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俯冲型和碰撞型含矿斑岩地球化学组成的差异*

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Abstract Porphyry Cu-Mo-Au deposits occur not only in an arc setting, but also in a collisional belt. These ore-bearing porphyries in different tectonic settings have distinctly different geochemistry in trace elements, implying that they have different compositions in source or dynamic mechanisms. Comparing with collisional-type ore-bearing porphyries, the subduction-type rocks have obviously high HREE and Y concentrations, low Sr/Y, $(La/Yb)_N$ and $(Dy/Yb)_N$ ratios, suggesting that their source are mainly consisted of amphibole but less or no garnet. Although some of subduction-type ore-bearing porphyric rocks have somewhat adakitic geochemical signature, most samples show characteristics similar to the normal arc volcanic rocks, which are likely the product of mantle wedge, metasomatically enriched during slab subduction, through MASH (melting-assimilation-storage-homogenization) process. The collisional-type ore-bearing porphyric rocks clearly have characteristics of typical adakites, which be likely related to the earlier episodes of subduction in their source. The geochemistry of major and trace elements of ore-bearing porphyric rocks in Pulang-Xuejipin is similar to that of the subduction-type. They are likely the products by partial melting of metasomatized mantle wedge by subduction fluid or sediment, trigged by slab break-off of westward-subduction of Ganzi-Litang Ocean, instead of by direct partial melt of an oceanic slab.

Key words Subduction-type; Collisional-type; Ore-bearing porphyric rocks; Pulang-Xuejipin; Geochemistry

摘 要 Cu-Mo-Au 含矿斑岩不仅可以形成于与洋壳俯冲相联系的弧环境,而且也产于碰撞造山带内。通过对比俯冲型和碰撞型含矿斑岩的地球化学特征,发现它们特别在微量元素上具有较大差别,暗示它们有着不同的物源区组成或形成机制。同冈底斯带碰撞型含矿斑岩相比,太平洋东岸俯冲型含矿斑岩有着明显高的 HREE 和 Y 含量,低的 Sr/Y、$(La/Yb)_N$ 以及 $(Dy/Yb)_N$ 比值,表明其物质源区不含或含有少量的石榴子石并可能以角闪石组成为主。统计发现这些俯冲型含矿斑岩部分样品具有埃达克岩地球化学特征,但大部分样品却显示出具有与正常岛弧系列火山岩相似的特征,它们很可能是板片释放流体交代地幔楔形成的熔体并在后期经历 MASH 过程的产物。冈底斯带碰撞型含矿斑岩具有典型埃达克岩地球化学特征,指示其形成条件达到了石榴子石相变,可能形成于增厚的下地壳,其物质源区很可能与前期的洋壳俯冲有着密切的联系。普朗-雪鸡坪含矿斑岩具有与俯冲型含矿斑岩十分相似的地球化学特征,它们有可能是西向俯冲的甘孜-理塘洋发生断离,进而诱发前期俯冲流体交代的富集地幔楔发生部分熔融的产物,而并非是俯冲洋壳直接发生部分熔融的产物。

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1 引言

斑岩型矿床作为一种重要的铜、钼和金矿床资源,一直备受工业界和科学界的关注。斑岩型矿床主要产于与洋壳俯冲有密切联系的岛弧及陆缘环境(Skewes and Stern,1995; Kirkham,1998; Kay *et al.*, 1999; Kerrich *et al.*, 2000; Richards *et al.*, 2001)。基于大量弧环境斑岩型矿床研究而建立的经典斑岩铜成矿模型(Sillitoe,1972),在后来环太平洋成矿带斑岩型矿床的勘查中取得了重大突破(如,Mitchell and Garson,1972; Jorhan *et al.*, 1983; Solomon,1990; Bektas *et al.*, 1990; 芮宗瑶等,2004)。近年来,中国矿床学家在对青藏高原斑岩型矿床的研究中发现,斑岩型矿床不仅可以产于岛弧及陆缘弧环境,还可以形成于碰撞造山带中(芮宗瑶等,1984; 侯增谦等,2001; 曲晓明等,2001; Hou *et al.*, 2003, 2004),并据此建立了相应的碰撞造山带斑岩矿床成矿模型(芮宗瑶等,2006; 侯增谦等,2007; 杨志明和侯增谦,2009; Hou *et al.*, 2011)。那么形成于不同构造背景的斑岩型矿床,即与洋壳俯冲有着紧密联系的斑岩型矿床(本文简称为俯冲型斑岩矿床)和在陆-陆碰撞造山环境中形成的斑岩型矿床(本文简称为碰撞型斑岩矿床),它们的物质源区组成以及动力学机制上有着什么区别和差异?本文在收集、整理已有的环太平洋东岸典型斑岩型矿床和青藏高原南部典型的碰撞造山带斑岩型矿床地球化学数据的基础之上,对比研究它们在物质源区组成方面的差异,为进一步探讨其它地区含矿斑岩(如"三江"地区普朗-雪鸡坪含矿斑岩)形成的构造环境提供依据。

