IONAL GEOLOGICAL CONGRESS

# 地质综合场论

## 理论·方法·应用

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# ON GEOLOGICAL GENERAL FIELD

## Theory·Method·Application

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IONAL GEOLOGICAL CONGRESS

# 前　言

本书的出版恰逢第30届国际地质大会，谨以此书献给这一国际地质学界的盛会在我国首都北京的隆重召开。

在此以前，国内外学者已开始从不同的角度触及到地质综合场这一领域的某些方面，例如研究较早又日渐深入的地球物理场、地球化学场等，以及近年来出现的地球综合场和地质异常等。作者在前人研究的基础上，根据自己的研究成果和特点，提出了地质综合场(1992)，并通过对其成份、内涵和结构的综合研究发展成为地质综合场体系(1995)。本书较系统地阐述了这一体系的成份、内涵和结构特征，体系中的时空有序结构、热力学和动力学成因，以及有关的综合信息场矿产预测方法。

作者在本书中期望突出以下四个特点：第一个特点是其综合性，根据“科学的学科分异与综合是自然科学发展的辩证法”[2]，本书综合了与地质综合场有关的自然科学和新全球地质学的基本理论，它是场论、协同论、系统论和耗散结构理论在地质领域的拓展和应用；第二个特点是其系统性，本书所建立的地质综合场体系，首次系统地阐述了综合场中的三大成分(地质场、地球物理场、地球化学场)、二大内涵(物质场、能量场)以及多层结构(多级背景场和异常场)之间的有机联系；第三个特点是定性和定量相结合，建立在地质综合场理论体系之上的综合信息场矿产预测方法，希望在地质预测和统计预测之间建立更为密切的联系，在探索地质成矿规律(结构性、有序性)的同时，综合各类定量预测方法，研究其统计规律性；第四个特点是理论和应用相结合，本书通过作者近几年在滇西和湖南(水口山、清水塘、香花岭矿田)等不同尺度的地

质综合场的研究，并结合前人对其他一些地区的综合信息矿产预测，展示了该理论和方法的应用。

由于作者面对的是博大而精深的领域，涉及到较多的相关学科，在编写中顿感知识之不足，不妥之处在所难免，谨望专家同行赐教和指正。在编写过程中，刘石年教授担负导言和全书1～8章的主笔，段家瑞教授共同编写了第8章，毛先成副教授参编了第6章，并担任第1、2章的审核和修改，此外，湖南省地质勘探局张敏和吴永芳二同志也参加了水口山矿田的研究工作。成书中曾得到中国科学院院士陈国达教授的指教，如地幔蠕动流问题等，博士导师戴培根教授也曾部分审读书稿，并给予宝贵意见。作者在论述自己的基本观点中，还引证了不少同行专家的有关文献，在此一并致谢！

作者于1996年3月30日

# 导　言

## 0.1　地质综合场概述

地质学自18世纪诞生以来，经历过分异与综合的发展历程。19世纪末到20世纪上半叶时期，地质学已发展成为一门具有多分支学科的实践性和地区性极强的科学。随后，不同的分支学科与物理学、化学和数学相结合，不仅使各类基础地质学科得到拓宽和加强，而且还产生出不少的边缘学科，如地球物理学、地球化学、数学地质、同位素地质学、地幔岩岩石学等等。地质学这一门古老的学科得以迅速发展，研究领域不断扩大，各分支学科不断完善，形成了一个内容丰富、范围广阔的地球科学领域。

然而，地球科学又具有共同的研究对象，各分支学科从不同的侧面和方向对地球科学的深入研究，为整个学科的系统综合奠定了基础。高度概括的地质学科理论体系的形成是地球科学所面临的第二次突破。

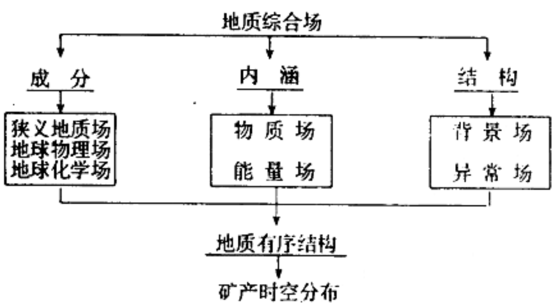
本世纪60年代后期，板块构造理论的兴起，引起了全世界地质界广泛的注意。许多基础地质学科及其边缘学科都参与进来，互相渗透，形成新全球构造学。这是地质学科的一次系统的综合。

