矿业可持续勘查开发“四元”模型

——地质 环境 技术 经济

Quaternion Model for Sustainable Exploration and Development of Mines (QMM): Geology, Environment, Technology, and Economy

舒思齐 张洪涛 裴荣富 等 著

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Quaternion Model for Sustainable Exploration and Development of Mines (QMM): Geology, Environment, Technology, and Economy

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内 容 提 要

本书从地质、环境、技术和经济4个方面研究了矿产资源合理勘查开发影响因素，建立了矿业可持续勘查开发"四元"模型（地质、环境、技术、经济）；并以西藏冈底斯成矿带为典型实例，研究了冈底斯成矿带铜多金属矿成矿地质特征、勘查开发技术和矿山环境保护技术，对冈底斯成矿带典型矿床（点）进行经济评价；并运用该模型对甲玛铜多金属矿勘查开发合理性进行评价。这一研究不仅有利于促进西藏冈底斯成矿带矿产资源勘查开发，而且对国内整装勘查区和"走出去"矿业企业开展境外矿业投资具有重要指导意义。

本书可供矿产资源管理者、矿业企业经营者、金融投资者参考，也可作为科研院所、大专院校研究、教学人员的参考书。

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序

矿产资源是经济、社会发展的重要物质基础。矿产资源安全是国家安全的重要组成部分，并在国家安全中占有基础地位。根据全球构造演化背景与成矿特征，全球四大成矿域（劳亚成矿域、冈瓦纳成矿域、特提斯成矿域和环太平洋成矿域）横跨中国境内。优越的成矿地质条件使我国成为世界上矿产资源比较丰富、矿种比较齐全的少数国家之一。

我国东部地区人口密集，西部地区大部分处于高寒高海拔地区，生态环境脆弱。我国矿业开发不能走“先破坏再治理”的老路；走“绿色矿业”之路，实现人与自然和谐发展，是一条符合我国实际的有效发展路径。然而，我国部分矿山长期无序、不合理勘查开发，造成了资源浪费和生态环境破坏，导致了一系列严重的矿山环境问题。

根据国情，我国东部挖潜增储不能解决根本问题，找矿重点不得不向西部转移。客观上，青藏高原注定成为我国地质找矿的重点区域。国务院参事、国土资源部原总工程师张洪涛领衔的“青藏高原地质理论创新与找矿重大突破”项目获2011年度“国家科技进步奖特等奖”，为西藏矿产资源勘查开发做出了卓著的贡献。

青藏高原素有“世界屋脊”和“地球第三极”之称，是亚洲乃至北半球气候变化的“感应器”和“敏感区”。青藏高原生态破坏的元凶之一是过度放牧。“羊单位理论”很好地诠释了在青藏高原开发矿业与保护高原生态环境之间的关系：1只羊需要50亩草场养活，即1个“羊单位”；1个牧民生存需要50个“羊单位”（2500亩）。而建设1座现代化大型矿山，只需要2000亩草场，比1个牧民需要的50个“羊单位”还少一些，可谓“开发一小点，保护一大片”。因此，合理勘查开发西藏矿产资源是促进西藏地区经济发展和生态环境保护的有效手段。

如何合理勘查开发矿产资源？裴荣富院士曾提出了矿产资源勘查开发的“景、场、相、床”等级体制成矿理论、“双控论－合理域”模型、“风险投资决策支持系统”“不同规模矿山合理开发年限”和“矿业‘5R’循环经济理论”等科学技术理论，从“地质、技术、经济”三个方面对矿产资源的合理勘查开发进行评价。舒思齐博士等创新性地将环境因素作为矿业勘查开发决定性因素，并以青藏高原冈底斯成矿带及甲玛铜多金属矿为例，从“地质、环境、技术、经济”4个方面开展跨领域、跨学科研究，提

出了矿业可持续勘查开发“四元”模型。这为我国矿业可持续勘查开发提供了一个很好的解决方案：从“地质、环境、技术、经济”4个方面对矿产资源勘查开发合理性进行评价，其中“环境”占有一票否决的地位，只有那些环境评价为“合理”的矿床才可进一步勘查开发。

