地质异常成矿预测
理论与实践

赵鹏大　陈永清　刘吉平　等著

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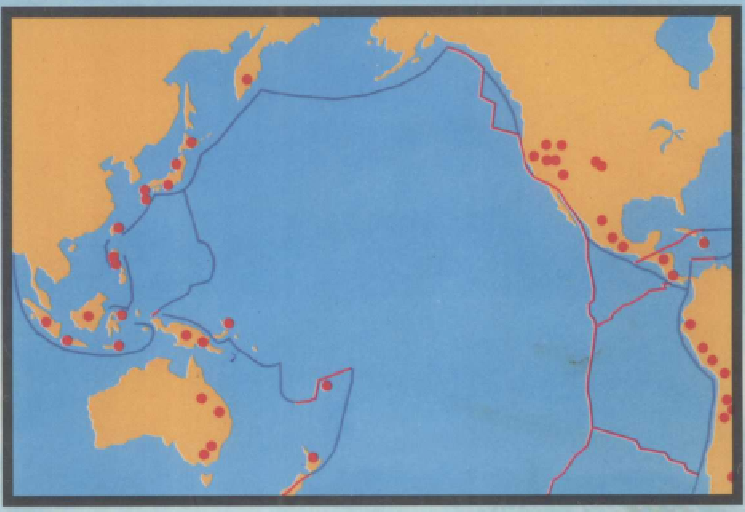
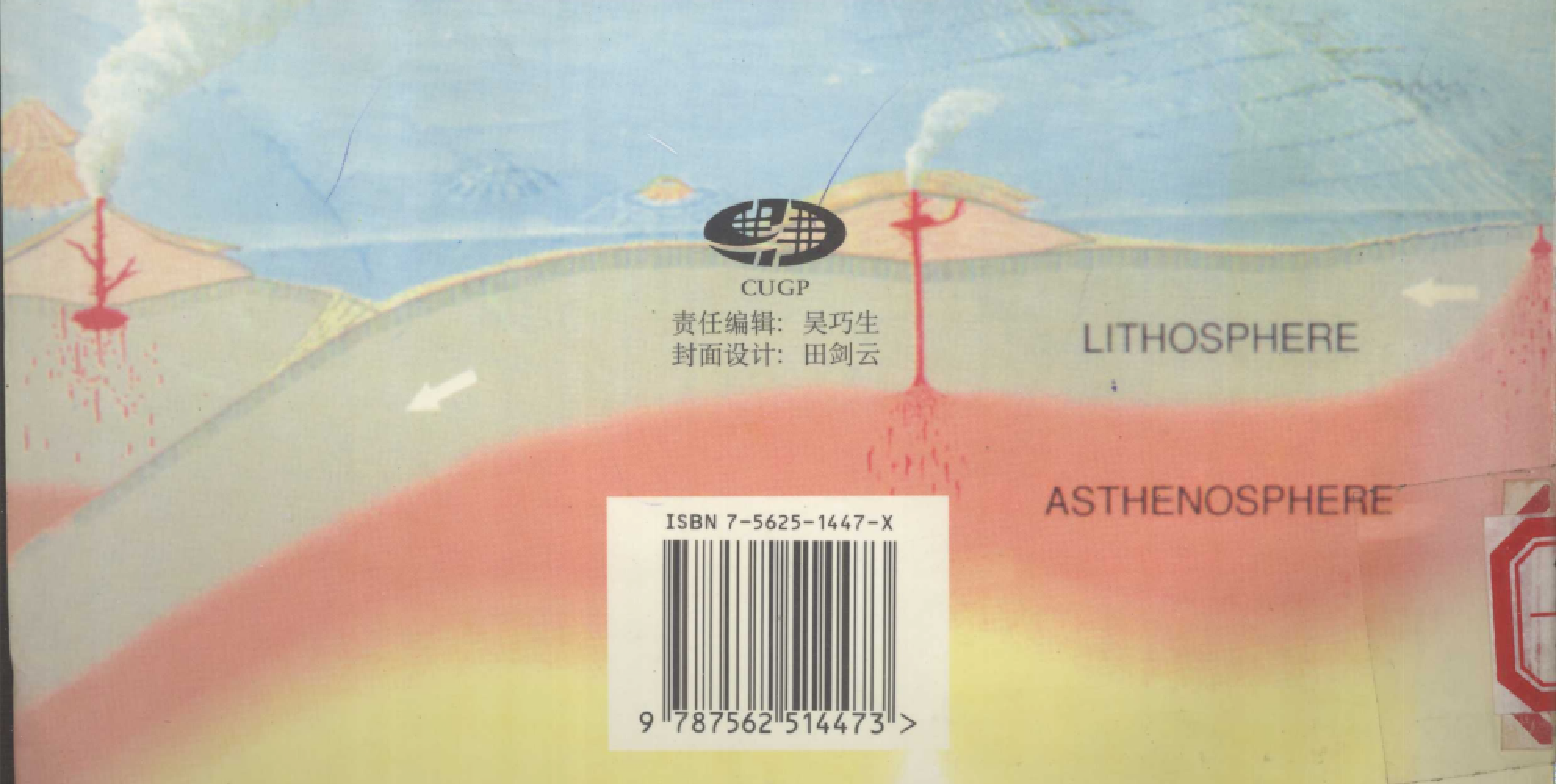
THEORY AND PRACTICE OF GEOANOMALY IN MINERAL EXPLORATION