鉴于"地质学是地球的科学，而地球是在物理作用下的化学体系"(P.J.Wyllie, 1971)，于崇文(1986)[1]、张本仁(1989)[2]、李嘉林(1989)[3]等从地球化学系统论和地球综合场的思想出发，提出建立成岩成矿统一理论的框架。但李嘉林主要从地球化学的角度分析了物质场和能量场的关系；赵鹏大等(1991)[4]提出过地质异常和地质异常场，是地质领域的新认识，赵鹏大(1994)进一步提出地球系统科学的科学思维。刘石年(1992, 1993)曾提出"地质综合场"，并通过近两年对其成份、内涵和结构的进一步分析(1995)，逐

步发展成为地质综合场体系，并期望它能够在阐明地质构造活动、成岩成矿机理、地质综合背景和地质异常，地质有序结构与矿产时空分布等方面成为学科综合的一个初步的尝试。

狭义地质场是指具有一定的时空范围和独立的演化历史及相应的地质结构构造的地区；广义地质场，或地质综合场，则是地质体或地质体的组合以及相应的物理性质和化学性质的综合概念。地质综合场在成份上包含了地质场、地球物理场和地球化学场；在内涵上它包含了物质场和能量场；在结构上它包含了背景场和异常场。因为无论是地质场、地球物理场还是地球化学场，就其本质而言，都只有物质的运动和运动的物质；而无论是物质场或能量场，在结构上都有不同级别的背景场以及背景之上的异常场。这些场首先具有数量特征，当空间中存在自然力场时，它们又具有矢量特征，其结果将形成不同形式的物质流和能量流。在体系不同程度的开放条件和总的非平衡状态下，体系将会不断与环境交换物质和能量，当外部条件的变化达到一定的阀值(临界点)时，由于随机涨落的放大和局域平衡状态的产生，会出现不同类型和级别的时空有序结构。不同等级的矿产即产于不同级别的地质有序结构之中。

地质综合场体系的系统框架可用框图简式表示如下：



## 0.2 地质综合场体系与地幔耗散结构

地质综合场时空尺度可以扩展到整个地史和壳幔体系。壳—幔体系的主要动力学过程是地幔蠕动流。最简单的模式是由 K、Th、U 等放射性元素的蜕变给地幔增热，然后由于地幔蠕动和温度梯度而造成缓慢对流。在蠕动过程中地幔向外场耗散热能，同时驱动地壳板块或壳体(陈国达，1992)[6]缓慢运动。然而，进一步的研究显示了地幔动力学的复杂模式，地幔蠕动流可能是多种状态和多级有序的结构，如定常态、非定常态和混纯态，以及全地幔对流、上地幔对流和局部异常地幔造成的蠕动流。

(1)定常状态　地幔物质(包括放射性元素)的分布是不均匀的，因而地幔中存在温度梯度和密度差异，并导致地幔发生蠕变及流动，地幔蠕动流按其类型可分为扩散流和汇聚流。前者类似于 Scheidegger(1982)[65]根据流体动力学的必要条件和模拟试验结果所提出的 *a* 型对流，后者类于他提出的 *b* 型对流。当地球运动相对平稳以及外场扰动不大时，地幔蠕动流可以呈变化不大的定常状态，拖曳着岩石圈板块缓慢地移动，并控制着板内构造活动连续渐进地进行，此时地幔的热状态相当于耗散结构的一个稳定分支解。

(2)非定常态　非平衡态热力学分析表明，当系统的控制参数值处于失稳临界点时，外场的扰动及系统内部的涨落就决定了系统的发展趋势。当外场的扰动呈周期性变化时，系统内扩散型和汇聚型流动状态和流动方向交替变成随时间周期振荡的非定常地幔蠕动流。地球自转加速度的周期性变化可以成为外场的周期性扰动因素，地磁场极性反转事件加强了两者之间的联系。由于地幔蠕动流的形式和方向的改变，导致体系状态发生突变跃迁，相应产生急剧的构造岩浆活动。地幔流动状态和方向多次交替的结果，将导致大地构造运动的多旋迴性以及旋迴的周期性。

