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安徽省兆吉口铅锌矿床成矿地球化学机制研究

刘艳鹏 [1, 2, 3)], 朱立新 [4)*], 马生明 [5)]

1)中山大学地球科学与工程学院, 广东广州 510275;　2)中山大学地球环境与地球资源研究中心, 广东广州 510275;
3)广东省地质过程与矿产资源探查重点实验室, 广东广州 510275;　4)中国地质调查局, 北京 100037;
5)中国地质科学院地球物理地球化学勘查研究所, 河北廊坊 065000

自 20 世纪 30 年代起, 勘查地球化学就在矿产资源勘查领域发挥着重要作用。目前, 矿业界对勘查地球化学回归到基础勘查理论研究有着明确的需要。多维异常体系应用基础理论的提出是我国学者在该领域的积极响应。多维异常体系定义为“在特定的成矿地质时期, 成矿系统中存在的空间有序共存、成因机理各异、成矿指示递进的多属性异常体系”。其中, 多属性异常的形成机制及其在成矿空间中的结构关系, 是探讨矿床成矿地球化学机制和指导矿产勘查的基础, 同时也是勘查地球化学研究的前沿方向。本论文以位于安徽省东至县的兆吉口浅成低温热液型铅锌矿床为研究对象, 通过元素质量迁移定量计算, 研究典型剖面上元素活动规律, 构建矿致异常结构模式, 揭示矿床成矿地球化学机制; 利用图示方法展现不同水平断面上元素异常分布形态, 为深部成矿预测指明方向; 利用分形模型和基于成分数据理论的主成分分析、因子分析等方法, 研究地表岩屑中元素分布特征及影响因素, 指导研究区外围矿床地球化学勘查。

研究发现, 兆吉口铅锌矿成矿系统的平均质量变化率为 4%, 意味着成矿系统是开放的, 有外部物质参与成矿, 整个成矿系统在成矿过程中质量是净带入(增加)的。赋矿破碎带上盘青白口系地层平均质量变化率为–18%, 表示青白口系地层中元素质量是净带出(减少)的; 赋矿破碎带、矿体和下盘蓟县系地层等地质单元的质量变化率分别为 14%、23%和 8%, 表明这几个地质单元内元素质量是净带入(增加)的。常量元素 SiO_2、Fe_2O_3、MgO、CaO、Na_2O、K_2O 等在青白口系地层中带出, 在矿体部位带入增加; 成矿元素 Cu、Au、Ag、Pb、Zn、Mo 及其伴生元素 As、Bi、Sb、Se 和矿化剂元素 S 等从矿体上、下盘的围岩向矿体部位带入程度增加; 亲石元素 Ba、Be、Sr、Nb、P 等在青白口系地层中带出, 在赋矿部位和蓟县系地层中带入; 铁族元素 Mn、Cr、Sc、V、Ni 等在整个研究范围内带入; 稀土元素做为一组元素在青白口系地层中带出。兆吉口铅锌矿床成矿系统中存在着系统质量变化率(μ)异常、Na_2O 等元素负异常、矿化剂元素 S 正异常、S-FeO-Pb+Zn 协同平衡和 Pb、Zn、Cu、Ag、As 和 Sb 等元素正异常, 表现出多属性异常特征。多属性异常表现在既有成矿及伴生元素(例如 Pb, Zn, Cu, Ag, As 和 Sb)、矿化剂元素(S)、常量元素(例如 Na_2O)和亲石分散元素等不同类型元素的异常, 又有正异常和负异常, 同时强调元素间的协同平衡。