2 含矿斑岩的分布特征和形成时代

全球斑岩铜矿的分布主要集中在3条大的成矿带上:环太平洋成矿带,特提斯-喜马拉雅成矿带和古亚洲成矿带(中亚成矿带),由于前二者主要形成于中-新生代且地质信息保存完整而成为人们探讨斑岩成矿动力学机制的热点。据统计,在世界范围内,97%的大型-巨型斑岩铜矿产于岩浆弧环境(Kerrich *et al.*, 2000)。岛弧环境的经典成矿省主要分布于太平洋西岸,如印度尼西亚和菲律宾岛弧(Hedenquist and Richards,1998; Cooke *et al.*, 2005);而陆缘弧环境的经典成矿省则主要分布于太平洋的东岸,如环太平洋矿带智利-秘鲁矿集区、巴拿马-哥伦比亚矿集区、美国西南部-墨西哥矿

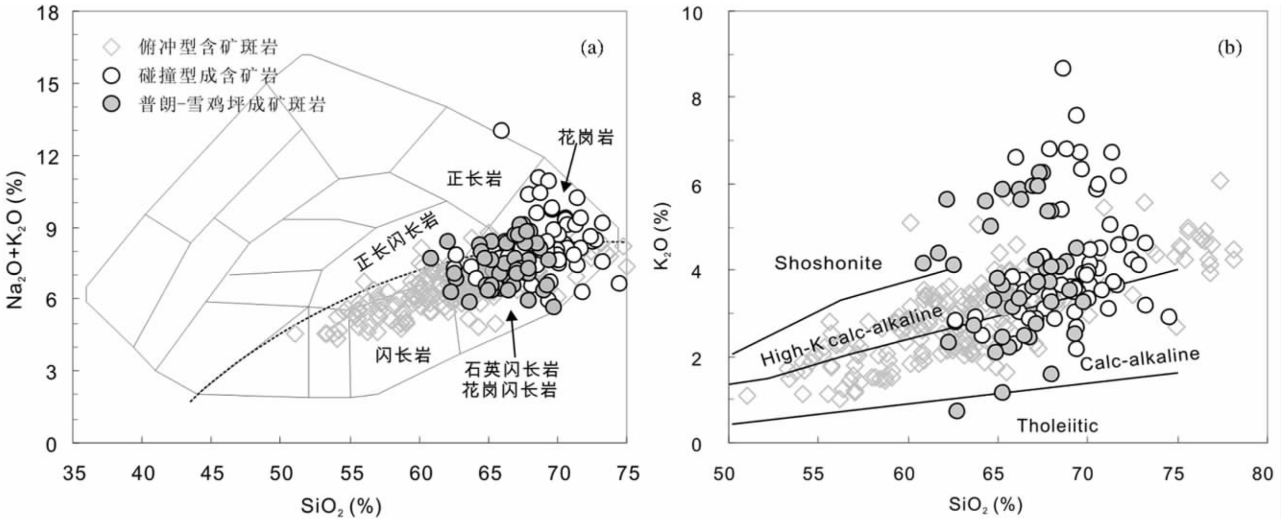

图1 含矿斑岩 SiO_2 vs. Na_2O+K_2O (a) 和 SiO_2-K_2O (b) 图(底图据 Le Bas *et al.*, 1986)
数据来源:俯冲型含矿斑岩,Muntean and Einaudi (2000), Richards *et al.* (2001), Ulrich and Heinrich (2001), Reich *et al.* (2003), Gonzalez-Partida *et al.* (2003), Bissig *et al.* (2004), Cannell *et al.* (2005), Hollings *et al.* (2005), Richards *et al.* (2006), Stern *et al.* (2010);碰撞型含矿斑岩,Hou *et al.* (2004), Qu *et al.* (2004), Guo *et al.* (2007), Gao *et al.* (2007);普朗-雪鸡坪含矿斑岩,曾普胜等(2006),王守旭等(2007),冷成彪等(2007),庞振山等(2009), Li *et al.* (2011),任江波(2011),任江波等(2011). 后文图表的数据来源和图例同图1

Fig. 1 The diagrams of SiO_2 vs. Na_2O+K_2O (a) and SiO_2 vs. K_2O (b) for mineralization-related porphyries from world (original diagram is after Le Bas *et al.*, 1986)
Data source of ore-bearing porphyries in arc-settings: Muntean and Einaudi (2000), Richards *et al.* (2001), Ulrich and Heinrich (2001), Reich *et al.* (2003), Gonzalez-Partida *et al.* (2003), Bissig *et al.* (2004), Cannell *et al.* (2005), Hollings *et al.* (2005), Richards *et al.* (2006), Stern *et al.* (2010); ore-bearing porphyries in post-collisional settings: Hou *et al.* (2004), Qu *et al.* (2004), Guo *et al.* (2007), Gao *et al.* (2007); ore-bearing porphyries of Pulang-Xuejiping: Zeng *et al.* (2006), Wang *et al.* (2007), Leng *et al.* (2007), Pang *et al.* (2009), Li *et al.* (2011), Ren (2011), Ren *et al.* (2011). Data and symbols in other figures and table as same as in Fig. 1

集区、美国西部-加拿大西部矿集区等(戴自希，1996)。其中超大型斑岩型矿床主要分布在太平洋东岸，它们形成于中-新生代。本文收集的有关俯冲型斑岩矿床的地球化学数据主要来自环太平洋东岸的斑岩矿床(Muntean and Einaudi，2000; Richards *et al.*，2001; Ulrich and Heinrich，2001; Reich *et al.*，2003; Gonzalez-Partida *et al.*，2003; Bissig *et al.*，2004; Cannell *et al.*，2005; Hollings *et al.*，2005; Richards *et al.*，2006; Stern *et al.*，2010)。

