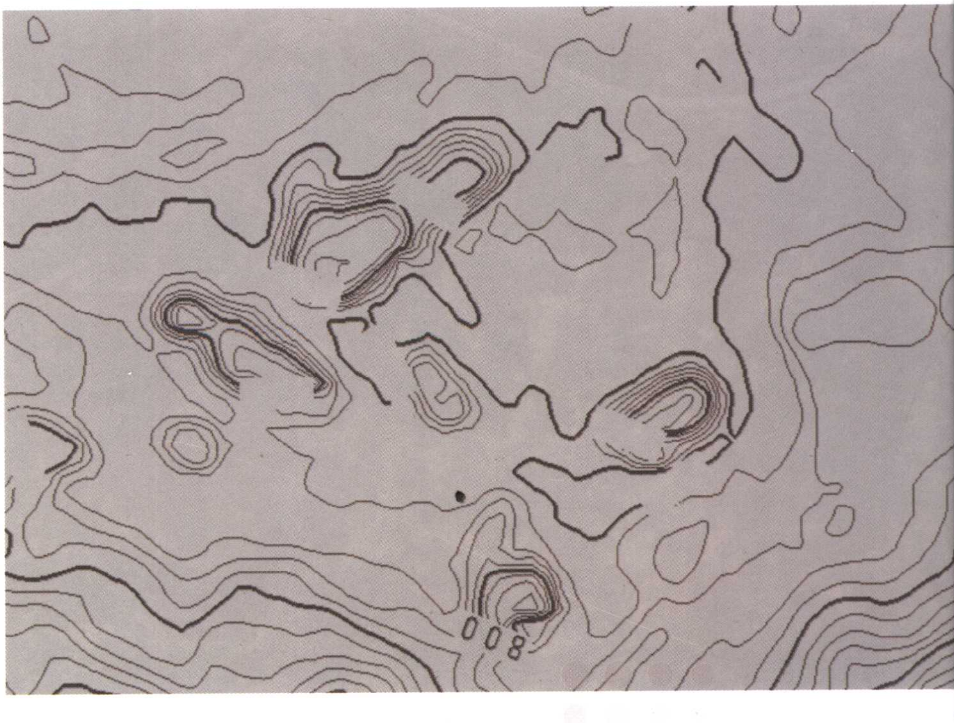
Dynamics of Tectonic Ore-forming Processes and Localization-prognosis of Concealed Orebodies

—As exemplified by the Huize Super-large Zn-Pb-(Ag-Ge)District, Yunnan

构造成矿动力学及隐伏矿定位预测

——以云南会泽超大型铅锌（银、锗）矿床为例

韩润生 陈 进 黄智龙 马德云 薛传东 李 元 等 著



科学出版社
www.sciencep.com

构造成矿动力学及隐伏矿定位预测

——以云南会泽超大型铅锌(银、锗)矿床为例

Dynamics of Tectonic Ore-forming Processes and Localization-prognosis of Concealed Orebodies

——As exemplified by the Huize Super-large Zn-Pb-(Ag-Ge) District, Yunnan

韩润生　陈 进　黄智龙　马德云　薛传东　李 元等　著

科学出版社

北　京

内 容 简 介

本书以云南会泽铅锌(银、锗)矿床为典型实例,主要进行了构造成矿动力学及其隐伏矿定位预测的系统概括。

在研究矿床成矿地质背景的基础上,概括了会泽铅锌(银、锗)矿床具有独特的成矿地质特征;从矿田构造、微量元素地球化学、同位素地球化学、流体包裹体地球化学等方面,系统研究了成矿物质来源、成矿流体来源以及构造、地层、峨眉山玄武岩浆活动与成矿的关系,建立了矿床成因模式;总结出矿床的构造控矿规律,恢复了矿区最大主应力值与方向;重点应用构造地球化学和构造应力场的找矿方法,建立和恢复了构造地球化学场和构造应力场及隐伏矿定位预测的 FCA 模型,并讨论其控矿特征及其机理,提出若干找矿靶位和重点靶区。通过密切合作,在成矿理论方面获得许多新的进展,在找矿技术方法应用方面取得重大的找矿突破。

本书可供从事找矿勘探、矿床地球化学、构造地球化学等有关的科研、教学、地质勘查工作者参考。

图书在版编目(CIP)数据

构造成矿动力学及隐伏矿定位预测:以云南会泽超大型铅锌(银、锗)矿床为例/韩润生等著. 一北京:科学出版社,2006

ISBN 7-03-017770-3

Ⅰ.构… Ⅱ.韩… Ⅲ.①金属矿床-成矿作用-构造动力学-研究-云南省 ②隐伏矿床-定位-预测-云南省 Ⅳ.①P618.202②P611

中国版本图书馆 CIP 数据核字(2006)第 090074 号

责任编辑:韩 鹏 谢洪源 / 责任校对:刘小梅
责任印制:钱玉芬 / 封面设计:耕者设计工作室

科学出版社 出版
北京东黄城根北街16号
邮政编码:100717
http://www.sciencep.com

中国科学院印刷厂 印刷

科学出版社发行 各地新华书店经销

*

2006 年 12 月第 一 版 开本:787×1092 1/16
2006 年 12 月第一次印刷 印张:13 1/2 插页 4
印数:1—1 500 字数:268 000