多属性异常的形成是成矿过程中元素质量迁移的结果, 结合稀土元素等地球化学证据, 提出了兆吉口铅锌矿床的成矿地球化学机制, 认为兆吉口铅锌矿床是由区域变质-构造运动-热液活动联合作用而形成的。在区域变质和/或构造运动期间发生的热事件, 使青白口系、蓟县系地层中元素发生活化, 并向赋矿破碎带中迁移, 在破碎带中成矿物质大量聚集的地段, 富集成矿。多属性地球化学异常在空间上有序共存, 构成矿致异常结构模式。研究区已知矿体位于 μ、Na_2O、S、Pb、Zn、Cu、Ag、As 和 Sb 等异常共存的中心。其中, Na_2O 的负异常面积最大, 涵盖整个赋矿空间和成矿及伴生元素异常范围; S-FeO-Pb+Zn 协同平衡关系存在于 S 异常范围内, 在 FeO 高含量区不存在矿体/石; Pb、Zn、Cu、Ag、As 和 Sb 异常存在于 S 异常的低 FeO 含量地段。在矿体部位, 系统质量平均增加了 30%。根据矿致异常结构模式判断, 研究区深部沿东至断裂两侧, 尤其是断裂带下盘仍有发现矿体的可能性。成矿系统中多属性异常结构模式在地表岩屑中具有继承性, 此发现为矿区外围地球化学勘查提供了理论依据。

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第一作者简介: 刘艳鹏, 男, 1990 年生。博士。主要从事勘查地球化学以及数学地质研究。E-mail: liu_ypeng@163.com。
*通讯作者: 朱立新, 男, 1963 年生。博士, 研究员, 博士生导师。主要从事勘查地球化学研究。E-mail: lixinz@cags.ac.cn。

分形模型及主成分分析、因子分析等统计分析结果显示，元素在地表岩屑中的分布主要受原岩含量、成矿作用以及风化作用的控制。其中，Al_2O_3、K_2O、CaO、MgO、SiO_2、TFe_2O_3、Ba、Rb、Sr、和 Te 等元素主要受原岩含量和风化作用控制；Na_2O 负异常特征由成矿作用形成，故其负异常指示成矿作用，其贫化程度在风化作用中得到加强；Pb、Ag、Zn、Cd、Cu、As、W、Sb 和 S 等元素主要受成矿作用的影响；Hf 和 Zr 由成矿和风化作用共同控制。地表岩屑中元素的分布及异常特征继承了成矿系统中的矿致异常结构模式，成为指导已知矿外围找矿的地球化学标志。

关键词： 兆吉口；浅成低温；铅锌矿床；硫异常；负异常；多属性异常；异常结构模式
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The Ore-forming Geochemical Mechanism of the Zhaojikou Pb-Zn Ore Deposit, Anhui Province

LIU Yan-peng[1, 2 ,3)], ZHU Li-xin[4)*], MA Sheng-ming[5)]

1) *School of Earth Sciences and Geological Engineering, Sun Yat-Sen University, Guangzhou, Guangdong* 510275;
2) *Centre for Earth Environment and Earth Resources, Sun Yat-sen University, Guangzhou, Guangdong* 510275;
3) *Key Laboratory of Geological Processes and Mineral Resources Exploration of Guangdong, Guangzhou, Guangdong* 510275;
4) *China Geological Survey, Beijing* 100037;
5) *Institute of Geophysical and Geochemical Exploration, Chinese Academy of Geological Sciences, Langfang, Hebei* 065000

Geochemical exploration has been playing a very important role in the field of mineral resources prospecting and evaluation. At present, the mining industry has a clear demand that the study of geochemical exploration should return to the focus of the basic theory. The multi-dimensional anomaly system (MAS) is one of Chinese responding in this regarding. MAS means that anomalies of many attributes which formed in different ways during a specific ore-forming period co-exist sequentially in space and indicate the ore bodies/deposits progressively. The spacial structure and formation processes of multi-attribute anomaly in MAS are the foundation to study ore-forming geochemical mechanism and prospect new ore bodies/deposits. Meanwhile, it is also the cutting edge of exploration geochemistry. In this dissertation, we selected the Zhaojikou epithermal Pb-Zn ore deposit, Anhui Province, as the object of study. First of all, the method of mass-transfer balance was used to study the elemental mobility in the ore- forming process, to construct an ore-forming anomaly model, and to reveal the ore-forming geochemical mechanism. Then, the distributions of elements of interest in different levels were visualized to show the ore prospecting direction in the deep. Finally, fractal model and PCA and factor analysis based on the compositional theory were used to study the distributions, anomalies, and controlling factors of elements of interest in the surface to help the geochemical exploration projects in the periphery of the Zhaojikou District.