陆-陆碰撞造山带含矿斑岩研究主要集中在特提斯-喜马拉雅成矿带的东部，即冈底斯斑岩成矿区和玉龙成矿区。冈底斯成矿区位于青藏高原拉萨地块的南缘，呈近 EW 向展布约 350km，由几个大型斑岩铜矿和一系列小型的矿床矿点构成; 含矿斑岩体主要沿南北向的断层分布，斑岩体多呈岩株岩瘤产出。冈底斯斑岩成矿区主要形成于 17 ~ 12Ma(Hou *et al.*，2004)。考虑到印度大陆与欧亚大陆碰撞的时间为 60 ~ 55Ma (Mo *et al.*，2008)，因此形成于中新世的冈底斯地区含矿斑岩为典型的陆-陆碰撞造山构造环境之产物。本文所收集的碰撞型含矿斑岩地球化学数据主要以冈底斯成矿区为主(Hou *et al.*，2004; Qu *et al.*，2004; Guo *et al.*，2007; Gao *et al.*，2007)。

普朗-雪鸡坪矿区是“三江”地区近年来发现的大型-超大型斑岩型矿床(曾普胜等，2003，2004，2006; Li *et al.*，2011)，含矿斑岩主要为石英二长斑(玢)岩和石英闪长岩，主体形成于 230 ~ 210Ma (曾普胜等，2003; 林清茶等，2006; 冷成彪等，2008; 曹殿华等，2009; 张兴春等，2009; 庞振山等，2009; Li *et al.*，2011; 任江波等，2011; 任江波，2011)。由于成矿时代和甘孜-理塘洋形成和发育的时代相差较大，其成矿环境和机制目前尚有争议(曾普胜等，2004; 侯增谦等，2004)。

3 地球化学特征

3.1 主量元素特征

太平洋东岸俯冲型含矿斑岩在 SiO_2-($K_2O + Na_2O$) 图(图 1a) 中主要为钙碱性系列，岩石类型主要为闪长岩和石英闪长岩或花岗闪长岩，同时有少量辉长闪长岩、花岗岩和正长闪长岩; 冈底斯碰撞型含矿斑岩主要为花岗岩和部分的石英(花岗) 闪长岩; 而普朗-雪鸡坪含矿斑岩主要是石英(花岗) 闪长岩，同时含有少量的正长闪长岩和花岗岩。在 SiO_2-K_2O 图(图 1b) 中，俯冲型含矿斑岩主要为钙碱性或高钾钙碱性系列，冈底斯碰撞型含矿斑岩主要为高钾钙碱性和 shoshonite 系列，有少量的样品属于钙碱性系列; 普朗-雪鸡坪含矿斑岩类似于俯冲型含矿斑岩，但少量样品属于 shoshonite。

在 SiO_2 与其它主量元素相关图中(图 2)，俯冲型和碰撞型以及普朗-雪鸡坪含矿斑岩有着相似的变化特征和变化范围，即随着 SiO_2 含量的增加，TiO_2、MgO、Fe_2O_3 和 CaO 含量降低，而 Na_2O 的变化趋势不明显; 但是，在相同的 SiO_2 含量条件下，碰撞型含矿斑岩和普朗-雪鸡坪含矿斑岩的 $Mg^{\#}$ 明显高于俯冲型含矿斑岩，特别是普朗-雪鸡坪含矿斑岩具有较高的 MgO 和 P_2O_5 含量(表 1)。

3.2 微量元素特征

经球粒陨石标准化的稀土(REE) 配分曲线图中(图 3a)，俯冲型和碰撞型以及普朗-雪鸡坪含矿斑岩均表现为轻稀土(LREE) 富集、Eu 无明显负异常、轻稀土(LREE) 和重稀土(HREE) 分异明显的特征。且俯冲型含矿斑岩的 REE 含量以及 HREE 含量明显高于碰撞型含矿斑岩。普朗-雪鸡坪含矿斑岩与前者有着相似分布特征和分布范围。

在微量元素蛛网图上(图 3b)，俯冲型和碰撞型以及普朗-雪鸡坪含矿斑岩均具有富集强不相容性元素 Rb、Th、U，亏损 Nb、Ta 和 Ti 的特点，无明显 Sr 的负异常，这与其无明显的 Eu 负异常是一致的。但是，与同碰撞型和普朗-雪鸡坪含矿斑岩相比，俯冲型含矿斑岩的部分微量元素含量有着较大的变化范围。

3.3 含矿斑岩的埃达克(质) 岩特征

最近的一些研究表明，埃达克质岩与斑岩型矿床有着一定的关系(如，Defant and Kepezhinskas，2001; Oyarzun *et al.* 2001; 张旗等，2004; 王强等，2008)。在有关埃达克(质) 岩的相关判别图(图 4a，b) 中，俯冲型和碰撞型含矿斑岩有着明显的区别，前者的 Y 和 Yb_N 值明显高于后者，但前者的 Sr/Y 和 $(La/Yb)_N$ 比值却比后者低。因此，碰撞型含矿斑岩样品主要落入埃达克质岩的范围之中，而俯冲型含矿斑岩大部分位于正常的岛弧火山岩的范围，仅有部分样品属于埃达克质岩。普朗-雪鸡坪含矿斑岩与俯冲型含矿斑岩有着相似的分布范围和特征(表 1)。