定价:68.00 元

《构造成矿动力学及隐伏矿定位预测》

——以云南会泽超大型铅锌（银、锗）矿床为例

作 者 名 单

韩润生　陈　进　黄智龙　马德云
薛传东　李　元　邹海俊　李　勃
胡煜昭　马更生　黄德镛　王学琨

教育部优秀人才培养计划项目（NCET-04-917）
云南省自然科学基金项目（99D0003G）　　　　联合资助
云南省省院省校合作项目（2000YK-04）

序

在我国，老矿山的资源不足和资源危机问题日益突出，隐伏和深部矿床的找寻已是当务之急，大家都在关心和探索深部找矿的思路和方法。近几年来，在一些老矿山如云南个旧、湖北铁山、青海锡铁山、辽宁红透山等地的深部探矿中均有新的发现，其中的一个重要原因是深入细致地进行了矿田构造研究，查明了控矿构造的类型和垂直分带趋势，以及成矿后构造的活动规律。这样，就加深了对矿体产出规律的认识，提高了找矿的命中率。

矿田构造学专门研究构造控矿作用，其研究内容和方法在找矿实践中逐步发展，并与其他地质学科相互融通，其中的一个重要得多学科研究领域是将构造作用与地球化学过程相结合的构造地球化学研究。这一方面的研究正在不断深入，并且在矿产资源预测中取得了良好效果，云南会泽铅锌矿的深部探矿经验就是其中的突出一例。

会泽铅锌矿主要由矿山厂和麒麟厂二矿床组成，是有百年以上历史的老矿。它的矿体赋存在石炭系白云岩中，规模大，矿石富（Zn+Pb：25%～35%）且伴生 Ge、Ag 等有益组分，明显受构造控制，埋藏很深，其独特的地质成因和巨大经济价值引起业界关注。近几年来，韩润生教授等与矿山密切合作，在前人工作的基础上，针对矿床的特点进行了系统的矿床学、构造地球化学和构造成矿动力学研究，查明了矿体的产出规律，预测并发现了两个巨大的隐伏矿体，实现了找矿的重大突破。这一研究成果的主要内容包括三个方面：

首先，在阐明区域成矿地质背景的基础上，经过详细的构造观测，鉴定了各种断裂力学性质，划分出构造期次，模拟了矿田构造应力场的演变过程，阐明了主成矿期的构造应力场特征及其对地球化学场、矿液运移势场和能量场的控制，查明了“多字型”和“阶梯式”两种控矿构造型式和构造等距性是控制矿体形态、产状的主要因素。

第二，以构造成矿动力学为主线，进行了详细的构造地球化学填图，论证了成矿元素组合异常与矿化富集体的相关性。系统地研究了矿床的地质地球化学特征，查明了成矿物质来源，将构造变形、能量、流体和地球化学相结合，清晰地阐明了矿源—输运—聚积的成矿过程，建立了矿床成因模式，并指出了峨眉山玄武岩浆活动与会泽铅锌矿的成因联系。

第三，进一步总结了构造成矿动力学及其用于隐伏矿预测的内容和方法，基于全面、翔实的多元信息，提炼了找矿预测标志，准确地判断了矿体产状，应用 FCA 模型（模糊综合评判模型）并集成多种软件，进行了隐伏矿体的定位预测，优选了重点找矿靶区，实施了工程验证，找到了深部矿体。

上述研究思路和方法的成功运用，不仅发现了麒麟厂矿区的主矿体延深已超过 1 300m，是我国目前已知埋藏最深的金属矿床，显示了其所处的滇东北及毗邻地区多金属矿床的巨大潜力，而且还提供了深部探矿的成功经验，对很多老矿山的攻深找盲工作

有重要的启发和借鉴意义。

我曾参观过会泽铅锌矿，也阅读了该书的主要篇章，我认为该书的学术思想先进，基础研究扎实，关键问题清晰，多元信息丰富，论述精细，探讨深入，是一部理论与实际紧密结合，在构造成矿理论和方法上有创新，在深部找矿中有显著实效的高水平著作。目前，我国的矿产资源形势严峻，迫切需要加强和改善矿床学等学科的研究工作，以便使理论研究成果能更好地为发现矿床服务。我认为，韩润生教授等在这方面提供的成功经验，给我们以很好的启迪，有着重要的理论和实际意义。我衷心祝贺该书的出版，并向作者们表示诚挚的敬意。

翟裕生

2006.7.30

前　言

矿产资源是人类赖以生存和发展的自然资源。随着我国经济的高速发展，矿产资源面临严峻挑战，其供给对国际市场的依赖程度已达20%，很多老矿山后备储量和后备基地不足的矛盾愈显尖锐，资源枯竭造成严重的“四矿”问题愈显突出，国家的资源安全问题也日益紧迫，这一严峻形势严重制约我国全面建设小康社会和实施重大的发展战略。因此，亟待寻找接替资源和发现新的矿产资源基地，尤其是我国紧缺的矿种（铜矿、富铅锌矿等）。但是，目前找矿难度日益增大，隐伏矿定位预测已成为国际地学界的主要难题之一。所以，需要地学工作者应用新的成矿理论、研究思路和找矿技术方法，发现老矿山深部及外围的大型、超大型矿床（体），实现地质找矿的重大突破，保障我国经济的可持续增长与国家的资源安全，实现社会和谐、经济持续发展。