该书提出的矿业可持续勘查开发“四元”模型令人鼓舞，可作为我们今后合理勘查开发矿产资源的评价尺度。

中国工程院院士：

2017年5月18日

前　言

矿产资源是国家经济和社会发展的重要物质基础，承担着人类生存、繁衍和发展所需全部物质的85%以上，是经济、社会、科技等各个领域从落后走向进步、从低级走向高级的发展动力。人类文明的每一次进步，都与矿产资源的利用能力、方式和水平的提高有关。

实现矿业可持续勘查开发是推进经济社会健康发展和人类文明进步的重要保障。世界环境与发展委员会（WCED）比较系统地分析和研究了可持续发展问题，指出可持续发展就是既满足当代人的需求，又不对后代人满足其需求的能力构成危害的发展。矿业可持续勘查开发是指合理勘查开发矿产资源，实现资源利用、环境保护、科技创新和经济社会的协调发展，既能满足当代人对矿产资源的需求，又不对后代人利用矿产资源和生存环境造成危害的可持续发展方式。

随着我国新型工业化、信息化、城镇化、农业现代化深入推进，矿产资源供需矛盾日益突出，人们对矿业勘查开发存在一些困惑。

1）在地质勘查早期如何识别具有开发潜力的矿床（点）？不考虑经济成本和开发技术条件的大量矿产勘查工作，导致一批已探明储量的矿床不能开发利用，形成一批“呆矿”，闲置了大量矿产资源勘查开发资金。据调查，我国计划经济时期探明的27种主要矿种的储量利用率仅为38%。

2）如何做到生态环境保护与矿业开发的协调发展？矿业勘查开发导致的土壤污染、水污染、空气污染、生物多样性破坏和次生地质灾害等事件频发。矿业“三废”造成环境污染的事件屡见不鲜。目前仅金属矿山堆存的尾矿就高达100余亿吨，并以每年10亿吨以上的排放量剧增。大量固体废物排放与堆存占用了大量宝贵的土地资源，并对空气、土壤、地表水和地下水产生二次污染。

3）如何提高资源利用效率？我国矿产资源产出率低、综合利用率低和再生资源回收利用率低，资源高消费低效益的经济增长方式急需改变。大量矿业固体废物的排放造成大量有价金属与非金属资源的流失，成为严重制约矿山发展的重要因素。2013年，我国尾矿综合利用量仅为3.12亿吨，综合利用率仅为18.9%。

4）青藏高原矿产资源是否可以开发？具有“三江之源”和“中华水塔”之称的青藏

高原矿产资源极为丰富，但其生态环境异常脆弱。已查明的矿产资源中，西藏有12种资源储量位居全国前五，18种位居全国前十，铜、铬的保有储量及盐湖锂矿的远景储量位居全国第一。然而，其生态环境一旦被破坏，不但很难恢复，而且会威胁数以亿计人民的健康。长期以来，中央及西藏地方政府对于西藏矿业开发持谨慎态度。

为指导矿业可持续勘查开发，促进国内整装勘查开发区合理勘查开发矿产资源和“走出去”矿业企业开展境外矿业投资，本书以西藏冈底斯成矿带铜多金属矿为例，从地质、环境、技术和经济四个方面建立矿业可持续勘查开发“四元”模型（Quaternion Model for Sustainable Exploration and Development of Mines，英文简称：QMM）。

$$\text{GETE} = W_1 \cdot \sum_{k=1}^{4} w_{1k} \cdot u_{1k} + W_2 \cdot \sum_{l=1}^{5} w_{2l} \cdot u_{2l} + W_3 \cdot \sum_{m=1}^{4} w_{3m} \cdot u_{3m} + W_4 \cdot \sum_{n=1}^{4} w_{4n} \cdot u_{4n}$$

GETE为矿业可持续勘查开发指数。

本书各章节撰写分工如下：第一章绪论，由舒思齐、张洪涛执笔；第二章成矿地质条件，由向君峰、裴荣富执笔；第三章矿山环境保护技术，由朱晓华、舒思齐执笔；第四章固体矿产资源勘查开发技术，由吴春平、郑文宝、张婉执笔；第五章固体矿产资源经济评价，由舒思齐、孙张涛执笔；第六章矿业可持续勘查开发“四元”模型，由舒思齐、张洪涛、裴荣富执笔；第七章矿业可持续勘查开发智能系统，由莫燕执笔。全书由舒思齐、张洪涛、裴荣富统稿。