4 讨论

4.1 俯冲型和碰撞型含矿斑岩物质源区的差异性

俯冲型钙碱性含矿斑岩过去通常被认为是俯冲洋壳直接熔融的产物(如，Sillitoe，1972; Burnham，1979)，然而最近的研究表明，除少数具有埃达克质岩亲和性的钙碱性岩浆为年轻洋壳直接熔融的产物外(如，Defant and Drummond，1990; Sajona *et al.*，1998; Martin，1999; Yogodzinski *et al.*，2001)，绝大多数的钙碱性岩浆可能与板片释放的流体交代了的地幔楔，在随后的构造改造过程中发生部分熔融，并经历了 MASH 过程(即熔融作用、同化作用、存储、均一化) 的产物(Hildreth and Moorbath，1988)。俯冲型含矿斑岩无明显 Sr 和 Eu 的负异常、低的 $(Dy/Yb)_N$ 比值(图 5a)、高的 HREE 含量(图 3a)，表明其物质源区为斜长石的不稳定区，可能不含或仅含有少量石榴子石但是含有角闪石。这些特

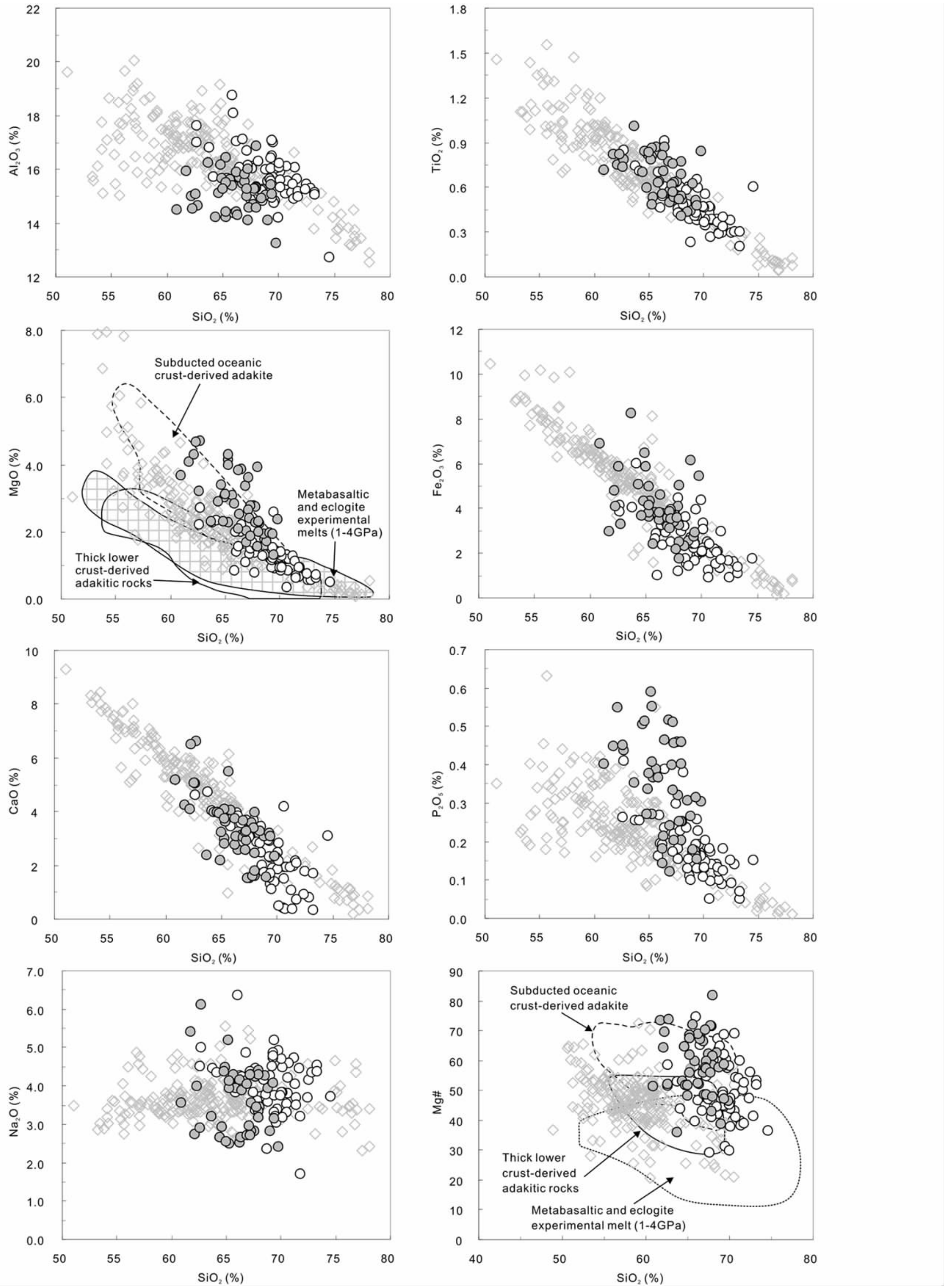

图2 含矿斑岩 Harter 图(SiO_2-MgO, SiO_2-Mg[#]图据王强等, 2008)

