31	3.51	3.02	0.00	0.25	0.03	0.05
	上四分位	0.24	4.39	3.53	3.12	0.00	0.29	0.04	0.05
	中位值	0.27	4.43	3.57	3.16	0.01	0.31	0.04	0.06
	下四分位	0.30	4.47	3.61	3.18	0.01	0.33	0.05	0.06
	极大值	0.34	4.49	3.69	3.22	0.01	0.37	0.06	0.07
	平均值	0.27	4.42	3.58	3.14	0.01	0.31	0.04	0.06
ZK11-09-B9 (*n*=15)	极小值	0.06	4.49	3.31	3.05	0.00	0.22	0.04	0.01
	上四分位	0.11	4.53	3.37	3.09	0.00	0.23	0.05	0.01
	中位值	0.18	4.55	3.45	3.18	0.00	0.25	0.07	0.02
	下四分位	0.34	4.63	3.47	3.18	0.00	0.26	0.08	0.06
	极大值	0.66	4.69	3.51	3.27	0.01	0.28	0.09	0.07
	平均值	0.24	4.57	3.43	3.15	0.00	0.25	0.07	0.03
样品号		Li	Ca	Na	K	Total	Y total	X total	
ZK11-10-B2 (*n*=10)	极小值	0.05	0.00	0.00	4.73	20.59	3.30	4.81	
	上四分位	0.09	0.01	0.00	5.01	20.67	3.55	5.06	
	中位值	0.14	0.01	0.01	5.07	20.75	3.61	5.11	
	下四分位	0.18	0.01	0.04	5.18	20.78	3.65	5.20	
	极大值	0.22	0.05	0.10	5.54	20.91	3.97	5.55	
	平均值	0.14	0.01	0.03	5.10	20.74	3.60	5.14	
ZK11-10-B4 (*n*=10)	极小值	0.20	0.00	0.02	4.85	20.72	3.72	4.88	
	上四分位	0.23	0.00	0.03	4.92	20.79	3.79	4.97	
	中位值	0.25	0.01	0.04	4.94	20.82	3.82	4.99	
	下四分位	0.27	0.01	0.05	5.03	20.87	3.83	5.06	
	极大值	0.30	0.02	0.09	5.35	21.16	3.90	5.44	
	平均值	0.25	0.01	0.04	4.99	20.86	3.81	5.04	
ZK11-09-B9 (*n*=15)	极小值	0.13	0.00	0.00	4.89	20.65	3.59	4.92	
	上四分位	0.15	0.01	0.01	4.96	20.73	3.62	5.02	
	中位值	0.17	0.01	0.02	5.03	20.74	3.69	5.06	
	下四分位	0.18	0.01	0.04	5.17	20.78	3.71	5.18	
	极大值	0.24	0.02	0.08	5.26	20.98	3.77	5.30	
	平均值	0.18	0.01	0.03	5.06	20.77	3.68	5.09	

