环境地球化学评价与环境治理研究

——以海南石碌铁矿区为例

廖香俊　等著

地质出版社

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廖香俊
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内容提要

本书以地球化学理论为指导，以岩（矿）石－尾矿－土壤－水－水系沉积物－植物－人为系统，采用地球化学、环境学、生态学等多学科协同及野外调查—实验测试—栽培试验—模拟试验—综合研究等方法，研究了矿区环境污染的历史、现状、发展趋势及其主要影响因素，提出了矿区环境污染的植物治理与化学治理方案。

本书适用于从事环境科学、地球化学及采矿的科研和生产人员使用，也可供地质类及环境科学类高等院校师生参考。

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主持国家及省（部）级重要科研项目10余项、省（部）级重要勘查项目50余项。获国家科技进步二等奖1次，省(部)级科技一等奖2次、二等奖4次、三等奖1次。出版专著5部，发表学术论文50余篇。2007年被中共海南省委组织部评定为海南省“515人才工程”第一层次人才。

序

《环境地球化学评价与环境治理研究——以海南石碌铁矿区为例》一书出版问世了。本书是著者综合其完成的海南省自然科学基金项目“海南西南地区矿山污染与治理研究”、国土资源部与海南省人民政府合作项目“海南岛生态地球化学调查”及博士学位论文专题研究成果提炼撰写而成的。

自工业革命200多年来，人类社会在极短的时间里发生了前所未有的巨变。与此同时，为人类社会发展提供资源、能源的地球环境也发生非人所愿的变化，诸如气候变暖、水体污染、土壤污染、物种灭绝、土地沙化等等。这些自然环境的改变深刻影响到人类的生存和可持续发展，从而迫使人们回过头来，反思自己的发展模式、生产和生活方式等对自身赖以生存的自然环境的影响——环境问题业已成为当今世界普遍关注的重大问题。

面对诸多环境问题，改变社会经济发展模式是根本性的，但是，基于现代科技手段进行环境的修复也是必不可少的。当环境问题同样摆在地球化学工作者面前时，环境地球化学学科应运而生。发展到今天，环境地球化学在环境修复、人体健康、生态效应、污染治理等方面日见其功，特别是在矿山环境修复方面，环境地球化学方法技术具有更专业的、更直接的针对性和有效性。

到今天为止，我国的海南岛仍然是举世公认的生态环境优良区，堪称是世界上为数不多的未被（或轻微）污染的“净土”。虽然如此，随着当地经济社会的发展，局部的环境问题逐渐凸现。其中，矿业开发带来的局部生态环境恶化已经开始影响到当地居民的生存质量。如已有70多年开采历史的昌江石碌铁矿，因开采冶炼形成的排土场、尾矿库等废弃物已对当地土壤、地表水、地下水等环境要素造成重金属元素污染，进而直接或间接地危害到当地居民的身体健康。

本书中，著者针对石碌铁矿矿区环境地球化学与环境治理等科学问题，以环境地球化学理论为指导，以岩（矿）石—尾矿—土壤—水—水系沉积物—植物—人为系统，以重金属元素迁移途径为线索，采用地球化学、生态学等多学科协同及野外调查—实验测试—栽培试验等方法，研究了矿区环境污染的历史、现状、发展趋势及其主要影响因素，找出了直接的污染源及其污染方式，提出了矿区环境污染源的植物治理与化学治理方法体系。

这是一本顺应世界经济社会发展而著的适时之作，研究方法先进，资料翔实，论证严谨，具有很强的可操作性，实现了理论研究与实践应用相结合，对于石碌铁矿区的环境污染治理具有重要的现实意义。在矿产资源开发日益活跃的今天，该研究的方法和成果对于矿山环境修复和保护具有推广借鉴意义。本书的出版必将推动矿山环境地球化学研究的重大发展。

張本仁 2010年6月

前　言

资源与环境问题是当今世界普遍关注的重大问题。之所以如此，不仅因为资源与环境是人类赖以生存和发展的基础，而且由于工业革命200多年来，工业社会的发展曾严重依赖于资源的大规模消耗，建立在以依靠消耗不可再生资源为基础之上的工业化，以对大自然进行开发掠夺、牺牲生态环境换来的经济增长，使世界环境迅速恶化，自然资源急剧消耗，人与自然的关系日趋紧张。整个20世纪，人类消耗了1420亿t石油、2650亿t煤、380亿t铁、7.6亿t铝、4.8亿t铜，资源的消耗和不足问题已成为进入21世纪亟须解决的问题。资源的过度开发和不合理利用，引发了一系列生态环境问题，如全球气候变化、水污染、生物物种灭绝、酸雨污染、土地沙化等。