云南会泽铅锌矿开采历史悠久，是我国著名的典型铅锌矿床之一，在我国和云南省有色金属工业发展中处于举足轻重的地位，也是川-滇-黔铅锌多金属成矿区中赋存于碳酸盐岩中的超大型铅锌（银、锗）矿床，已愈来愈引起国内外地质学家的浓厚兴趣和广泛关注。1941年前后，我国著名学者谢家荣、许杰、顾功叙、孟宪民等先后进行了地质调查；新中国成立初期，邓玉书、范承均等在矿山厂、麒麟厂矿区进行1∶20 000地质填图；1951年组建会泽铅锌矿后，有色地质302队进行大规模地质勘探工作（1953～1956），于1956年提交了“会泽铅锌矿储量计算报告”并获国家储量委员会批准；1956～1959年继续进行勘探工作，同时提交新的储量报告；1965年，会泽铅锌矿勘探队在1 991～1 931m中段进行加密勘探，在麒麟厂矿区获得Pb+Zn金属储量39.44万t；1980～1983年，除继续进行找矿勘探工作外，对地层、构造、成矿规律及矿床成因等方面进行了初步研究；1992年，会泽铅锌矿开始实施麒麟厂矿区资源接替工程，在1631中段发现了6号矿体，探获Pb+Zn金属储量78万t。截至1998年，在麒麟厂矿床共探获Pb+Zn储量117万t（据会泽铅锌矿资料）。1980年以来，不少地质勘查单位、科研院所、高等院校等的专家和学者曾在该区进行了不同程度的地质调查、矿产勘查和科研工作，其成果发表在各种杂志上（廖文，1984；张位及，1984；陈士杰，1984，1986；赵准，1985；杨国高等，1992；陈进，1993；柳贺昌，1995a，b，1996；柳贺昌，林文达，1999；郑庆鳌，1997；孙志伟，1998；韩润生，李元，2000；黄智龙等，2000；韩润生等，2001，2002，2003，2004）。1999年，在云南省自然科学基金项目“有色金属矿构造成矿动力学及隐伏矿定位预测方法探索研究”（NO. 99D0003G）与云南会泽铅锌矿委托项目“云南会泽铅锌矿区找矿预测研究”（1999-01）的资助下，与原云南会泽铅锌矿（云南驰宏锌锗股份有限公司）密切合作，在会泽麒麟厂矿区进行构造地球化学和矿田构造研究，提出了矿区深部若干个隐伏矿定位靶区，经矿山工程验证，发现8号隐伏矿体，这是会泽铅锌矿找矿史上的重大突破。该项研究成果曾获2002年云南省科技进步一等奖；2000年10月，昆明理工大学、云南会泽铅锌矿及中国

科学院地球化学研究所合作申报获准云南省省院省校合作项目“会泽铅锌矿区深部及外围隐伏矿预测及增储研究”（NO. 2000YK-04），昆明理工大学承担《会泽铅锌矿区深部及外围隐伏矿定位预测》课题，在麒麟厂矿区外围深部的大水井地区发现了 10 号隐伏矿体。

国内外许多重要矿床的发现都表明，正确的思维和科学、合理的方法是最重要的因素之一（裴荣富等，2001）。澳大利亚著名的勘查地质学家 R. 伍德尔（1992）曾精辟地概括“矿产发现是创造性活动的结果，是创新思维的结果，也是明智的科学研究的结果”。因此，该项目的整体研究针对隐伏矿定位预测的关键问题，将地质理论和找矿方法与找矿实践有机地结合起来，在成矿地质背景和成矿理论研究的基础上，采用新的找矿思路和找矿方法，抓住矿床受构造控制的特点，以构造成矿动力学（Dynamics of Tectonic Ore-forming Processes）研究（韩润生，2003）为核心，进行隐伏矿定位预测，取得了显著的理论、方法与应用成果。

1. 理论成果

1）川-滇-黔成矿区的成矿作用与元古宇基底构造层、古生界盖层有密切关系。基底构造层是赋矿层位（如四川天宝山铅锌矿床、小石房铅锌矿床）；盖层中碳酸盐岩为主要的赋矿层位（如泥盆系、石炭系和二叠系）中均有矿床（体）产出。总体说来，川-滇-黔铅锌多金属成矿区具有多层位赋矿的特点。其中，盖层中泥质岩夹煤层对矿床的形成起地球化学障的作用；赋矿地层（元古宇与古生界）中均夹厚度不等的蒸发岩层，提供了矿床形成的部分硫源，蒸发岩层也是成矿的有利因素，指示了沉积环境的岩相古地理特征。

2）川-滇-黔成矿区受深断裂的控制。小江断裂、昭通-曲靖隐伏断裂及水城-紫云断裂为成矿区的深部构造，分别控制了川-滇-黔成矿区、矿田及矿床的展布。会泽铅锌（银、锗）矿床受 NE 向东川-镇雄构造带中的会泽金牛厂-矿山厂构造成矿带控制，NE 向矿山厂断裂带、麒麟厂断裂带及银厂坡断裂带分别控制了矿山厂矿床、麒麟厂矿床及银厂坡矿床。