ZHAO PENGDA　CHEN YONGQING　LIU JIPING *et al.*





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前　言

物化探异常作为矿床预测的重要依据是人们所熟知的，而“地质异常”的概念和意义在本世纪90年代之前却较少论及。事实上，“地质异常”较之物化探异常具有更深刻的涵义，无论在成矿预测领域还是在解决基础地质问题方面皆具有更广阔的应用前景。地质异常作为在物质组成、结构、构造和成因序次与周围环境具有显著差异的地质体或地质体组合，这一概念已经涵盖了矿床作为“地壳中有用组分自然浓集地段”的自然属性。因此，查明地质异常构成了成矿预测的基础。它亦是产生特殊类型和新类型矿床的前提条件，是物化探异常产生的根源。矿床是地质异常事件的产物，物化探异常是这一产物在物理性质和化学性质上的表现形式。

地质异常成矿预测以“求异”作为寻求新矿床的出发点。“求异”是地球科学的一种具创新性的思维方式。但是自19世纪30年代，C. 莱伊尔提出“将今论古（Present is the key to past)”的现实主义原则以来，“相似类比”原理在地质学研究方法论中一直占据主导地位。伴随着地球科学研究的全球化，伴随着“事件地质学”以及大型、超大型矿床等前沿课题的深入研究，“求异”思维在解决关键性地学问题方面显得越来越重要。是否可以这样说：“求异”是解决重大地质事件的钥匙（Seeking anomalies or differences is the key to great geological events)。

前苏联学者A.H. 布加耶茨（1973）曾提出过这样的假说：“最重要的矿床赋存于地壳中具有最大异常地质结构性质组合的地段”。这一假说已经逐渐被众多金属（Cu、Au等）的洲际成矿带与不同类型的岩石圈板块边界相吻合这一事实所证实。目前面临的问题是上述假说的逆命题并不一定成立。换句话说，重要的矿床必定位于具有最大地质异常结构的地段，但是具有最大地质异常结构地段不一定必然存在矿床。因此，如何根据地质异常致矿原理去寻找新的矿床构成了本书的主题。

不同尺度的地质异常对不同等级的矿产资源域（体）具有对应控制关系。即：全球性地质异常控制洲际成矿域的分布，区域地质异常控制成矿省的分布，局部地质异常控制矿田、矿床和矿体的分布，查明这种对应控制关系是地质异常矿体定位的前提。

地质异常作为一个具有时空结构的物质实体，在存在意义上，它表现为不连续性和突变性、不均一性和多样性、随机性和不确定性、等级性和相对性以及不规则性和自相似性等复杂性特征；在演化意义上，它可视为在远离平衡态的开放系统中，由非线性动力学机制形成的具有非平衡结构的复杂性地质体组合。这表明非线性科学在揭示地质异常特征及成因机制，并最终回答在相似的地质背景下为什么会出现有矿和无矿、大矿和小矿、富矿和贫矿、优矿和劣矿这一长期困扰科学家的本质问题方面具有关键性作用。

目前矿产勘查已进入以信息找矿为特征的集理论、方法、技术于一体的系统定量找矿的新时代。新的探测技术、测试技术和信息处理技术为定量成矿预测提供了新的技术支撑。这些新技术的应用必将提高成矿预测的精度和效益。