海南的资源与环境是海南经济社会发展的优势所在。海南是我国矿产资源相对丰富且种类独具特色的省份之一：全省保有储量位居全国前10位的矿产有石英砂、钛铁矿与锆英石砂矿、油页岩、宝石、富铁矿等9种；所辖海域的石油、天然气与钛铁矿、锆英石、独居石砂矿有较大的潜力；富矿比例较大，矿床开采技术条件较好，已探明天然气田多属高产能的大中型气田，铁、石英砂、金等重要矿产品位高，大多数矿床具备“近、浅、易”的特点，或者开采技术条件比较简单，适宜露天采，选冶条件良好；矿产资源具有优势，海域的石油、天然气、天然气水合物，陆域的富铁矿、石英砂、锆英石、钛铁矿砂矿、金、饮用天然矿泉水、医疗热矿水等是海南的优势矿产，高岭土、油页岩等矿产具有比较优势。海南的生态环境质量是全国最好的区域之一，2009年海南岛森林覆盖率达到59.2%，环境空气质量总体优良，基本保持国家一级水平，80%以上的江河湖库水质达到或优于国家地表水Ⅲ类标准，84.5%的近岸海域海水水质符合国家一、二类标准。20世纪90年代初在海南举行的一次国际环境保护会议上，联合国环境专家指出，海南是世界上为数不多的未被污染的“净土”，她是大自然馈赠给我们的珍贵遗产，她属于全世界，属于全人类。

矿产资源和生态环境地质调查研究是海南地质工作的重要任务。虽然海南矿产资源相当丰富，但海南的地质工作程度较低，矿产资源的勘查程度较低，海域石油、天然气、天然气水合物等资源潜力大，但有相当一部分未经勘查。海南生态环境质量好，但随着开发建设的推进，也出现了不少问题，如土地沙化、海岸侵蚀，部分地区发育有崩塌、滑坡、泥石流等地质灾害，矿产开发导致土壤、水资源受到污染等。这些问题都迫切需要通过地质调查和研究加以解决。

石碌铁矿是亚洲最大的富铁矿，也是海南开采历史最长、开采规模最大的矿山。经历70多年的开采，产生了大量的废弃物。2007年开始正式规模开采铜钴矿，并开展铜钴矿的冶炼和加工，矿区的环境压力越来越大。笔者结合海南省科学基金项目“海南西南地区矿山污染与治理研究”、国土资源部与海南省人民政府合作项目“海南岛生态地球化学调查”及博士学位论文专题研究，对石碌铁矿矿区环境地球化学与环境治理进行了研究。本书即在上述工作基础上，以地球化学理论为指导，以岩（矿）石－尾矿－土壤－水－水系

沉积物－植物－人为系统，采用地球化学、生态学等多学科协同及野外调查—实验测试—栽培试验—模拟试验—综合研究等方法，研究了矿区环境污染的历史、现状、发展趋势及其主要影响因素，提出了矿区环境污染的植物治理与化学治理。

研究取得的主要成果如下：

（1）从岩石地球化学特征着手研究了矿区环境的地球化学背景。研究表明，研究区As，Cd，Cu，Hg，Cr，Pb，Zn等有害元素在侵入岩中含量一般都高于全海南岛侵入岩的背景水平。其中，中元古代花岗片麻岩中除Pb外的其他元素含量是最高的；沉积－变质岩中各元素也具有同样的分布特点，且铁矿体、铜钴矿体围岩石碌群中As，Co，Cr，Cu，Mn，Ni，Fe的含量最高。对于矿山开采活动的主要对象——铁矿石和铜钴矿石而言，铁矿石中除Fe外其他元素含量一般较低，但其围岩中Hg，Ni等元素的含量高；铜钴矿石中除Cu，Co元素外，As，Cd，Hg，Ni，Pb，Zn的含量也很高。因此，铁矿和铜钴矿的开采，都可能带来As，Cd，Hg，Ni，Pb，Zn，Mn等伴生元素以及成矿元素Cu，Co，Fe对环境的影响。