作者在本书的研究过程中，得到国土资源部党组成员、中国地质调查局局长钟自然博士，中国地质调查局副局长王研博士、李金发博士、王昆博士，中国地质调查局总工程师严光生博士，中国地质科学院党委书记王小烈研究员等的大力支持。中国地质大学（北京）赵鹏大院士、王成善院士，西藏自治区多吉院士，中国矿业大学（北京）武强院士，国务院发展研究中心资源与环境政策研究所谷树忠研究员，国土资源部李裕伟研究员，中国地质调查局邢树文研究员，中国地质科学院矿产资源研究所唐菊兴研究员、肖克炎研究员，国家测试中心刘晓端研究员对本专著初稿提出了宝贵的修改意见。在西藏野外工作期间，西藏自治区地质矿产勘查局第六地质大队张焕彬队长、西藏华泰龙矿业开发有限公司西藏甲玛铜多金属矿区魏峰经理、中国地质调查局朱春华博士、北京矿冶研究总院陈经华博士和黄丹硕士、中国地质大学（北京）王瑜副教授提供了大量帮助。在此，对上述单位、个人及为本研究提供帮助的其他专家表示衷心的感谢！

本书研究范围广、涉及学科多、工作难度大。书中难免存在不足之处，敬请读者批评指正。

作者

2017年4月15日

Forward

As a crucial basis for economic and societal development, mineral resources provide 85% of the necessary materials for maintaining the living, reproduction and development of the human kind, and drive the advancement and progresses of the social economy, science and technology. Each progress of human civilization is closely tied to the amelioration of mineral resources utilization.

The sustainable exploration and development of mines guarantees the healthy development of society and economy, as well as the progress of human civilization. The World Commission on Environment and Development has conducted systematic analysis and research into the sustainable development issue, defining sustainable development is development that meets the needs of the present without compromision the ability of future generations to meet their needs. The sustainable exploration and development of mines refers to such a means of development which ensures reasonable exploration and development of mineral resources, collaborative development among resource utilization, environmental protection, technical innovation and social and economic development, and one which does no harm the ability of future generations to utilize minerals resources and their living environment.

The imbalance between supply and demand of mineral resources has been exacerbated by the ongoing new-type industrialization, informationization, urbanization and agricultural modernization in China, resulting in confusions regarding the exploration and development of mineral resources among people.

(1) How to identify the deposits with economic potential during the early stage of geological exploration? A number of ore deposits with proven reserves are unable to be utilized due to ignorance of economic costs and the restrictions of develoment technology, leading to the existence of numerous idle mines and large amount of unused exploration funds. An investigation indicates that only 38% of the 27 major minerals reserves proved in the planned economy period have been utilized.

(2) How to coordinate the protection of ecological environment and development of mines? The exploration and development of mineral resources has also led to frequent cases of soil

pollution, air pollution, water pollution, bio-diversity destruction and secondary geo-hazards. There have often been reported cases of environmental pollution caused by mineral waste water, gas and residue. Currently, tailing piles from metal mines alone reach an amount up to more than 10 billion tons, with a rapid growing rate of 1 billion tons per year. The large discharge and piling of mineral solid wastes has occupied substantial precious land resources and caused secondary pollution on the air, soil, surface water and groundwater.

(3) How to improve the efficiency of resource utilization? The low output rate, comprehensive utilization rate and recovery rate, urge our nation to shift the current economic development mode of high consumption and low efficiency of resources. The large emissions of mineral solid wastes have led to drainage of large quantities of valuable metals and nonmetals, severely constraining the mining development. However, the domestic comprehensive utilization of major mineral resources is increasingly improvecl. In 2013, we integratedly utilized up to 312 million tons of tailing resources, which contributed to a comprehensive utilization rate of 18.9%.