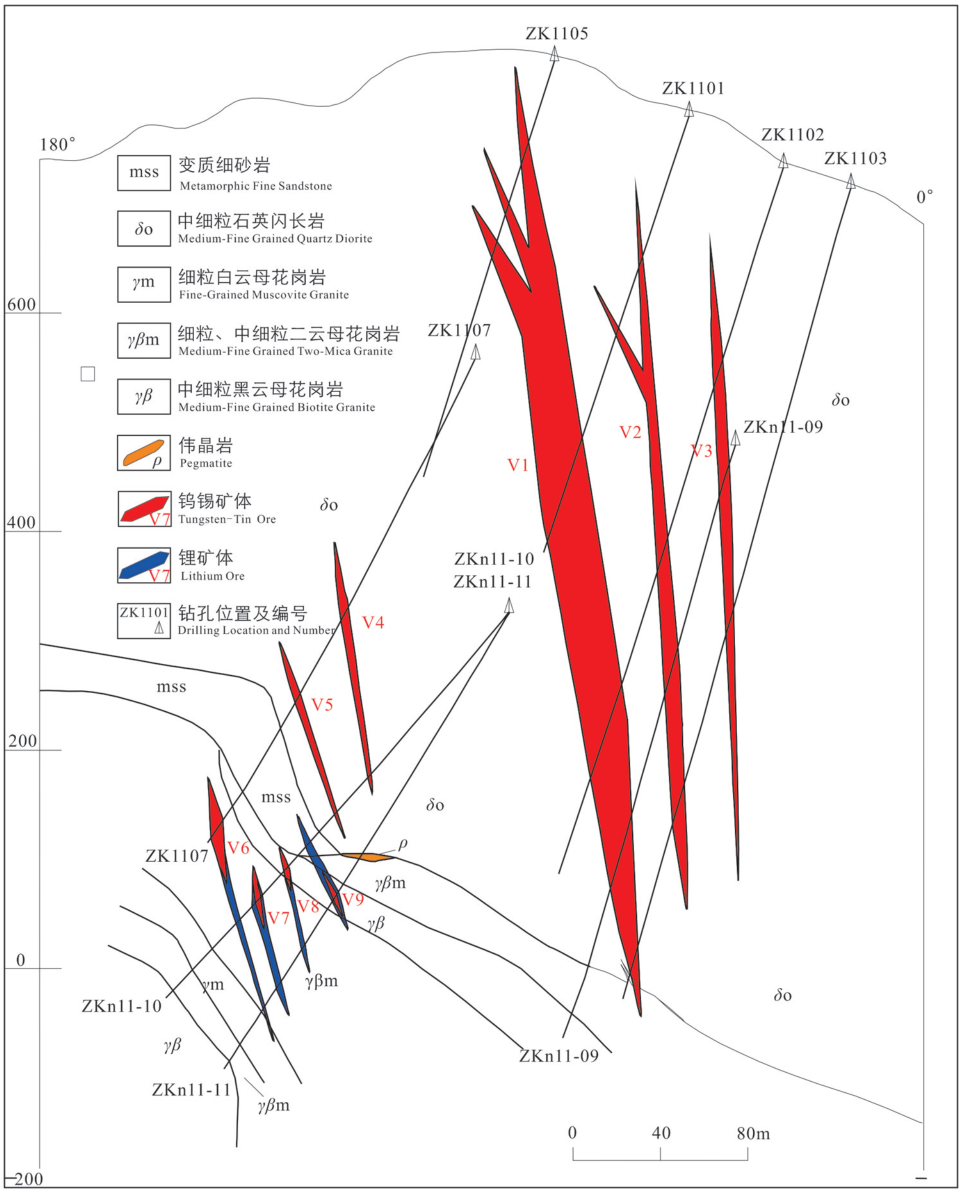

图3 石雷矿区11号勘探线简图

Fig.3 No.11 Sketch map of exploration line in the Shilei mining area

母花岗岩，但其成矿母岩是否为高分异的锂氟花岗岩，且钨锡矿与锂等稀有金属成矿关系如何依然有待进一步研究（Legros et al., 2018）。总之，该发现丰富了钨锡矿床的成矿理论，拓宽了区域云英岩型锂矿的找矿勘查思路，并为进一步该类型矿床的找矿空间提供了依据。

4 南岭钨锡矿中云英岩型锂矿成矿潜力及找矿方向

随着锂云母提锂技术的逐渐成熟，赣西北九岭地区岩体型锂矿的找矿突破（李仁泽等，2020），赣南石英脉型钨锡矿床深部及外围云英岩型锂矿的引起了同行的关注（王学求等，2020；娄德波等，2022）。已有的资料表明（陈毓川等，1989），云英岩是岩浆气液交代花岗岩的产物，依据其形态，云英岩可以划分为岩体型和脉带型。岩体型云英岩主要分布于白云母花岗岩体的岩凸部位，如崇义县茅坪钨矿床，云英岩上部产有石英脉型钨锡矿脉带，其下是石英脉+云英岩脉带，呈“草帽”状，是岩体型和脉带型的复合型，主要含锂矿物为铁锂云母和含

锂白云母，具有形成大型锂矿床的潜力；脉带型云英岩主要分布在花岗岩与围岩的内接触带上，如九龙脑岩体内洪水寨钨钼锂矿床，西华山钨矿床、张天堂岩体内塘飘孜钨矿床等，其赋矿围岩均为黑云母花岗岩，具有形成中型锂矿床的潜力。

以往的地质勘查工作仅评价云英岩中的钨锡矿，其共伴生云英岩中锂没有进行系统的评价。初步的野外地质调查表明，赣南地区已发现含锂矿物有铁锂云母（茅坪钨矿床、淘锡坝锡矿床等）、含锂多硅白云母（石雷钨锡矿床）、锂云母（铁山垅钨矿床外围），以铁锂云母为主，云英岩中锂含量的高低与含锂云母成正相关，现已发现铁锂云母脉的Li_2O含量最高可达1.04%（淘锡坝）。西华山—漂塘—茅坪—塘漂孜钨矿带分布著名的西华山、漂塘、茅坪等大型钨锡矿床，其共伴生的云英岩均有不同程度锂矿化显示，个别矿床具有形成大型锂矿床的潜力。除对已知石英脉型钨锡矿床深部及外围云英岩开展锂矿地质勘查及评价工作外，需要注重对赣南地区花岗岩型锂矿床地质找矿工作部署。目前，龙南九曲地区已经新发现了白云母钠长石锂矿体，这为赣南地区寻找宜春“414”岩体型锂钽矿床提供了很好的线索。