Fig. 2 Harter diagram for ore-bearing porphyries in the world (diagram of SiO_2 vs. MgO and SiO_2 vs. Mg[#] based on Wang *et al.*, 2008)

表 1　俯冲型和碰撞型含矿斑岩以及普朗-雪鸡坪含矿斑岩部分地球化学数据统计对比表

Table 1　Statistics for geochemical data of subduction-type and collisional-type and Pulang-Xuejipin ore-bearing porphyric rocks

元素	数据区域	东太平洋俯冲型含矿斑岩 (n = 229)	冈底斯碰撞型含矿斑岩 (n = 61)	普朗-雪鸡坪含矿斑岩 (n = 42)	元素	数据区域	东太平洋俯冲型含矿斑岩 (n = 229)	冈底斯碰撞型含矿斑岩 (n = 61)	普朗-雪鸡坪含矿斑岩 (n = 42)
Na_2O (wt%)	分布范围	2.31 ~ 5.57	1.70 ~ 6.36	2.40 ~ 6.10	Sr ($\times 10^{-6}$)	分布范围	2 ~ 1100	118 ~ 1072	424 ~ 1390
	平均值	3.65	4.04	3.62		平均值	517	570	766
K_2O (wt%)	分布范围	1.02 ~ 6.06	2.15 ~ 8.65	0.71 ~ 6.23	Y ($\times 10^{-6}$)	分布范围	3.50 ~ 44.60	2.90 ~ 14.00	9.01 ~ 19.92
	平均值	2.98	4.16	3.90		平均值	17.47	6.89	15.09
K_2O/Na_2O	分布范围	0.25 ~ 2.62	0.51 ~ 3.71	0.12 ~ 2.35	Sr/Y	分布范围	0.05 ~ 123.66	23.14 ~ 187.68	24.16 ~ 99.29
	平均值	0.84	1.11	1.20		平均值	17.46	88.91	52.66
MgO (wt%)	分布范围	0.06 ~ 8.11	0.33 ~ 2.72	1.30 ~ 4.69	$(La/Yb)_N$	分布范围	2.37 ~ 42.55	11.65 ~ 63.19	7.12 ~ 39.88
	平均值	2.34	1.27	2.89		平均值	16.78	31.54	18.27
$Mg^{\#}$	分布范围	20.52 ~ 72.46	28.90 ~ 74.58	43.24 ~ 81.93					
	平均值	45.86	50.55	59.86					

注: n = 229 表示统计的样品数量

征与俯冲型含矿斑岩在 Sr/Y-Y 及 $(La/Yb)_N$-Yb_N (图 4a, b) 图中的分布范围相一致; 而大离子亲石元素 (LILE, 如 Rb, K) 的富集和高场强元素的 (HFSE, 如 Nb、Ta 和 Ti) 亏损很可能代表了同期或早期俯冲流体的特征。另外, 俯冲型含矿斑岩具有变化范围较大的 La/Yb 比值, 可能与其熔体形成的深度有着较大的变化有关, 同时也表明这种斑岩很可能是部分熔融与结晶分异两种机制共同作用的产物。

碰撞型含矿斑岩的成因与俯冲增生而导致的加厚下地壳的部分熔融作用有关 (如, Hou *et al.*, 2004; Qu *et al.*, 2004; Guo *et al.*, 2006; Gao *et al.*, 2007, 2010)。这种含矿斑岩具有高的 Sr 含量, 无明显 Eu 负异常, LREE 和 HREE 分异明显, HREE 明显亏损, 以及具有高的 Sr/Y、$(La/Yb)_N$ 和 $(Dy/Yb)_N$ 比值, LILE 富集和 HSFE 强烈亏损等特征, 表明其物质源区为直接或间接经历过俯冲流体交代的角闪榴辉岩或石榴石角闪岩 (Hou *et al.*, 2004; Qu *et al.*, 2004)。另外, 碰撞型含矿斑岩明显高的 La/Yb 比值和较低的 La 含量表明其形成的深度至少在 40km 以上, 其形成机制主要以部分熔融为主。

4.2　埃达克(质)岩与含矿斑岩

埃达克(质)岩是指由俯冲的年轻的热的洋壳在榴辉岩相条件下经部分熔融形成的, 并具 $SiO_2 \geqslant 56\%$、$Al_2O_3 \geqslant 15\%$、$MgO < 3\%$ (很少 > 6%)、低的 Y ($\leqslant 18 \times 10^{-6}$) 和 HREE (如, $Yb \leqslant 1.9 \times 10^{-6}$) 以及高的 Sr ($> 400 \times 10^{-6}$) 等地球化学特征的一套中酸性岩类的总称 (Defant and Drummond, 1990)。最近的研究显示, 具有类似地球化学特征的岩石还可以形成于如下几种条件: 即玄武岩浆经高压结晶分异作用 (Macpherson *et al.*, 2006)、拆沉的下地壳的部分熔融 (Xu *et al.*, 2002; Gao *et al.*, 2004)、增厚的下地壳的部分熔融 (Atherton and Petford, 1993; Chung *et al.*, 2003, 2009; Hou *et al.*, 2004; Wang *et al.*, 2005; Xiao and Clemens, 2007) 以及岩浆混合作用 (Guo *et al.*, 2007; Qin *et al.*, 2007; Streck *et al.*, 2007) 等。由此可见, 埃达克(质)岩可以形成于多种地球动力学环境 (如俯冲带, 陆陆碰撞, 伸展等环境) (曾键年和许继峰, 2008)。