3）峨眉山玄武岩浆的喷溢与会泽铅锌（银、锗）矿床的形成有成因联系。其主要依据有：①川-滇-黔成矿区的分布与峨眉山玄武岩空间展布特征基本一致，玄武岩的厚度与铅锌矿床有明显的关系，尤其在滇东北地区的铅锌（银、锗）矿床，其关系更为明显；②玄武岩浆喷发时间为晚二叠世，K-Ar 法年龄为 218.6～253.3Ma（柳贺昌，林文达，1999）；会泽铅锌（银、锗）矿床闪锌矿（矿石矿物）的 Rb-Sr 等时线年龄为(224.8±1.2)Ma～(226.0±6.9)Ma，方解石（脉石矿物）Sm-Nd 等时线年龄为（225±38)Ma～(226±15)Ma（黄智龙，陈进，韩润生等，2004）；矿石矿物的铅同位素模式年龄主要为 210Ma 左右（31 件）；古应力值声发射法（AE 法）估计该矿床形成于海西晚期。所以，矿床的成矿年龄与峨眉山喷发年龄基本一致；③从矿物包裹体氢、氧同位素（δD-$\delta^{18}O_{H_2O}$）图解看，成矿流体主要来自岩浆水和变质水。玄武岩浆喷溢过程为会泽铅锌（银、锗）矿床的形成提供了热动力条件、流体组分和部分矿源；④玄武岩中 Pb、Zn、Ag 等成矿元素丰度高，并在滇东北地区见玄武岩中赋存铜、铅、锌等矿化元素的硫化物。

4）会泽铅锌（银、锗）矿床具有独特的成矿地质特征，主要表现在：①矿石品位高（Pb＋Zn 25%～35%，最高达50%以上）；矿化范围高度集中，矿化面积＜$10km^2$；②矿石富含银及大量分散元素（Ge、In、Cd、Tl等），Ag、Ge储量已达中-大型矿床规模；③矿石组成与矿石组构相对简单，矿床主要在热液期形成；④矿床明显受构造和岩性控制。三个矿床分别受矿山厂、麒麟厂和银厂坡断裂带控制，矿体均赋存于NE向压扭性层间断裂破碎带内，矿体延深大于走向延长2～4倍，并形成独特的控矿构造型式；⑤围岩蚀变简单且局限，主要表现为碳酸盐化、黄铁矿化及少量硅化；⑥矿体具有较明显的矿物组合分带；⑦控矿因素、矿床地质、矿床地球化学、成矿流体的成分、温度、盐度等特征不同于典型的MVT型铅锌矿床；⑧独特的矿床成因——“流体贯入-（蒸发）地层萃取-构造控制”。

5）矿床地球化学特征反映成矿流体为多源的，硫源主要来自海水硫酸盐，铅锌等矿源主要来自深源、基底构造层，其次为盖层。主要表现在：①摆佐组（赋矿地层）主要由不纯的中-粗晶白云岩夹白云质灰岩组成，是有利的成矿岩石组合。SiO_2、TiO_2含量较高，两者呈正相关关系。矿体的上覆地层为下二叠统梁山组，由碳质页岩、细砂岩夹煤层组成，为不透水层，对矿床的形成起遮挡层与保存的作用；②基底构造层、震旦系高；③成矿流体处于中-高温（方解石均一温度164～221℃；闪锌矿均一温度300～350℃）、中等盐度（8.5wt%NaCl）条件，流体类型为Ca^{2+}-Na^{+}-Cl^{-}-HCO_3^{-}-SO_4^{2-}型；④$\delta^{34}S$集中在12‰～16‰之间，少数＜5‰，以富集重硫为特点；铅同位素组成以正常铅为主，源区为多源铅；氢、氧、碳同位素组成特征反映成矿流体属壳-幔源的混合流体；⑤成矿期不同方向和性质的断裂构造岩的稀土元素组成及其分配模式明显不同；方解石的稀土元素组成代表成矿流体的稀土元素组成；在断裂构造活动过程中，矿石（矿物）和矿化构造岩HREE富集反映它们是成矿流体/岩石相互作用的产物；构造岩的稀土元素组成特征反映了主要的成矿流体不直接来自下石炭统摆佐组。

6）矿区存在5组断裂构造，其力学性质经历了复杂的转变过程：①NE向断裂：压性-左行压扭性→右行扭（压）性→张性→左行扭压性；②NW向断裂：张性→左行扭性→右行扭性；③NNW向断裂：左行扭性→左行扭压性→右行扭压性；④近EW向断裂：右行扭性→左行扭性→压性；⑤近SN向断裂：压性-压扭性→左行压扭性→压性→右行扭性。

7）在成矿作用过程中，构造是成矿作用的主导因素之一。构造作用产生的热力和动力驱动成矿流体运移，同时亦可使成矿物质集中，进入构造空间。当物理化学条件改变时，流体在构造中沉淀成矿，亦是矿床（体）最终定位的场所。矿床的构造控矿规律主要表现在：①成矿的主要导矿构造、容矿构造和配矿构造；②矿区构造体系上，恢复了不同期主压应力方向与大小；③NE构造带是矿区主要的成矿构造体系，为找矿突破奠定了理论基础；④不同级次的构造具有不同的控矿特征：区域性控矿构造（小江断裂、昭通-曲靖隐伏断裂），控制了区域矿带的展布；矿田控矿构造（如矿山厂断裂），控制了矿床的空间分布；矿床（体）的控矿构造（如NE向断裂及层间断裂），控制了矿体的形态、产状、规模等特征；⑤“阶梯状”和“多字型”构造是矿区内具有普遍性的控矿构造型式，矿床具有等间距和等深距成矿的特点；⑥容矿地层、含矿断裂与矿体