The results show that the average mass-transfer rate of the ore-forming mass system is a. 4%, indicating that the ore-forming system was open, external substances participated in the ore-forming process, and the total mass of the ore-forming system increased. The average mass-transfer rate of Qingbaikou System is a. -18%, indicating that its total mass lost. The average mass-transfer rate of the fracture, ore-body, and Jixin System are a. 14%, 23%, and 8%, respectively, indicating that the total mass of these three parts gained. As major elements, SiO_2, Fe_2O_3, MgO, CaO, Na_2O, and K_2O were lost in Qingbaikou System and gained in the ore-body. Lead, Zn, Cu, Au, Ag, Mo (as ore-forming elements,), As, Bi, Sb, Se (as associated elements), and S (as mineralizing agent) were gained increasingly from the walls to ore-body. Barium, Be, Sr, Nb, and P (as lithophile elements) were lost in the Qingbaikou System and gained in the ore-bearing areas and Jixian System. Manganese, Cr, Sc, V, and Ni (as siderophile elements) were gained in the whole ore-forming systems. The REEs were lost in the Qingbaikou System. There are system mass-transfer μ anomaly, negative Na_2O anomaly (as major element), positive S anomaly (as mineralizing agent), the correlation of S-Fe-Pb+Zn, and positive Pb, Zn, Cu, Ag, As, and Sb anomalies in the ore-forming system of the Zhaojikou Pb-Zn ore deposit. These anomalies show multi-attribute characteristics. The multi-attribute anomaly characteristics mean that not only ore-forming elements (e.g., Pb, Zn, Cu, Ag, As, and Sb), but also mineralizing agents (i.e., S) and major elements (e.g., Na_2O) are anomalous, emphasizing positive anomaly, negative anomaly, and correlation among different elements.

The multi-attribute anomaly results in the ele-

ment migration during ore-forming processes. Considering the REEs, we proposed the ore-forming geochemical mechanism of the Zhaojikou epithermal Pb-Zn ore deposit. The Zhaojikou epithermal Pb-Zn ore deposit was formed by regional metamorphism, structural movement, and fluid activity. The heat resulted from regional metamorphism and/or structural movement reacitived some elements in the strata. These reacitived elements moved for the fractures, and precipitated there. The sequential co-existence of multi-attribute in space formed the ore-forming anomaly structure model. The known ore-body lies in the centre where μ, Na_2O, S, Pb, Zn, Cu, Ag, As, and Sb anomalies overlap. The negative Na_2O anomaly covers the broadest area, overlapping all the ore-bearing areas and Pb, Zn, Cu, Ag, As, and Sb anomalies areas. The correlation of S-Fe-Pb+Zn exists in the S anomaly area. There is little/no ore in the high concentration of FeO area. Lead, Zn, Cu, Ag, As, and Sb anomalies occur in the place of S anomaly area where FeO is low. The mass gained 30% in the ore-bearing zones. According to the ore-forming anomaly structure model, there is possibility to find new ores in the deep along Dongzhi Fault, especially in the foot wall. The multi-attribute anomaly structure is inherited in the elemental anomalies in the surface. The surficial inheritance of the multi-attribute anomaly structure provides the geochemical exploration project with theoretical bases.

The results of fractal, PCA, and FA showed that the distribution of elements of interest in the surface was jointly controlled by the original contents in the rock, weathering, and ore-forming processes. Aluminum oxide, K_2O, Rb, Ba, TFe_2O_3, Sr, Na_2O, CaO, MgO, SiO_2 were mainly affected by the original contents and weathering processes. The negative anomalous feature of Na_2O, was formed in the ore-forming processes and enhanced by weathering, and is of ore prospecting function. Whereas Pb, Zn, Ag, Cu, Cd, W, Sb, and As were mainly affected by ore-forming processes. Hafnium and Zr were controlled by both weathering and ore-forming processes. Sodium oxide was depleted in both weathering and ore-forming processes. The depletion feature was enhanced by weathering. The distribution of elements of interest in the surface inherited the anomaly features which formed during mineralization and plays as geochemical signals of ore prospecting in the periphery of Zhaojikou District.

Key words: Zhaojikou; epithermal; Pb-Zn ore deposit; S anomaly; negative anomaly; multi-attribute anomaly; anomaly structure model

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