（2）对矿区土壤、尾矿、水系沉积物、水、植物等各环境介质的环境地球化学进行了研究。

1）从海南岛全区土壤到研究区内区域性土壤、与矿山开采活动密切关联的局部土壤、尾矿库区上游土壤、尾矿库区下游土壤，有害元素含量逐步升高，特别是尾矿库区下、上游土壤中元素含量比值明显大于1，说明尾矿是影响其下游土壤有害元素含量的源头。结合表层土壤的富集因子进行研究，区内区域土壤有害元素地球化学异常大多是人为作用即矿山开采所致。

2）研究区内的各期尾矿库的尾矿和排土场废石中有害元素含量较高，铜钴尾矿中有害元素的含量高于铁矿尾矿。尾矿中最稳定的元素是Cr，有机结合态是尾矿中较常见的有害元素的赋存形式；各期尾矿库表层的有害元素有效态一般高于深层；铜钴尾矿中大部分有害元素的有效态含量及潜在活动性比铁矿尾矿更高。

3）矿区内20世纪80年代和当今水系沉积物有害元素特征研究表明，近20年来水系沉积物中有害元素含量均呈增加态势。对比80年代与当今两个时间点的有害元素含量，可知尾矿库和铁矿排土场等对水系沉积物中有害元素的改变存在一定时间的延迟。这种延迟也正是尾矿库地球化学演化过程的真实写照。

4）研究区内地表水在径流过程中与河床的岩石、土壤、水系沉积物等发生物理、化学、生物及吸附等作用，岩石、水系沉积物、土壤中某些元素（如铁、锰及重金属等）被水溶解进入水中，使水中元素含量增加。石碌河矿区段河水的铁、锰元素含量普遍偏高，尤其是与Fe1铁矿尾矿库及铜钴矿尾矿库（Cu-Co2）相连的支流更高。这与尾矿库淋滤水、复杂的区域水岩交换有关。研究区地下水中铁、锰元素含量总体偏高，在矿区尾矿库地段，由于受尾矿渗透的影响，尾矿中铁、锰金属元素和硫化物等组分经溶解进入地下水，使地下水中重金属元素含量剧增。

5）不同生长背景区小油菜对土壤中有害元素的吸收特性，均表现为根大于叶，叶大于茎，而且各部位对土壤的地球化学性质反应灵敏，小油菜和土壤有害元素含量具有正相关特征；土壤中某些元素如Cd，Pb，Zn，Hg等更易于被小油菜吸收。

（3）矿山开采、尾矿和矿山废石等，改变了矿区土壤、地表水和地下水中的有害元

素组成，降低了土壤和水的环境质量，且与区外土壤和水形成了鲜明的对比，最终影响到农作物的安全性。矿区土壤 As，Cd，Cu，Hg，Zn 等元素大多超过国家土壤环境质量 1 级标准，尾矿库、排土场下游土壤环境质量更差，有的元素超过 3 级标准。根据内梅罗指数，矿区石碌河尾矿库河段地表水属严重污染，排土场下游地表水属中度污染，明显不同于矿区外围地表水；尾矿库周围地下水属于严重污染。矿区尾矿库下游土壤中种植的小白菜受到污染，As，Cd，Hg，Pb 含量超标。矿区环境质量总体较差。矿区尾矿库尾矿、排土场废石是影响矿区环境质量的主要因素。

（4）对土壤的环境质量演化预测表明，研究区内因矿山开采和尾矿库等影响，矿区土壤环境质量呈总体下降趋势；石碌河整个河段河水，在今后 30 ~ 35 年内，其中 Mn，Fe 等元素和硫酸盐、硝酸盐等组分含量将超过生活饮用水卫生标准；矿区水系沉积物中有害元素含量也会持续增长。总之，矿区不同环境介质的环境质量将会下降的趋势进一步演化，随着铜钴矿的规模开采和冶炼的进行，矿区面临的环境压力将越来越大。

（5）为寻找尾矿治理的有效植物，开展了尾矿库区的自然植被调查。调查表明，尾矿库中自然生长的植物有 40 多种，其中狭叶香蒲在海南是首次发现；狭叶香蒲、水蓼、水竹、白茅、斑茅等是尾矿库中的优势植物，其中水蓼、水竹、狭叶香蒲对 Fe，Mn，Cu，Pb，Zn，As，Hg 等有害元素有较强的吸收能力和耐性;尾矿库区植物的种类、盖度、多样性与尾矿存放的时间及其N，P，K 等养分含量关系密切，尾矿存放时间越长，N，P，K 等养分含量越高，植物种类越多、盖度和多样性指数越高。