具有“三为一体”的特点，对隐伏矿预测具有重要的指导意义。

8）采用模糊数学的理论与方法，综合矿床的各种成矿有利地质因素，建立了隐伏矿定位预测的模糊综合评判（Fuzzy Comprehensive Adjudgement）模型（FCA 模型）。构造地球化学研究表明：①构造地球化学异常是矿化集中区的反映，可进行隐伏矿定位预测，指出重点找矿靶区和具体靶位；②反映某些控矿构造型式；③预示成矿流体的流向；④提供隐伏矿的大致产状及矿床成因等方面的信息；⑤构造地球化学异常受成矿构造应力场控制。

9）通过矿田构造应力场的动态演化模拟，得到矿田不同时期古构造应力场，绘制出构造应力场的动态演化图（主成矿期前、主成矿期及主成矿期后）。由于海西期构造运动，引起小江断裂和昭通-曲靖隐伏断裂带的左行走滑，产生北西-南东向挤压应力，形成有利的构造通道，发生深部流体“贯入”成矿作用，形成会泽铅锌（银、锗）矿床。构造应力场的控矿特征表现为构造应力场控制构造地球化学场、变形场、流体的运移势场、能量场等。通过构造应力场和构造地球化学场的互相结合，可建立完整的隐伏矿预测的勘查模式。

2. 方法与应用成果

1）进一步总结出构造成矿动力学及其隐伏矿定位预测的研究内容与方法。应用其理论与方法，在会泽铅锌（银、锗）矿床隐伏矿定位预测方面取得了突破性进展，获得了显著的找矿效果。

於崇文院士（1998）提出的成矿作用动力学，着重从微观角度研究成矿作用，揭示了成矿作用的本质，即成矿作用的成矿速率和机制及其时间演化与空间展布（成矿作用的时空结构）的矿床成因问题。笔者认为，构造成矿动力学可分为三个层次：区域构造成矿动力学、矿田（床）构造成矿动力学和微观构造成矿动力学。从宏观和微观角度研究成矿作用过程，通过构造应力场、构造地球化学、矿田构造等方面的综合研究，获得大量的成矿信息和各种参数，通过现代计算机技术处理，绘制出构造地球化学-地质图、构造应力场图，进行隐伏矿定位预测与快速评价。这是在隐伏矿预测理论与方法的重要创新，为成矿作用动力学及成矿预测学增添了新的研究内容。研究表明，该方法对在会泽铅锌（银、锗）矿区、滇东北-黔西北地区，乃至川-滇-黔成矿区的找矿研究具有重要的指导作用，成矿理论与有效的找矿方法的优化组合是取得隐伏矿找矿突破的关键。

2）建立的 FCA 模型是构造地球化学研究的进一步拓展。应用 FCA 模型及其实现的软件，联合 Statistics、MapGIS、MorPas 等计算机软件，是实现矿床深部及外围的定位预测的高效的数据处理方法和辅助决策工具，是构造地球化学找矿方法的有效补充和创新。

3）提出在麒麟厂矿床深部有隐伏矿体存在的地质条件，提出会泽铅锌矿区和麒麟厂矿床深部若干重点找矿靶位和靶区：麒麟厂矿床深部与外围 1 571m 中段 44—62 勘探线间、100—130 线间、88—100 线间等靶区。其中 44—62 线间、100—130 线间等定位靶区已被验证工程验证。在麒麟厂矿区深部 1 571m 中段以下发现富而厚大的 8 号矿体，在其近外围 1 571m 中段发现了 10 号富厚矿体，已探明的铅锌金属资源储量约 130 万 t，会泽铅锌（银、锗）矿床的金属储量迅猛增长，从而使该矿床进入世界级超大型铅锌矿

床的行列，并获得了巨大的经济效益和社会效益。

需要特别说明的是，为了保持研究的连续性和本区地层的可对比性，在本专著中仍沿用石炭系三分的划分方案，未采用两分方案；沿用二叠系两分的划分方案，未采用三分方案。

本专著是云南省自然科学基金项目（99D0003G）和云南省院省校合作项目（2000YK-04）及教育部优秀人才培养计划项目（NCET-04-917）等联合资助项目成果的系统总结，研究成果经补充修改出版成书。

在项目研究和野外工作过程中，得到云南驰宏股份有限公司、云南冶金集团总公司、云南会泽铅锌矿、有色金属矿产地质调查中心、中国科学院地球化学研究所及昆明理工大学等有关领导的关心和大力支持。得到了云南冶金集团王洪江副总经理、王吉琨副总工、云南驰宏锌锗股份有限公司浦恩社副总经理、浦邵俊矿长、崔茂金处长及高德荣、吴代成、赵德顺、杨云书、罗大峰等工程技术人员，中国科学院地球化学研究所刘丛强研究员、胡瑞忠研究员、张辉研究员及矿床地球化学开放室的科技人员，云南省地矿局张翌飞教授级高工、李文昌总工，云南有色地质勘查局黎功举教授级高工、崔银亮教授级高工，昆明理工大学冉崇英教授、李勃教授、李峰教授、庙延钢教授、梁永宁教授、杨世瑜研究员、杨海林副教授及李康健、周梅工程师、庄凤良高工的支持和帮助，在此表示深深地谢意！还得到了中国地质科学院陈庆宣院士，中国地质大学翟裕生院士，有色金属矿产地质调查中心主任孙肇均教授、梅友松教授、王京彬教授及方维萱研究员等专家的亲切指导，在此表示衷心地敬意！