(3)混沌态　利用非线性动力学的 Lorenz 方程[66]的低阶展开式证明，当 Prandtl 数无限大时，Lorenz 方程并不会给出混沌解，对流腔胞结构是稳定或亚稳定的。Stewart 和 Turcotte(1989)考虑了 Lorenz 方程的高阶展开式[67]，分析表明，在 Lorenz 截断的合理范围之外，在无限大的 Prandtl 数和很高的 Rayleigh 数条件下，由于热方程的对流项中存在着非线性的耦合，地幔蠕动流将呈现与时间有关的混沌态。这正如 Prigogine 的耗散结构分析所示，当系统远离平衡时，系统由于多次失稳，逐级分支，将由有序转变为混沌，具有奇异吸引子，它是不可逆的耗散运动和运动轨道不稳定性两者共同作用的结果。

壳幔体系中的地幔蠕动流是地壳热状态和应力状态的主要影响因素，其中扩散型地幔蠕动流向地壳耗散热能，造成水平张应力和较高的热状态，汇聚型地幔蠕动流给地壳造成水平压应力和较低的热状态。这是地质综合场体系的主要动力学和热力学成因。在地幔蠕动流所形成的温度梯度和压力梯度作用下，壳幔体系中存在着物质的扩散运移和成矿分异，形成地壳多级宏观有序结构。

## 0.3　地壳多级分异与多级成矿背景场

(1)地壳一级分异，发生在大洋和大陆地壳之间，分异的外因是在地幔对流蠕动作用下板块或壳体的运动，分异的内因是在温压场作用下地幔物质的垂直运动和水平侧向移动。物质分异首先发生在裂谷和洋中脊，在低压环境下，深部地幔物质上涌，基性超基性物质趋前分异，并伴随有趋低压成矿元素上升，中酸性物质及趋高压元素滞后；然后随增长板块在水平方向的移动发生侧向分异，最终使整个洋壳成分更偏基性，陆壳成分更偏酸性，形成地壳一级成矿背景场。

(2)地壳二级分异，主要发生在大洋地壳内部及大陆地壳内部，与其内部的构造发展历史及成岩成矿物质的进一步分异有关，

演化分异的结果形成各具不同特色的大地构造单元及其成矿的专属性，如裂谷、海沟、岛弧、边缘海、地缝合线及板内环境，成为地壳二级成矿背景场。

(3)地壳三、四、五级分异，发生于大地构造的次级单元或不同级别的构造体系范围内，受不同级别的能量场的控制而产生物质分异，形成地壳三、四、五级成矿背景场。

地壳物质及结构构造的多级分异与地幔蠕动流的多级结构及其对构造运动的多级控制有关，其结果是在不同程度的开放条件和远离平衡状态下地壳内多级有序结构的形成。

## 0.4 地质背景、地质异常与地质有序结构的关系

地质异常及地质异常场与各级地质背景和地质有序结构存在密切的联系，是地质综合场体系的重要的结构特征。

(1)不同级别的地质背景场是相应级别的地质异常场的基础或环境，而不同级别的地质异常相对于背景而言是一种新的时空有序态。不论何种地质异常，都比周围背景或环境具有更高的复杂程度和更高的肯定性，也更加有序，更有组织，但也具有更低的熵和更小的形成概率。

(2)地质异常是地质异常场的全部或其中一部分，两者的关系以数学语言可表之：$(G_A)_{s/t} \subseteq (G_M)_{s/t}$，$(G_A)_s \supseteq \{G_b, G_f, G_d, G_s\}$。式中$(G_A)_{s/t}$表示静态或动态地质异常，$(G_M)_{s/t}$表示空间上的地质异常场或时间上的地质异常域。其中，静态地质异常$(G_A)_s$包括体型$G_b$、面型$G_f$、线型$G_l$、点型$G_p$地质异常[14]，体型地质异常和地质异常场同域，面、线、点型地质异常，为地质异常场内的部分。体、面、线、点型地质异常，是静态地质异常的完整组合，是一个地质异常系列。

(3)地幔蠕动流的扩散流中心及汇聚流中心，以及异常上地幔或地幔囊，往往在地壳中形成地质异常，是幔—壳成矿作用的活跃

部位。

## 0.5 地质综合场在找矿预测中的应用

(1)地质综合场具有结构性和随机性双重性质。前者表现在定常和非定常地幔蠕动的多级结构以及地壳多级有序结构;后者表现在壳幔体系中耗散结构的高级分支所形成的确定性混乱(混沌)。矿产时空分布也受规律性和随机性双重性质支配。我们可通过地质综合场的结构性研究,认识成矿规律,通过概率论和数理统计分析,认识矿产分布的随机性及其统计规律。