（6）开展了尾矿库区自然生长的优势植物水蓼、狭叶香蒲、水竹和海南优势热带作物对有害元素的吸收性和耐性栽培试验研究，取得了重要成果。

1）水蓼在治理尾矿 Cu，Pb，Zn，Mn 等元素中具有较强的能力：水蓼对 Mn 具有很高的吸收能力、富集能力和耐性，对 Mn 的转移系数、累积系数均大于 1，地上部分 Mn 的含量可高达 13 681.5 mg/kg,具备了对 Mn 作为超积累植物的特征；水蓼吸收 Mn 时，对 Fe、Cu，Zn 等有害金属很少会发生拮抗作用。

2）狭叶香蒲对 Cu，Pb，Zn 等有害金属元素具有较强的吸收能力和耐性，其对环境中 Cu，Pb，Zn 的最大耐性浓度分别为 2000 mg/kg，350 mg/kg，10 000 mg/kg，远远高于这些元素在尾矿中的含量。

3）剑麻对 Pb，Cd 等有害金属元素具有较强的耐性和富集能力，环境中 Pb，Cd 含量分别达到 15 900 mg/kg，1000 mg/kg 时，仍有较强的耐性；Pb，Cd 的最高含量，剑麻地上部分分别为 2220.26 mg/kg，2348.08 mg/kg，地下部分分别为 2544.78 mg/kg，16 620.52 mg/kg，地上部分和地下部分 Pb，Cd 的含量都很高；尽管 Pb，Cd 等有害元素在剑麻中转移系数小于 1，但剑麻的生物量大，对尾矿中 Pb、Cd 有较好的治理效果。剑麻的尾矿栽培模拟试验表明，H.11648 品种吸收有害元素能力强，并能使尾矿中有害元素有效态减少，是尾矿治理的较好的剑麻品种。

（7）为探讨尾矿化学方法治理的可能性，开展了模拟试验。尾矿的 EDTA 及盐酸淋洗模拟试验表明，在酸性或在有配合物环境中，尾矿中尤其是新尾矿中有害金属不稳定，易于从尾矿中迁出。尾矿化学治理模拟试验表明，石灰、有机肥和生物肥对老尾矿改良效果不明显，而对新尾矿具有一定的改良作用，0.1% 的石灰和 1% 的有机肥对新尾矿的改良效果最好。

（8）研究区主要的污染源是尾矿库尾矿和排土场废石，其治理以植物方法为主，化学方法相配合；治理的尾矿植物的选择应遵循"适者生存"的自然法则，要以尾矿库区自然生长的优势植物为主；污染源的治理要按区域采取不同的方案。研究成果创造性地提出了热带地区铁铜钴矿山环境治理的新方法。

1）尾矿库干燥区的治理。采用以种植剑麻为主，以适量石灰和有机肥化学治理为辅的联合协同方案。新尾矿库治理区石灰的使用量为0.1%，剑麻种植坑内有机肥的使用量为1%，剑麻的种植网度为3.6 m×1.2 m就可达到较好的治理效果：按国家二级土壤环境质量标准，旧尾矿库Cd的修复年限为2年，铜钴尾矿库Cd的修复年限为2年，新铁矿尾矿库Cd的修复年限为4年。尾矿库种植剑麻并进行加工，每公顷尾矿库可创年产值7.29万元，经济效益明显。

2）尾矿库废水沼泽区的治理。主要采用植物治理方案，废水区种植狭叶香蒲，废水区与干燥区过渡带种植水蓼和水竹，并允许其他生物自然生长，形成人工与自然生长的植物群落。狭叶香蒲和水竹吸收有害元素后不会通过食物链传递给人或其他生物，它们还有较高的经济价值，可用于编制器具和工艺品。