埃达克(质)岩与 Cu-Au-Mo-Ag-Fe 矿床的关系是国内外矿床学研究的热点, 它源自 Thieblemont *et al.* (1997)、Sajona and Maury (1998)、Oyarzun *et al.* (2001) 对与俯冲洋壳的部分熔融形成的岩浆-埃达克岩与大型-超大型斑岩铜矿关系的认识, 也与 Defant and Kepezhinskas (2001)、张旗等 (2004)、王强等 (2008) 对埃达克(质)岩石与成矿关系的研究有关。然而在大洋俯冲区越来越多的精细地球物理和岩石学模型研究结果显示, 在正常条件下, 俯冲洋壳俯冲深度达 100km 时其温度并没有超过 800℃ (Schmidt and Poli, 1998; Poli and Schmidt, 2002; Arcay *et al.*, 2007)。Richards and Kerrich (2007) 对比研究世界上大型和超大型斑岩型矿床后指出, 与这些矿床有关的含矿斑岩很可能是板片释放流体交代楔形地幔经部分熔融与 MASH 过程的产物, 并非直接源于洋壳的部分熔融。我们的统计结果也证明, 太平洋东岸超大型含矿斑岩的大多数样品也并不具有典型埃达克岩的地球化学特征, 而属于正常的岛弧系列火山岩。

碰撞型含矿斑岩具有明显的埃达克岩地球化学特征 (图 4a, b)。因为碰撞型含矿斑岩不仅具有某些壳源地球化学特征 (如高碱和高 K_2O, 图 1a, b), 而且也包含了与早期洋壳俯冲有关的某些特征 (如具岛弧特征的富集 LILE 和强烈亏损 HFSE 特征以及 Sr-Nd-Pb 同位素介于俯冲洋壳和壳源物质之间等) (Hou *et al.*, 2004; Qu *et al.*, 2004; Guo *et al.*, 2007; Gao *et al.*, 2007, 2010)。因此我们认为, 冈底斯碰撞型含矿斑岩的成因很可能与早期洋壳的多次俯冲在高原南部形成俯冲增生弧 (潘桂棠等, 2006; Zhu *et al.*, 2011), 在