总体上，南岭地区从早古生代特别到中生代强烈的断块运动及相伴随的岩浆活动，对内生稀有元素成矿起着主要作用，稀有元素成矿一般发生在多期活动的晚期岩体之中。随着国家科技水平不断提高，新一轮科技革命的不断发展，锂等战略性新兴产业矿产需求量将保持较快增长态势（王登红，2019；陈其慎等，2021；王成辉等，2022），南岭地区云英岩型锂矿的成矿作用研究和找矿勘查也将进一步得到重视。下一步工作中，需要开展同步的成矿理论研究工作，特别是一些复式岩体晚阶段岩浆作用与锂矿化的关系值得高度关注。

5 结　论

南岭东段石雷石英脉钨锡矿深部识别出云英岩型锂矿，含锂矿物主要为白云母–多硅白云母。

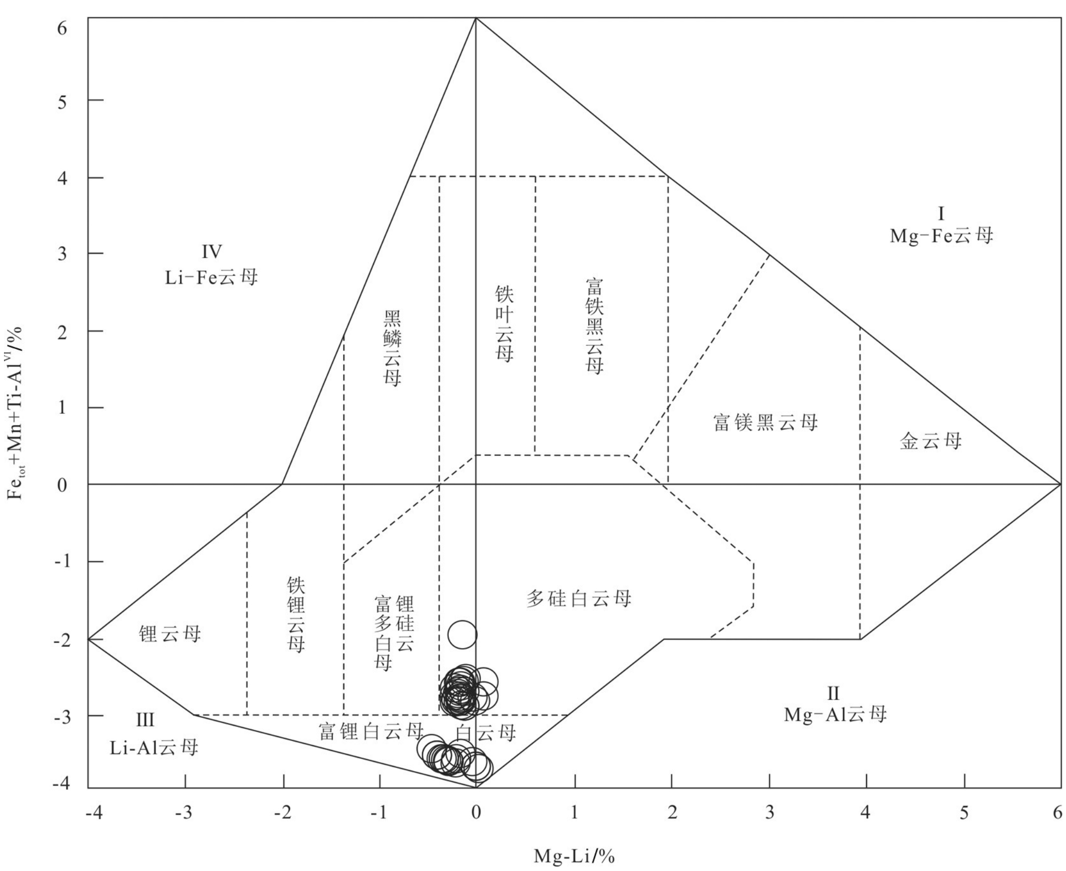

图4 石雷矿区云英岩中云母的Fe_{tot}+Mn+Ti+Al^{VI}–Mg–Li判别图解（据Guggenhim and Bailey, 1977）

Fig.4 Fe_{tot}+Mn+Ti+Al^{VI} vs. Mg-Li discriminant diagram of the mica of greisen in the Shilei mining area (after Guggenhim and Bailey, 1977)

其中,产于角岩化砂岩中的云英岩 Li_2O 含量平均可达0.25%,二云母花岗岩中石英(长石)脉−云英岩 Li_2O 含量平均为0.21%,二云母花岗岩中发育的含云母脉云英岩 Li_2O 平均为0.22%,具有潜在的综合利用价值。南岭地区具有良好的岩体型锂矿成矿潜力和巨大的找矿前景,石英脉型钨锡矿深部及外围发育的云英岩是主要的找矿目标。

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