(2)地质综合场为矿产的时空分布提供了地质构造背景、地球物理背景和地球化学背景。矿产分布于地质综合背景之上的地质有序结构和地质异常场之内。不同级别的地质异常场控制了不同级别的成矿区带、矿带、矿田和矿结等。高级序地质异常场具有更完全的成矿分离效应和更高的肯定性,是矿床产出的有利场所。例如云南澜沧—孟连火山岩带中,老厂大型铅银铜矿床以及阿卡白一级预测区都位于区带第三级成矿物质和结构构造异常场内。

(3)体—面—线—点型组合不仅是一个地质异常系列,也是一种逐步缩小找矿靶区的定性组合求异预测方法。其中大规模体型地质异常往往控制了成矿省或成矿区,面型地质异常往往是背景场跃迁到异常场的分界面,常常控制了不同级别的成矿带或矿带;点—线型地质异常往往对应着耗散结构的分支点,是热点—地幔柱,火山管道,岩浆、热液及热卤水通道,以及大型—超大型矿床产出的部位。例如白银厂大型铜多金属矿床,及东川大型铜矿床,均产于热点-地幔柱所形成的三叉裂谷的三叉点附近;金顶超大型铅锌矿床则具有典型的体—面—线—点型地质异常组合。

(4)不同期次或不同性质的物质场和能量场在空间叠加,可以形成各种类型的点源套合区,并控制了不同类型矿床的产出部位。单阶段场有四种点源套合区:①高温高压场;②高温低压场;③低

温高压场；④低温低压场。它们分别有利于比焓及比容等不同性质的元素或元素组合的聚集。点源套合法是进行隐伏矿床定位预测的一种有效的方法。

地质综合场理论是场论、耗散结构理论和协同论等学科在地质领域的扩展。在地质综合场理论指导下的综合信息场矿产预测方法，包含了王世称(1991)[5]提出的综合信息矿产预测方法，但其主要区别是它将从地质场、地球物理场、地球化学场的信息中研究成矿物质场和能量场的内在特征，以及在各种能量场作用下的成矿分离效应，并进而分离出各级成矿背景场和异常场，将背景之上的异常与地质有序结构相联系，根据地质有序结构的时空分布和综合信息的各种点源套合关系进行隐伏矿床预测。因此，综合信息场矿产预测方法包含了三亚类、有序结构分析法，综合信息类比法和组合信息求异法，三种方法又紧密联系，互相呼应。

在这里我们可以借用普利高律的一句话，当代科学的迅速发展，一方面是人对物质世界的认识在广度和深度上量的扩大，另一方面是由于研究越来越复杂的对象引起科学观念和研究方法的质的变化，即使我们具有利用知识和想象的能力，我们的思想和看法也永远不会正确和完善，它们只是一些近似，是达到自由王国的通道。我们只把这些初步的综合和解析当作一组思想和实施放入关心地球科学的人们中去发展和完善[8]。

# INTRODUCTION

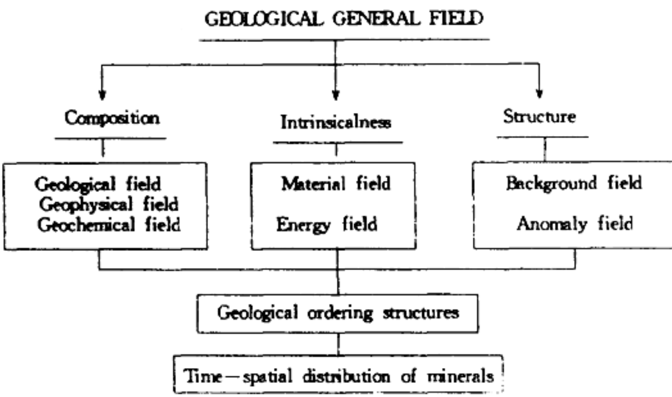
## 0.1 The Conception of Geological General Field

Nowadays, subject differentiating and integrating scientifically is dialectics of Earth science development. The system of geological general field might be a try of subject integration.