还要特别感谢中国科学院院士、中国地质大学翟裕生教授在百忙之中为本书作序。并向未提及到但给本书提供支持和帮助的单位和个人也表示衷心感谢！并以此书献给孙家骢教授和陈庆宣院士。

专著撰写分工是：绪论：韩润生、黄智龙；第一章：韩润生、胡煜昭、薛传东；第二章：韩润生、黄智龙、陈进、王学琨；第三章：韩润生、黄智龙、薛传东、李元；第四章：韩润生、马德云、李元、马更生；第五章：韩润生、李勃、邹海俊、薛传东；第六章：马德云、韩润生、邹海俊；第七章：韩润生、陈进、黄智龙、黄德镛；结语：韩润生、黄智龙。英文：童志才译。本书由韩润生、薛传东统一定稿完成。

由于构造成矿动力学是一门难度大、涉及面较广的学科，也是地球化学新的分支学科，其理论和方法还有待成熟，加之隐伏矿定位预测难度日益增大和本人水平有限，书中难免有不妥之处，敬请读者指正。

韩润生　黄智龙

（昆明理工大学　中国科学院地球化学研究所）

2005 年 10 月

Dynamics of Tectonic Ore-forming Processes and Localization-prognosis of Concealed Orebodies

——As exemplified by the Huize Super-large Zn-Pb-(Ag-Ge) District, Yunnan

Abstract

The Huize Zn-Pb-(Ag-Ge) district contains medium-to large-sized, high-grade, Zn-Pb-(Ag-Ge) deposits that occur in the Sichuan-Yunnan-Guizhou Zn-Pb-(Ag-Ge) metallogenic region. The total reserve of Pb and Zn exceeds 5 Mt. The super-large type deposit is one of famous and typical carbonate-hosted Zn-Pb deposits in China.

1. According to the researches of metallogenic region and stratigraphy, it is thought that the metallization of the Sichuan-Yunnan-Guizhou metallogenic region has close relations to the basement tectonic layer of Proterozoic erathem and the caprock of Paleozoic erathem. The basement tectonic layer is both source-bed and ore-host horizon (such as Tianbaoshi and Xiaoshifan deposits in Sichuan). The carbonate in the caprock is main ore-host horizon, such as the Devonian period, Carboniferous period and Permian period, which is occured ore deposit (orebodies). Generally, Zn-Pb ore-forming in the Sichuan-Yunnan-Guizhou metallogenic region has polygenetic, multiplayer ore-forming characteristics. Its mudrock band and coal measures strata play a geochemical barrier in the formation of ore deposit.

In Proterozoic erathem and Paleozoic erathem, there are different thickness evaporite rock formations. The research shows it offers a part of sulfur source to the formation of sulfide deposit. On the other hand, the formation of evaporite rock instructs sedimentation setting lithofacies paleogeographic characteristic which is a favorable factor of the formation of deposit (orebodies).

2. The regional structure characteristics show the Sichuan-Yunnan-Guizhou Zn-Pb Sb-(Au) metallogenic region is controlled by deep-seated faults, such as Xiaojiang fault, Zhaotong-Qujing concealed fault and Shoucheng-Ziyun fault etc. They are deep-seated structures of metallogenic region which control the arrangement of mineral belts, district and deposit in the Sichuan-Yunnan-Guizhou metallogenic region. The northeast-trending faults are main structures for derivative and housing ores, the Northwest-trending fault is main structures of distribution ores. If there are intersections in sets or over two

sets faults, it is the better metallogenic district and also becomes orebody concentration and thickness position. Huize Zn-Pb-(Ag-Ge) district includes the Kuangshanchang deposit in west section, the Qilinchang deposit in middle section and the Yinchangpo deposit in northeast section.

3. After the comprehensive research of the Emeishan basalt, it is put forward that the overflow of basalt magma is relation to genesis of the formation of the Huize deposits. These reasons are:

1) The distribution of the Sichuan-Yunnan-Guizhou Zn-Pb metallogenic region is basic harmony to space arrangement of Emeishan basalt, especially good relationship with Zn-Pb deposits in the northeast of Yunnan.

2) The same or similar diagenism and metallogenic ages. The basalt eruption time is late Permian period at the age of 218.6—253.3Ma (K-Ar method, Liu Hechang and Lin Wenda, 1999). The metallogenic age of the Huize district is (224.8±1.2)—(226.0±6.9)Ma (Rb-Sr isochron method sphalerite), and is (225±38)—(226±15)Ma (Sm-Nd isochron method by Calcite) (Huang Zhilong, Chen Jin and Han Runsheng, 2004). The model age of Pb isotope in ores is mainly 210Ma or so (31 samples). Acoustic Emission Method (AE method) by palaeo-stress value deduces the district formed in the late Hercynian. In accordance with above ages, it is thought that the age of metallogenic epoch is basically harmony with Emeishan basalt eruption time even close to eruption late period.

3) From H, O isotope (δD-$\delta^{18}O_{H_2O}$) diagram in mineral inclusion, the ore-forming fluid mainly come from magmatic water and metamorphic water. It is thought that the basaltic overflow processes offer thermodynamic conditions, some fluid components and mineral sources.