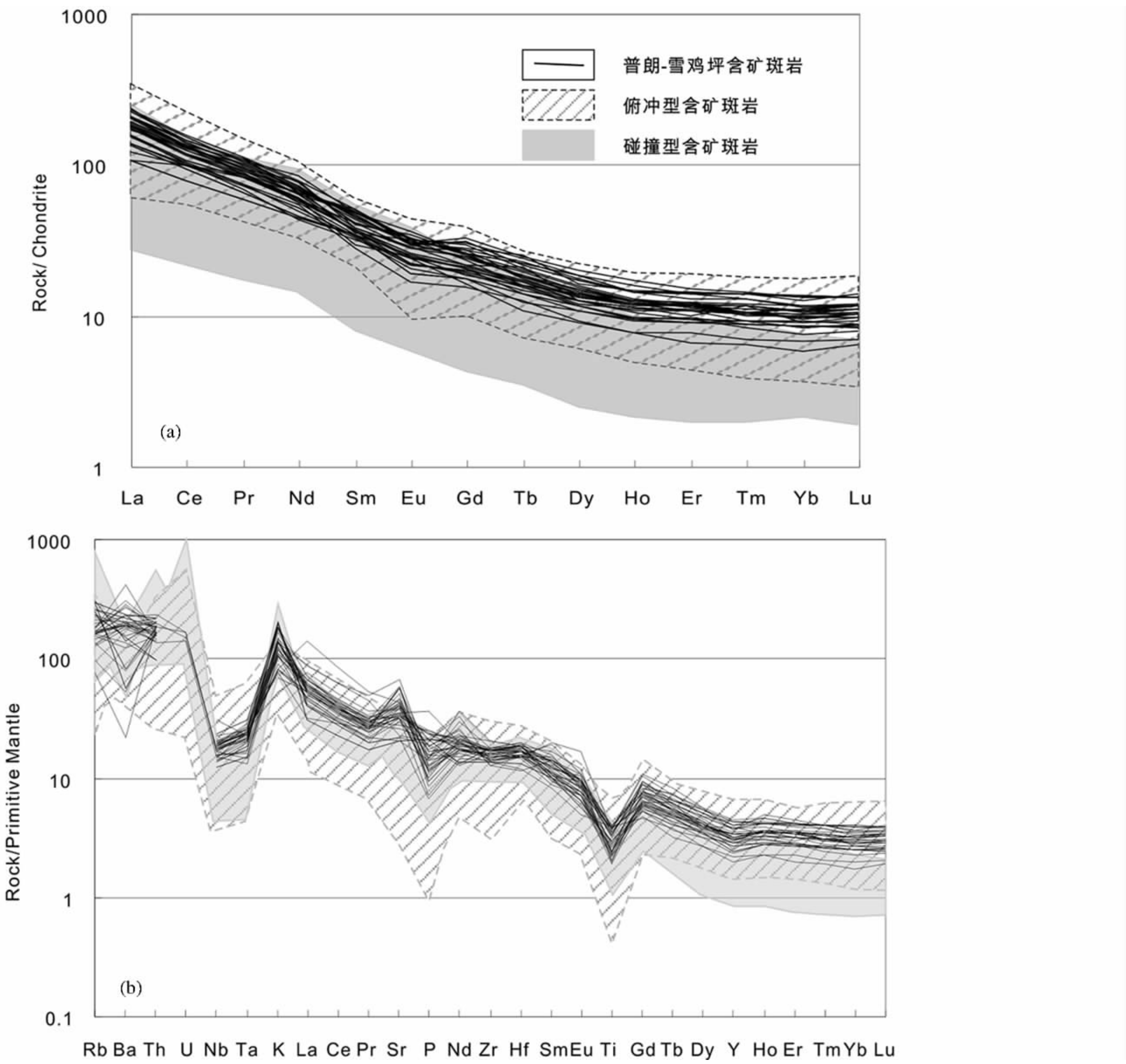

图 3 球粒陨石标准化配分 REE 图(a)和微量元素原始地幔标准化蛛网图(b)(标准化数据引自 Sun and McDonough, 1989)

Fig. 3 Chondrite-normalized REE (a) and multielement patterns normalized to primitive mantle (b) (normalizing values after Sun and McDonough, 1989)

后期的陆-陆碰撞过程中,又经历了缩短加厚,并在深部构造动力学机制发生变化(如板片断离、下地壳拆沉、地幔对流等)时的部分熔融有关。

4.3 普朗-雪鸡坪含矿斑岩形成的构造背景

普朗-雪鸡坪含矿斑岩区位于金沙江缝合带西侧义敦岛弧带南部的中甸弧内,是"三江"构造-岩浆-成矿带的重要组成部分(曾普胜等, 2003, 2004, 2006)。普朗-雪鸡坪含矿斑岩具有埃达克质岩石的某些特征(任江波, 2011; 任江波等, 2011),其主体形成于 230~210Ma(曾普胜等, 2003; 林清茶等, 2006; 冷成彪等, 2008; 曹殿华等, 2009; 张兴春等, 2009; 庞振山等, 2009; Li *et al.*, 2011; 任江波, 2011; 任江波等, 2011)。考虑到甘孜-理塘洋形成于晚石炭纪末或早二叠世初(闫全人等, 2005),其西向俯冲的时限为 237~206Ma(侯增谦等, 2004),因此,该区具有埃达克质岩特征的含矿斑岩不可能是年轻的、热的洋壳发生部分熔融的产物。

与俯冲型和碰撞型含矿斑岩相比,普朗-雪鸡坪含矿斑岩有着与俯冲型含矿斑岩十分相似的地球化学特征(图 1-图 5、表 1)。然而在相同的 SiO_2 条件下,普朗-雪鸡坪含矿斑岩却有着高的 MgO 和 P_2O_5 含量以及高的 $Mg^{\#}$(图 1、表 1)。这样的地球化学特征表明,普朗-雪鸡坪含矿斑岩与俯冲型含

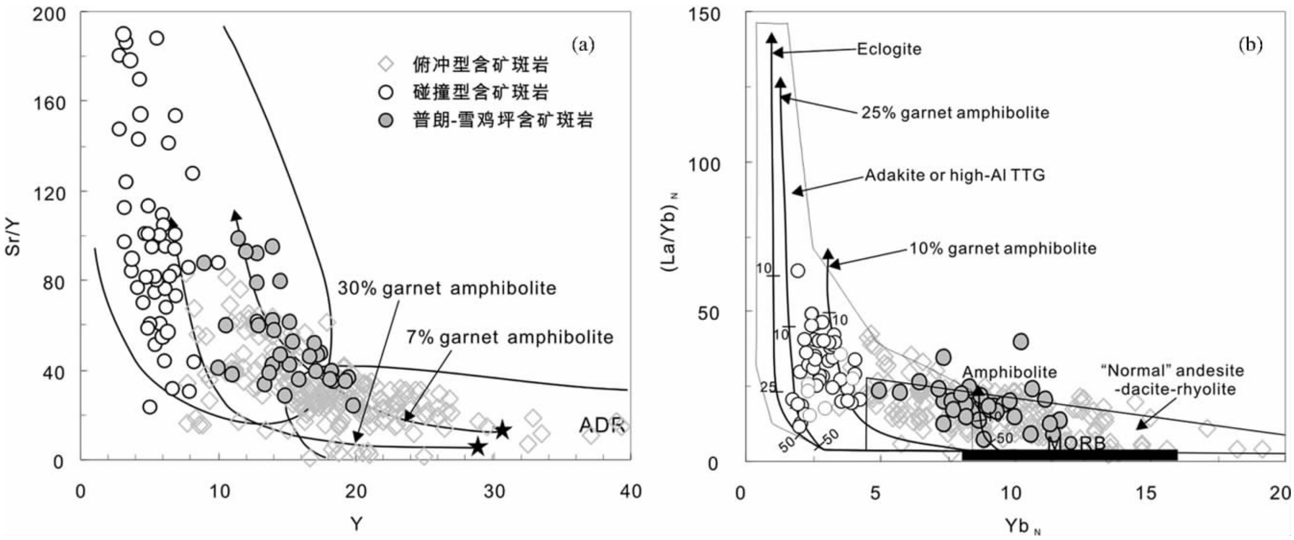

图4 含矿斑岩 Sr/Y vs. Y 图(a，据 Drummond and Defant，1990；Martin，1986)和(La/Yb)$_N$ vs. (Yb)$_N$ 图(b，据 Defant and Drummond，1990；Petford and Atherton，1996)