总之，地质异常成矿预测是在“地质异常致矿”新思路的指导下，运用多学科找矿信息，以非线性科学和高新信息处理技术为手段，以研究和定量圈定不同类型、不同尺度的致矿地质异常为基本途径，逐渐逼近工业矿体的一种具有创新性的定量成矿预测方法。该方法试图将控矿地质异常信息研究与矿异常信息研究相结合，显式地质异常信息研究与隐式地质异常信息研究相结合，深部地质异常信息研究与浅部地质异常信息研究相结合，直接找矿信息（地球化学信息）研究与间接找矿信息（地球物理信息和遥感地质信息）研究相结合；通过信息提取、信息关联、信息转换和信息综合等一系列信息处理过程，浓缩合成各类致矿信息；最终应用综合致矿信息定量标度致矿地质异常单元，通过对致矿地质异常单元的圈定和评价，达到圈定“5P”找矿地段的目的。

本书共分为十章，其组成和分工如下：前言（陈永清）；第一章，地质异常成矿预测基本原理（赵鹏

大，陈永清）；第二章，地质异常成矿预测方法体系（赵鹏大，陈永清）；第三章，遥感致矿地质异常信息提取（刘吉平）；第四章，地质、物化探异常信息提取及编图（陈永清，陈建国）；第五章，综合成矿预测中的非线性模型（申维，陈建国）；第六章，地质异常致矿概念模型（陈永清，刘红光）；第七章，地质异常找矿靶区定量评价模型（陈永清，夏庆霖）；第八章，鲁西金矿找矿有利地段圈定及评价（陈永清，夏庆霖）；第九章，铜石金矿产资源体潜在地段圈定及评价（陈永清，陈建国）；第十章，归来庄金矿区矿体远景地段圈定及评价（陈永清，刘红光）。

赵鹏大院士审阅了全书的提纲和初稿，并对各章节提出了修改意见；陈永清博士负责本书的编写和统稿工作。

本书的研究工作得到国家自然科学基金项目（No. 49502042）和国土资源部“九五”科技前沿计划项目（No. 9501108）的资助。在工作过程中，得到国土资源部矿产定量预测及勘查评价开放研究实验室、山东省地勘局、山东省地矿厅及其所属单位，以及湖北省武汉综合岩矿测试中心的大力支持和帮助。本书的出版得到中国地质大学“211 工程”建设项目的资助。在此，致以诚挚的感谢。

应用地质异常致矿理论进行成矿预测及靶区定量评价，是我们在矿产定量勘查领域所做的有益探索，较系统地开展这项研究在我国亦仅有十年的历史，理论和方法尚处于探讨阶段，不足之处恳求批评指正。

谨以此书献给中华人民共和国成立50周年及在新中国地矿战线上辛勤工作的人们！

作　者

1999年9月10日

Foreword

It is well known that geophysical and geochemical anomalies are very important evidences for prospecting for mineral deposits. But the concept of geoanomaly and its significance of mineral exploration are hardly expounded until 1990s. In fact, geoanomaly contains more profound implications than geophysical and geochemical anomalies, and has wide applications both in the assessment of mineral resources and in the explanation of some crucial geological phenomena. A geoanomaly is defined as a geological body or/and a combination of geological bodies that their composition, texture- structure and the order of genesis have obvious differences compared with those of their surroundings. The definition covers the natural property that mineral deposits are regarded as natural accumulation in the crust. Therefore, a thorough investigation of geoanomaly constitutes the basis of ore-forming prognosis. Geoanomaly is an essential prerequisite to finding out new types of mineral deposits and the origin arising geophysical and geochemical anomalies. Mineral deposits are results of geological anomalous events, and geophysical and geochemical anomalies are a form of expression of geoanomaly both in physical and chemical properties.

"Seeking anomaly or/and difference" is a starting point of the application of geoanomaly to the search for new types of mineral deposits. "Seeking anomaly or/and difference" is an innovative thought in geosciences. Since C. layer put forward the rule of realism that present is the key to past in 1830s "similarity-analogy" has been occupying a dominant place in the methodology of geosciences. With geosciences becoming a global science, with making a thorough investigation into some frontier subjects such as "Event Geology" and superlarge mineral deposits, "Seeking anomaly or/and difference" will play more and more important role in solving some great problems of geosciences.