4) Pb, Zn, Ag etc. metallogenic elements in basalt are special high, and there are a few sulfide in basalt at the same time in eastern Yunnan.

4. Detailed studies of the structural and geochemical controls of the origin of the Huize deposits indicate that the district possesses unique metallogenic characteristics. The characteristics show the metallogenic and ore-host specialties in Huize deposits have distinct difference compared with the typical MVT-type ore deposits:

1) The district is characterised by a particularly high ore grade (Zn+Pb≥25—35wt%, The richest ore grade is over 50%), thick orebodies (up to 30 m or more), and by a simple ore mineral composition (sphalerite, galena, pyrite and calcite as a major gangue mineral). The No. 10 orebody is particularly massive. The thickness and tonnage of the orebodies tend to progressively increase with depth.

2) Enrichment of Ag and other dispersed elements (Ge, In, Ga, Cd, and Tl) in the ores.

3) Galena, sphalerite, and pyrite being the major carriers of Ag, Ge, Cd and Tl.

4) Ore distribution is controlled by structure and lithological characters. The deposits all are controlled by the same fault structure. The orebodies are hosted in NE compresso-shear fault and interlayer crush belts.

5) Wall-rock alteration in the Huize Zn-Pb-(Ag-Ge) deposits is relatively simple and limited, mainly having carbonatization, pyritization and a little silicification.

6) Mineral zonation in the orebodies. The main orebodies show a mineral assemblage zonation from the footwall to the hangingwall of orebody, it is coarse crystalline pyrite and marmatite→sphalerite, galena and pyrite→finely crystalline pyrite and carbonate minerals.

7) Presence of evaporite layers in the ore-hosting wall rocks of the Lower Carboniferous Baizuo Formation and the underlying basement.

8) The metalization area is smaller than 10km^2. The ore-host strata is simple and main orebodies are only ocuured in dolomite of the Baizou Formation. The occurrence of orebodies is harmony with wall rock occurrence. It is a steep dip orebody. The orebody extends 2—4 times longer than its strike. The total is stratiform, stratoid orebody. It is consist of flat column, lenticular, sack-like and vein, anomalistic orebody along layer. The main orebody has rich, thick, big feature (For example, Nos. 1, 6, 8 and 10 orebodies).

5. Ore deposit geochemistry characteristics

1) The Baizu formation of ore-host strata is consist of impurity meso-coarsely crystalline dolomite and dolomitic limestone, argillite (a little) and favorable metallogenic rock assemblage. It includes higher SiO_2, TiO_2 contents. Both are positive correlativity.

Ore deposit overlying strata is the Liangshan formation of lower Permian system. It is consist of carbonaceous shale, fine sand rock and coal layer. It is waterproof strata which plays a barrier role in the formation of ore deposit.

2) The contents of metallogenic elements in regional stratigraphy are several times higher than the Crust abundance. Pb, Zn contents in the basement structure layer are even higher.

3) The research of fluid inclusion shows the metallogenesis is at meso-hypothermal (the homogenization temperature for calcite is 164～221℃; 300～350℃ for sphalerite), medium salinity (8.5wt%NaCl). The fluid type is Ca^{2+}-Na^{+}-Cl^{-}-HCO_3^{-}-SO_4^{2-}.

4) Isotope composition characteristics: $\delta^{34}S$ focuses on 12‰—16‰, few $\delta^{34}S<5$‰, rich in heavy sulphur. It doesn't exclude to mix into deep source sulphur and is multi source sulphur. Pb isotope composition is mainly normal Pb. The source area is multi source Pb. In accordance with H, O, C isotope characteristic, the metallogenic

fluid is crust-mantle-derived mixed one.

5) Rare earth elements (REE) in tectonites have low contents, big changes from 0.87×10^{-6} to 336.39×10^{-6}. ΣREE of Common tectonites is less than 100×10^{-6}. δEu shows the tectonites are polluted by different material source as it appears positive, negative and normal. The other features which REE in NE-treding fault tectonictes is higher than NW, SN and EW-trending tectonites show NE-trending metallogenic structure is even larger than the fluid affects.

These features show metallogenic fluid is multi source which sulphur source comes from seawater sulfate and Pb, Zn source come from deep-seated source, basement tectonic layer and the caprock.

6. By the macro-and micro-observation and mechanic analysis of fault structural planes, the research of orefield structure and formation development acquires 5 sets fault structure in the district. The transformed process of mechanic character is:

1) NE-trending fault underwent compressive and left-lateral compresso-shear → right-lateral shear (compressive) → tensile → left-lateral shear-compressive mechanic character.

2) NW-trending fault underwent tensile→left-lateral shear →right-lateral shear mechanic character.

3) NNW-trending fault underwent left-lateral shear→left-lateral shear-compressive→right-lateral shear-compressive mechanic character.

4) Near EW-trending fault underwent right-lateral shear→left-lateral shear→compressive mechanic character.

5) Near SN-treding fault underwent compressive and compresso-shear→left-lateral compresso-shear→compressive→right-lateral shear mechanic character.

Meanwhile, mechanic characters of faults determine maximum main stress direction of every structure stage in the field and divide, combination and formation development order of tectonic systems.

7. According to mechanic characters of fault structures and ore deposit geological-geochemical characteristics, for the first time we are put forward two ore-controlled structure types: xi-type and step ore-controlled structure. So, ore deposit has isometric interval and bathymetric interval metallogenic characteristic. This rule has important instructive significance for concealed ores finding and ore-finding prognosis.