Li Jialing(1989)proposed a concept of"Earth general field"[3], but he only analysed the material field and energy field; Zao pengda (1991)[4] researched the geological abnormal and anomaly field; Liu Shinian(1992, 1993)also proposed the "Geological general field" and analysed overall its composition, intrinsicness and structure, and then developed it into a system of geological general field.

The geological general field (or generalized geological field)is a comprehensive concept of geological bodies or their assemblage and relative physical-chemical characteristics. In composition, it includes geological and geophysical as well as geochemical fields; Intrinsically it includes material field and energy field; structurally it includes background field and anomaly field. Either in geological fields or geophysical and geochemical fields, intrinsically there are only moving material and movement of material. While either in material fields or energy fields, there all exist different scale of background fields and anomaly fields upon background. These fields have numeric characteristics at first. When natural forces exist in space, they also have vector characteristics. The result is the formation of material flows and energy flows in variety forms. In different grade of open condition and gross nonequilibrium state, the system could exchange continually its material and energy with environment. When the outer conditions change to certain threshold value, different kind and scale of time-spatial ordering structures could be occurred because of the enlargement of random fluctuation and the occurrence of partial equilibrium. Different scale of minerals distribute in different grade of geological ordering structures.

The systematic framework of geological general field (abbr. GGF) can be illustrated as following:




## 0.2 GGF System and Mantle Dissipative Structures

The time-spatial scales for geological general field can be extended over the whole geohistory and crust-mantle system. The main dynamic process of crust-mantle system is the mantle creeping flow.

The simplest model is that mantle increases heat caused by molting of radioisotope U, Th, K, etc, and then moves owing to the mantle creep and temperature grade. In the process of creep, the mantle dissipates heat energy to outer field, and drives the crust plate or crust-body (Chen Guoda, 1992)[6] moving slowly at the same time. Nevertheless, the farther research has shown the complex model of mantle dynamics. The creeping flow of mantle could be multistate as stationary, nonstationary and chaos states, and multiorder structures as whole mantle convection, upper mantle convection and the mantle creeping flow cause by abnormal mantle

(1) Stationary state. The distribution of mantle materials (including radioisotopes) is inhomogeneous, so there is temperature grade and density difference in mantle, which result in creeping flow of mantle. The creeping flow of mantle can be divided into two kinds: diffusive flow and convergent flow that the former is similar to the a-type and the latter is similar to the b-type of convection proposed by Scheidegger (1982)[65]. When Earth's movement is relatively stable and the disturbance of outer field is not big, the creeping flow of mantle could be a stationary state. It drags the plate or crust-body moving slowly and controlls the tectonic action in plate developing continually and progressively. In this situation, the heat state of mantle corresponds to a stable bifurcate solution of dissipative structures.

(2) Nonstationary state. The analysis by nonequilibrium thermodynamics shows that when the value of controlling parameters is locating at a critical value, the disturbance of outer field and the fluctuation of system itself would decide the developing trend of system. When the disturbance is periodically changing, the flow state and direction would be alternative. The result is the formation of nonsta-

tionary creeping flow of mantle that oscillates periodically with time. The periodical changement of acceleration of Earth's rotation could be the outer field of periodical disturbance. The polarity reversal event of Earth's magnetic field might enforce a natural connection with both of them. The alternation of the form and direction of creeping flow of mantle would result in nutation and transition of the systemic state. Corresponding tectonic-magmatic action would be taken place. Many times of alternation of the mantle creeping state and direction would result in multicycle and periodicity.

(3) Chaos state. Lorenz equation[66] dealing with nonlinear dynamics proved that its lower-order spread formula can not give the chaos salution when Prandtl value is infinity. The convection structures would be stable or metastable. Stewart and Turcotte (1989)[67] considered the high-order spread formula of Lorenz equation. Their analysis shows that out of the reasonable range of Lorenz's truncation and in the condition of infinite Prandtl and very higher Rayleigh value, the convection would be a chaos state correlated with time because of the nonlinear coupling existed in convection nomial of thermal equation. It is also analysed by Prigogine and Nicolis[63] that when the system is far from equilibrium state, it would be change from order to chaos state because of the desabilization time after time and multistage bifurcation. It has the strange absorbent, which is the result of coaction of the irreversible dissipative process and the nonstability of moving orbit.