A. H. Bugaets (1973) proposed: "The most important mineral deposits occur in the sectors of the crust where there is the combination of the greatest anomalous geological structure, and, therefore, the anomalous combination of the objects is the most perspective ore-finding areas". The hypothesis has been demonstrated by the facts that the intercontinental ore-forming belts of Au, Cu, W and Sn etc. coincide with the various types of boundaries of the plates. But now the problem confronting us is that the converse proposition is completely untenable. In other words, it is certain that the commercial ore deposits be situated at the areas of the greatest anomalous geological structure; but there are not ore deposits in all the anomalous areas. So, how to search for new types of mineral deposits according to the principle of geoanomaly constitutes a subject of this book.

Geoanomaly could be classified into four categories: the global, the regional, the local, and the microscopic according to their magnitude. Some geological facts have illustrated that intercontinental ore-forming domains coincide with global geoanomalies, ore-forming provinces coincide with regional ones, ore fields (ore deposits, or bodies) coincide with local ones, and microscopic ones are extremely useful to locate buried ore bodies (Zhao, and Chen, 1998) . To ascertain the ore-controlling relationships is an essential prerequisite of application of geoanomaly to the location of ore body.

Geoanomaly, as a substance (entity) of temporal and spatial structure, has the following characteristics: discontinuity and convulsion, heterogeneity and diversity, random and uncertainty; hierarchy and relativity, irregularity and self-similarity in existence; and in evolution, it is regarded as a combination of complex geological bodies of non-equilibrium texture formed from nonlinear dynamic mechanism in far away from equilibrium state. It implies that nonlinear sciences might play an important role in revealing the characteristics and genetic mechanism of geoanomaly and in answering eventually the reason why ore deposits exist in one place and no ones in another place under the similar geological setting.

At present, mineral exploration has stridden forward a new era of application of comprehensive ore-forming information to systematically quantitative search for buried large and superlarge ore deposits with help of sophisticated techniques. The sophisticated survey, analytical, and information processing techniques supply new support for mineral exploration. The application of sophisticated techniques to mineral exploration is certain to raise the accuracy and effectiveness of ore-forming prognosis.

In conclusion, geoanomaly ore-forming prognosis is a new method of quantitative assessments of undiscovered mineral deposits on the basis of "seeking anomaly or/and difference" with the help of both nonlinear sciences and sophisticated data processing techniques. Comprehensive ore-forming information at the corresponding scales is applied to study and delineate various scales and types of geoanomalies; and "ore anomalies" are gradually approached through delineating the ore-forming geoanomaly from regional to local in proper order. The method attempt to make the combination of both the ore-controlling anomaly with the anomaly of ore, the obvious geoanomaly with the hidden, and to make the deep ore-finding information with the shallow, the direct ore-finding information with the indirect; and to make the concentration of various ore-forming information through a series of information processing procedures such as the extraction, connection, transform and synthesis of multi-discipline ore-forming information eventually to delineate quantitatively "5P" ore-finding target areas through quantitatively delineating and assessing ore-forming geoanomaly units using integrated ore-forming information.

The book consists of ten chapters besides foreword. Chapter 1 Basic principles of application of geoanomaly to ore-forming prediction (written by Zhao Pengda and Chen Yongqing); Chapter 2 Methods of application of geoanomaly to ore-forming prediction (written by Zhao Pengda and Chen Yongqing); Chapter 3 Extraction of information of remotely sensed ore-forming geoanomaly (written by Liu Jiping); Chapter 4 Extraction and compilation of geological, geophysical and geochemical information (written by Chen Yongqing and Chen Jianguo); Chapter 5 Nonlinear models in synthetic ore-forming prediction (written by Shen Wei and Chen Jianguo); Chapter 6 Geoanomaly ore-forming conceptual model (written by Chen Yongqing and Liu Hongguang); Chapter 7 Quantitative assessing model of geoanomaly ore-finding target area (written by Chen Yongqing and Xia Qinglin); Chapter 8 Delineation and assessment of preferable gold ore-finding area in western Shandong uplifted area (written by Chen Yongqing and Xia Qinglin); Chapter 9 Delineation and assessment of potential gold ore resource area in Tongshi gold ore field (written by Chen Yongqing and Chen Jianguo); Chapter 10 Delineation and assessment of perspective gold ore body area in Guilaizhuang gold mine (written by Chen Yongqing and Liu Hongguang); Foreword (written by Chen Yongqing).