Fig. 4 Sr/Y vs. Y (a，after Drummond and Defant，1990；Martin，1986) and (La/Yb)$_N$ vs. (Yb)$_N$ (b，after Defant and Drummond，1990；Petford and Atherton，1996) diagrams for ore-bearing porphyries in the world

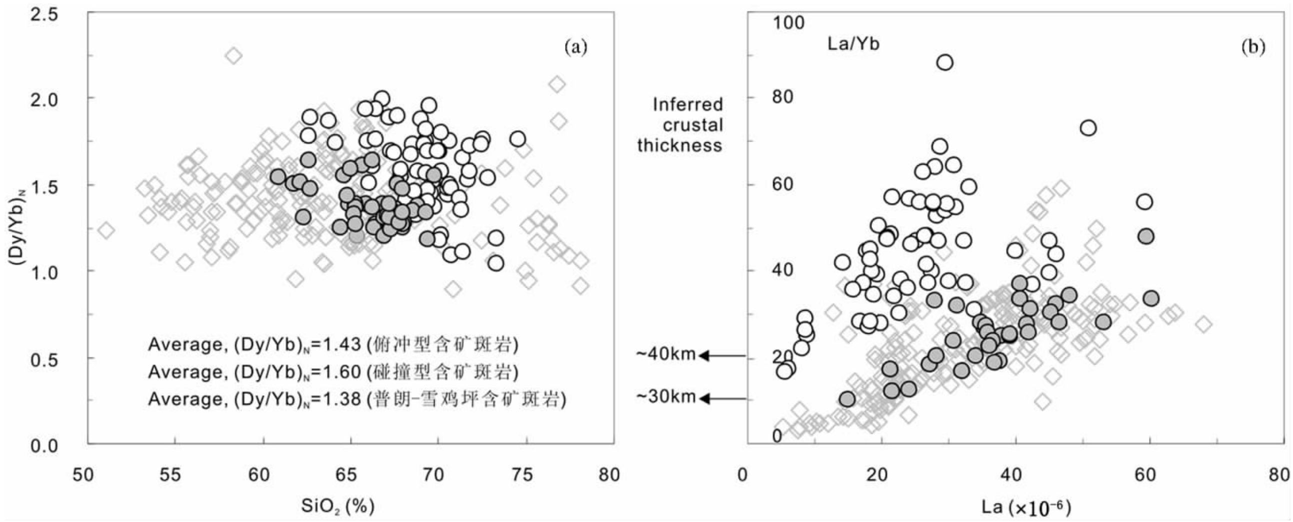

图5 含矿斑岩(Dy/Yb)$_N$-SiO_2(a)和 La-La/Yb(b)图(据 Chung *et al.*，2009)

Fig. 5 (Dy/Yb)$_N$ vs. SiO_2 (a) and La vs. La/Yb (b) diagrams for ore-bearing porphyries in the world (after Chung *et al.*，2009)

矿斑岩可能具有相似的构造背景，但其成矿动力学机制可能有所不同。曾普胜等(2003，2004，2006)根据普朗-雪鸡坪含矿斑岩形成时代的不同将其分为东带和西带，并且认为它们不是同一构造事件的产物；然而最近的研究结果显示，普朗-雪鸡坪成矿区东带和西带它们有着一致的形成时代(任江波等，2011)，指示它们是同一构造事件的产物。同时任江波(2011)报道，在中甸弧南部发育有与普朗-雪鸡坪含矿斑岩同期形成的安山岩和 E-MORB 型的玄武岩。另外，普朗-雪鸡坪成矿区西侧的羌塘地块在中三叠世时期(~230Ma)已经开始向东挤压并与中甸弧发生碰撞(Yuan *et al.*，2010)。因此我们认为，普朗-雪鸡坪含矿斑岩很可能是在甘孜-理塘洋西向俯冲增生的构造背景下，由晚三叠世西向俯冲的甘孜-理塘洋壳发生断离(Yuan *et al.*，2010)，进而沿着板片窗上升的软流圈导致前期被俯冲流体交代的富集地幔楔物质发生部分熔融的产物。而软流圈的减压熔融则形成了普朗-雪鸡坪矿区的 E-MORB 型的玄武岩。

5 结论

(1) 俯冲型和碰撞型含矿斑岩虽然有着相似的主量元素分布特征,但是它们却有着不同的微量元素分布区域,暗示它们有着不同的物质源区组成;

(2) 碰撞型含矿斑岩具有典型埃达克岩地球化学特征,它们的物质源区很可能与前期的洋壳俯冲有着密切的联系;俯冲型含矿斑岩并非全部具有典型的埃达克质岩特征,它们很可能是板片释放流体交代楔形地幔部分熔融并经历MASH过程的产物。

(3) 普朗-雪鸡坪含矿斑岩具有典型的俯冲型含矿斑岩特征,它们有可能是西向俯冲的甘孜-理塘洋发生断离,进而诱发前期俯冲流体交代的富集地幔楔发生部分熔融的产物。

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