From regional metallogenic structure, orefield metallogenic structure and ore deposit metallogenic structure, ore-controlled metallogenic structure is divided into three grades. These are: regional ore-controlled structure (Xiaojiang fault, ZhaotongQujing concealed fault) control the arrangement of regional mineral belt, orefield ore-controlled structure (e. g. Kuangshanchang fault) control the space configuration of ore deposit, ore deposit (orebodies) ore-controlled structure (e. g. NE-trending fault and interformational tectonic rupture zone) control orebody shape, attitude and size etc.

8. Tectono-geochemistry researches metallogenic material source, transformation, distribution and accumulation metallogenic processes. By the geochemical information of metallogenic elements and correlation elements from tectonite and modern advanced technology, the chemical elements are made cluster statistic analysis. At the same time, to make factor analysis and get different factors and score contour chart, distribution regularity, fixed quantity feature can make location prognosis of concealed ores. This method acquired a very good geological effective in prognosis of concealed ores of the Huize deposit (see chapter 7).

9. By means of the research of tectonic stress field, we can make the dynamic evolution simulation of orefield tectonic stress field, acquire different period paleotectonic stress field of orefield, draw the dynamic evolution map of tectonic stress field (major metallogenic pre-period, metallogenic initial stage, major metallogenic main stage and major metallogenic post-period), analyze the distribution feature of tectonic main stress and differentiate the formation and evolution of tectogenesis, fold and fault. According to this, we can determine main metallogenic tectonic period is harmony with the eruption stage of the Ermeishan basalt (late Permian Period). Due to tectogenesis and magmatic process, they give rise to left-lateral strike-slip of Xiaojiang fault and Zhaotong-Qujing concealed fault belt, produce northwest-southeast direction compression stress, form favorable tectonic path in order to be absorbed in deep-focus fluid, be resulted in metallogenic process, be formed the Huize deposits.

The ore-controlled features of tectonic stress field indicate tectonic stress field controls tectono-geochemistry field, deformation field, ore fluid transportation potential field, energy field etc. By means of the mutual combination of tectonic stress field and tectono-geochemistry field, we may set up a more complete survey model of prognosis of concealed ores.

10. To set up ore-finding model for prognosis of concealed ores. After the research of comprehensive analysis, we offer the ore-finding model (Fuzzy Comprehensive Adjudgement Model (FCA model)) for the concealed ores of the Huize deposits combined with the Huize mine, study out deep-seat ore-finding programme and favorable area, put forward specific predictive target area and target position.

11. Main achievement and progress in the technology and method are as following.

1) At first, we apply the theory and method of Dynamics of Tectonic Ore-forming Processes and achieve breakthrough progress in the prognosis of concealed ores of the Huize Zn-Pb-(Ag-Ge) deposit. The author thinks ore-forming process includes magmatic type ore deposit, sedimentary type deposit, metamorphic type ore deposit and re-

worked type ore deposit offered by Mr. Tu Guangze in 1980s. The reworked type depozit is 4th genesis type of contemporary ore deposit, which their metallogic process has close relationship with structure and tectogenesis. Thermodynamics produced by tectonization might drive transportation of metallogenic fluid and could also reconstruct and activate metallogenic material concentration in geologic body at the same time so that they enter weaken belt and favorable space which is final location place of ore deposit (orebody) and also location target area of ore-forming prognosis.

Dynamics of Tectonic Ore-forming Process may be divided into three arrangements, which include regional dynamics of tectonic ore-forming process, orefield (deposit) dynamics of tectonic ore-forming process and dynamics of micro-tectonic ore-forming process. The two latters have close relationship, sometimes indiscerptible, practical significance and instructive action. Recently, concealed ore-finding and predication are one of most difficult problems in geological ore-finding which has been paid attention by broad geologists and experts. we study ore-forming process at the macroscopical and microcosmic points of view, tectonic stress field and geochemistry field and acquire amount of ore-forming geologic information and various parameters change into various factor score figure indicated on a map and draw out tectono-geochemistry-geological map by means of modern computer process to make prognosis and predication of concealed ores. This is a important innovation of ore-finding theories and methods.

Dynamics of Ore-forming Process offered by academician Yu Chongwen in 1998 emphasizes to study ore-forming processes from microcosmic point of view, reveals essence of ore-forming processes, that is metallogenic problems for the drive power of ore-forming processes, ore-forming velocity, mechanic and time evolution, space arrangement (ore-forming processes and space-time structure).

However, Dynamics of Tectonic Ore-forming Process makes new breakthrough progress in theoretical system and method application, makes up and develops the study contents of dynamics of ore-forming process. Therefore, Dynamics of Tectonic Ore-forming Process is both the branch field of dynamics of ore-forming process and the branch subject of geochemistry.

2) All study shows the Huize deposits are of special super-large type deposits. Its metallogenic settings, ore-forming conditions, ore-controlled factors, ore deposit features, ore deposit geochemistry features, ore-forming material origin and metallogeny etc. compared with the similar ore deposits at home and abroad have notable difference and unique features. It can be named as Qilinchang-type Zn-Pb-deposit.

3) After all studies, we predicted that there are deep-seated concealed ores conditions at the Qilinchang area, put forward and circle prognosis belts of concealed ores and target areas (see text in detail). After engineering test and verification, rich and large