The creeping flow in crust-mantle system is the principal influential factor on the thermal and stress states of crust. The mantle creeping flow of diffusion-type dissipates heat energy to crust, and results in horizontal tensile stress and higher thermal state. The mantle creeping flow of convergence-type results in strong horizontal mpressive stress and lower thermal state. This is principal dynamogenesis of the system of geological general field. In the action of temperature and pressure grade. The metallogenic materials would differentiate and form multistage-ordering structures.

### 0.3 The Multiorder Differentiation and Multiorder Metallogenic Background Field in Crust

(1) The first-order differentiation of crust. It occurs between oceanic crust and continental crust. The ectogensis of differentiation is the tectonic action caused by the movement of plates or crustbodies with the mantle creeping flow. The endogenesis is the vertical and horizontal lateral migration of mantle materials in the action of temperature and pressure field. At first the differentiation of materials occurs at the rift or mid-oceanic ridge. In tensile environment, heat mantle materials in depth rise up and differentiate, form basic front and accompany with low pressure-trending metallogenic elements. Then the materials produce lateral shift differentiation along with the movement of accreting plate in horizontal direction. At last the composition of oceanic crust would be more basic-trending while the continental composition be more acid-trending. The result is the formation of the first-order metallogenic background field.

(2) The second-order differentiation of crust. It occurs in the oceanic or continental crust, and correlates with the developed history of tectonics and the differentiation of diagenetic and metallogenic materials once again. It results in the formation of varied characteristic tectonic-metallogenic unit, e. g. rift, trench, arc, marginal sea, suture, and intraplate environment. They are the second-order metallogenic background field in crust.

(3) The third -, fourth -, fifth - order differentiation of crust. They take place in subsidiary tectonic cells or different order structures. Because of the material differentiaton controlled by different orders of energy fields, the third -, fourth -, fifth - order matallogenic background fields is respectively formed.

The multistage differentiation of crust correlates with the multiorder structures of mantle creeping flow and their multiple controlling over the tectonic action. The diffenent grade of metallogenic background fields are all the multi order dissipative structures in crust - mantle system in the condition of open and far from equilibrium states.

## 0.4 The Correlation of the Geological Background, Anomaly And Geological Ordering Structures

(1) The different grade of geological background fields are the basis or environment of corresponding grade of anomaly fields, while the latter is a kind of new time-spatial ordering structure relatively to the former. Any kind of geological anomalies have higher complexity and perfecter metallogenic differentiation as well as higher organization than background field. They also have lower entropy and smaller formative possibility.

(2) The geological anomalies are full or parts of the geological anomaly field. The mathematical relation of them can be represented as following:

$(G_A)_{s/t} \subseteq (G_M)_{s/t}$, $(G_A)_s \supseteq \{G_b, G_f, G_l, G_s\}$

Here, $(G_A)_{s/t}$ is a group of different orders and kinds of the static or dynamic geological anomalies. $(G_A)_{s/t}$ is a corresponding group of the geological anomaly field in space or a geological anomaly domain in time. The state geological anomaly ($G_A$)$_s$ includes body-face-line-spot type.[14] It is a complete pattern and series of geological anomalies.

(3) The diffusive center and convergent center of mantle creeping flow and anomaly mantle or mantle sack often produce geological anomalies in crust, which are the important parts of mantle-crust metallogenesis.

## 0.5 The Application of Geological General Field

(1) The geological general field is characterized by dual propertes of structure and probability. The structrual property can be shown as multistage ordering structure in stationary, nonstationary etc. mantle creeping flow and multiorder mantle convection in space. The probability reflects in the deterministic chaos caused by the high-grade bifurcation of dissipative structures in crust-mantle system. The time-spatial distribution of minerals is also controlled by dual properties of regularity and probability. We can recognize the metallogenic law through research in the structures of geological general field, and the probability of minerals distribution and statistical regularity through analysis by statistics.

(2) Geological general field supplies minerals with the geological, geophysical and geochemical backgrounds. The ore deposits distribute in the geological ordering structures and anomaly fields upon comprehesion background. The metallogenic provinces, belts, districts etc. are controlled by different orders of geological anomaly fields. The higher the grade of the ordering structure and geological anomaly fields is, the perfecter the metallogenic fractionation is. The high ordering structures are the favorable sites for minerals oc-