(4) Can the mineral resources in Qinghai-Tibetan plateau be developed? The Qinghai-Tibetan plateau, which is renowned as the Water Tower of China and the Cradle of the Yangtze River, Yellow River and Langcang River, is endowed with abundant mineral resources but a vulnerable eco-environment. Of all the proven mineral resources in Tibet, the reserves of 12 kinds rank top 5 in China and 18 kinds rank top 10. The recoverable reserves of copper and chromium and prospective reserves of salt lake lithium deposits rank the first in China. However, once the vulnerable eco-environment is destroyed, it is not only hard to recover, but might also threaten the health of thousands of millions of people. The central and local government has long been prudent over mineral exploration and development in Tibet.

In order to promote rational exploration and development of the domestic integrated zone and facilitate the overseas mineral investments, this paper focuses on the Gangdese copper-polymetallogenic belt and establishes the Quaternion Model for Sustainable Exploration and Development of Mines (Abbreviation: QMM) from geological, environmental, technical, and economic perspectives.

$$\mathrm{GETE} = W_1 \cdot \sum_{k=1}^{4} w_{1k} \cdot u_{1k} + W_2 \cdot \sum_{l=1}^{5} w_{2l} \cdot u_{2l} + W_3 \cdot \sum_{m=1}^{4} w_{3m} \cdot u_{3m} + W_4 \cdot \sum_{n=1}^{4} w_{4n} \cdot u_{4n}$$

GETE is the index of Sustainable Exploration and Development of Mines.

The first chapter of this paper is the general introduction, undertaken by Shu Siqi and Zhang Hongtao; the second chapter is about metallogenic geological conditions, undertaken by Xiang Junfeng and Pei Rongfu; the third chapter centers on environmental protection technologies of mines, undertaken by Zhu Xiaohua and Shu Siqi; the fourth chapter is exploration and development technologies of solid mineral resources, undertaken by Wu Chunping, Zheng Wenbao, and Zhang Wan; the fifth chapter is the economic assessment on solid mineral resources, undertaken by Shu Siqi and Sun Zhangtao; the sixth chapter is the quaternion model for sustainable exploration and development of mines (QMM), undertaken by Shu Siqi, Zhang Hongtao and Pei Rongfu; and the seventh chapter is the intelligent system for sustainable exploration and development of mines, undertaken by Mo Yan. Shu Siqi, Zhang Hongtao, and Pei Rongfu act as the compilers-in-chief.

This monograph has been completed with strong support from Dr. Zhong Ziran, Vice Minister for Geological Survey of Chinese Ministry of Land and Resources, and President of China Geological Survey, Dr. Wang Yan, Dr. Li Jinfa, and Dr. Wang Kun, Vice-Presidents of China Geological Survey, Dr. Yan Guangsheng, the Chief Geologist of China Geological Survey, and Prof. Wang Xiaolie, Vice-President of Chinese Academy of Geological Sciences. We have also received precious revision suggestions from Academician Zhao Pengda and Wang Chengshan from China University of Geosciences (Beijing); Academician Duo Ji from Tibet Autonomous Region; Academician Wu Qiang from China University of Mining and Technology (Beijing); Gu Shuzhong from the Institute of Resources and Environment Policy, Development Research Center of the State Council; Li Yuwei from the Ministry of Land and Resources; Xing Shuwen from China Geological Survey, Tang Juxing, and Xiao Keyan from the Institute of Mineral Resources, Chinese Academy of Geological Sciences; Liu Xiaoduan from the National Geo-Analysis Center, Chinese Academy of Geological Sciences. During the field work in Tibet, we gained enormous support from Zhang Huanbin, Director of No. 6 Division of Tibet Geological Bureau; Wei Feng, the manager of Tibetan Jiama (Gyama) Copper Polymetallic Ore Company of Tibet Huatailong Mining Development Co. Ltd. and Dr. Zhu Chunhua from China Geological Survey, Dr. Chen Jinghua and master Huang Dan from Beijing General Research Institute of Mining and Metallurgy offered data for the study. Wang Yu, the associate professor from China University of Geosciences (Beijing) has provided help for the indoor research. Hereby, our sincere acknowledgements go to all the above-mentioned organizations and individuals as well as other experts who offered help to the study.

On account of a wide range of research scopes, multi-disciplines and complicated field & laboratory analyses involved in this monograph, defects are inevitable. Suggestions are highly welcomed and appreciated from the readers.

Authors

April 15, 2017

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