Academician Zhao Pengda carefully went over the manuscript of the book, and put forward insightful amendments for it. Dr. Chen Yongqing is responsible for the revision of the manuscript.

This work was performed under financial support from both the National Nature Science Fund Commission (Grant 49502042) and Ministry of Land and Resources (Grant 9501108). During the process of our carrying out these research projects, Support was also given by The Laboratory of Quantitative Prediction and Exploration Assessment for Mineral Resources, Ministry of Land and Mineral Resources, Shandong Bureau of Geology and Mineral Resources, and Wuhan Center of analyzing the samples from rock and ore. We express our heartfelt thanks to them.

Application of geoanomaly ore-forming theory to systematically carrying out quantitative assessment of mineral resources is a positive probe into new ore-finding theory and way, which is ten years from now and the theory and method is in the exploring stage. So we hope that colleagues make valuable comments on it so that it be perfected in practice.

Greet the 50th Anniversary of the Foundation of the People's Republic of China with this book!

Authors
September 10, 1999

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第一章　地质异常成矿预测基本原理

第一节　致矿地质异常概念

地质异常致矿是基于这样一些事实：世界上一些大型和巨型内生金属矿床通常位于地质结构复杂的区域，如各种类型岩石圈板块的边界等，从而形成像环太平洋Cu-Mo和Au以及Sn-W成矿带等这样一些贯穿全球的洲际成矿带。A.H.布加耶茨等（1973）提出：最重要的矿床赋存于地壳中具有最大异常地质结构性质组合的地段，因此，对象的“异常”组合应该是最有远景的。D.A.Gorelov（1979）对前苏联不同地区内生热液矿床就位地质条件的统计分析表明：大多数工业矿床一个最普遍的特征是赋存这些矿床的矿田与其邻区相比具有异常的地质结构。地质异常被定义为在地质结构演化的特定阶段，某地区均一地质体的地质特征在统计意义上偏离其总体背景（D.A.Gorelov，1979）。Favorskaya和Tomson（1974）将矿体定义为与地质异常相联系的地球化学异常。

地质异常（geological anomaly）是在物质组成、结构、构造或成因序次上与周围环境具有显著差异的地质体或地质体组合（赵鹏大等，1991）。如果定义一个数值区间表示背景场，那么，高于或低于该数值区间的场就构成地质异常场。因此，它具有一定的强度和时空结构。地质异常场通常导致地球化学和地球物理场以及遥感影像异常。

第二节　致矿地质异常特征

地质异常作为一个具有时空结构的物质实体，具有一系列复杂性特征。

1.2.1　不连续性（discontinuity）和突变性（convulsion）

地质体的不连续界面或不同地质体的分界面，如不同规模和不同性质的断裂、侵入接触界面、不整合面，都是典型的面状地质异常。表现形式为地质体连续性的突然中断，同时伴有物质成分的更换及其物理和化学属性的变化。上述部位是成矿的有利空间，如脉状矿体、接触交代矿床，风化壳型矿床分别受断裂、侵入接触界面和不整合面的控制。地质体的不连续界面和不同地质体的分界面在物质成分和组构及其物理、化学属性上往往表现为典型的突变性。如鲁西地体与鲁东地体的分界面——郯庐断裂带具有独特的地质演化历史，并表现为显著的线性（北东向）重磁梯度带异常。

1.2.2　不均一性（heterogeneity）和多样性（diversity）

众所周知，地球垂向分层、横向分带，无论在物质组成还是结构构造上都表现为不均一性和多样性。在此复杂的地质背景上形成的地质异常则更具有典型性。譬如，金矿床作为典型的地质异常体，不仅时空分布具有不均一性，其内部变化亦属极不均匀型，金品位变化系数一般均大于120%。在地质统计学上，相距为零的两点，金矿化的变差函数不为零——“块金效应”，其值称为“块金值”。由于金矿化变异的这些特性，金矿化成为研究矿体变化性质、变化程度以及矿化变异地质数学方法的主要对象和典型代表（赵鹏大，1992）。金矿化的多样性表现在金矿几乎占据了矿床分类的每一个类型。