3）排土场的治理。一是要采取工程措施，防止发生滑坡和泥石流；二是要在植树复垦的基础上，适当套种剑麻进行治理。

本书的编撰主要由廖香俊完成，何玉生、吴丹、薛桂澄、杨安富等参与了部分章节的编写。

作者在研究和本书编写中得到了导师张本仁院士的精心指导，得到了中国地质大学教授张宏飞、鲍征宇、马振东、韩吟文、杜远生、钟增球、周汉文、胡圣虹、杨坤光、董勇、叶永昊、张哲等老师，刘荣博士以及中国地质大学研究生院、地球科学学院的其他领导和老师的指导和帮助。

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Preface

Resources and environment are one of the world's important issues of common concern. The reason why people are so concerned about is not only that the resources and the environment are the foundation of human being survival and development, but also that the development of industrial society had been heavily dependent on large-scale consumption of resources. During the industrial revolution of last 200 years, the industrialization build upon the consumption of non-renewable resource and economic growth developed on the exploitation of nature and the destruction of the ecological environment. These make the rapid deterioration of global environment, and rapid depletion of natural resources, and now the relationship between man and nature increasing tensions. Throughout the 20th century, human being had consumed 142 billion tons of oil, 265 billion tons of coal, 38 billion tons of iron, 760 million tons of aluminum, and 480 million tons of copper. Resource consumption and lacking is an urgent problem in the 21th century. Resource over-exploitation and irrational using have triggered a series of ecological and environmental problems, such as global climate change, water pollution, species extinction, and acid rain, desertification, etc.

Hainan's resources and environment are the advantages of economic and social development. Mineral resources in Hainan Province are rich and unique. Maintain reserves of mineral resources which are of the national top ten of mineral resources in Hainan province are quartz sand, ilmenite, zircon quarry, oil shale, gemstones, rich iron ore, etc, upto nine kinds. Moreover, within the jurisdiction of sea area, resources offshore oil, natural gas, and ilmenite, zircon, monazite sands have also greater potential.

In Hainan province, the ratio of rich ore deposits is higher, and mining conditions is better, and the proven natural gas fields are mostly high energy gas fields. The important minerals iron, quartz sand, gold and so on are also high. Most deposits have the characteristics of "accessible, shallow, and easy to mining," or that the mining conditions are relatively simple, suitable for open mining, and the smelting conditions are better too. Mineral resources have advantages, such as offshore oil, natural gas, and hydrates in the sea area, and rich iron ore, quartz sand, zircon, ilmenite ore, gold, natural mineral water, medical hot mineral water in the land. They are the dominant minerals in Hainan Province. Kaolin, oil shale and other mineral resources have also a comparative advantage. The environmental quality in Hainan is one of the best region in China. In Hainan island the forest coverage rate has reached 59.2% up to 2009; and the ambient air quality was generally in good status that basically maintained to the 1st level of national standard of China; over 80% of rivers, lakes and water quality were at or better than the 3rd level of national standard of surface water; 84.5% of the coastal sea waters meet the 1st and 2nd level of the national standards. In the early 90s of last century, one United Nations environmental expert, at an international environmental conference hold in Hainan, pointed out that Hainan was the few uncontaminated "pure land" of the world, and she was one of precious heritage of the nature to our human being, and she belonged to the world and belonged to all mankind.

Mineral resources and geological survey of ecological environment are the important tasks of geological work in Hainan. Although the mineral resources in Hainan are abundant, the geological work and the mineral resources exploration in Hainan are still low. Offshore oil, natural gas, hydrates and other resources have great potential, but the investigations are not enough yet. Hainan environmental quality is good, but with the development of construction, there had been many problems, such as desertification, coastal erosion, landslides, coast, debris flow and other geological disasters, pollutions of soil and water caused by the development of mining. These problems need to survey and research urgently by the geological scientists.

Shilu Iron is the largest rich iron ore mine in Asia, and has the longest mining exploitation history in Hainan. It had more than 70 years of mining history and generated a lot of waste. It started to large-scale mining copper and cobalt mines officially in 2007, and carried out copper smelting and processing, meanwhile the environmental pressure of mining is increasing. Combined with the Science Foundation of Hainan Province "Southwest of Hainan Mining Pollution and Governance", the cooperation project of Ministry of Land and Resources and the Hainan Provincial People's Government "Hainan Island Eco-geochemical Investigation" and Ph.D. thesis research topic, The author studied the Mining Environment Geochemistry and the environmental control at Shilu Iron. Guided by the geochemical theory, the book had an associated system which was consist of the rocks (ores), tailings, soils, waters, stream sediments, plants and human activities .An integrated study method was adopted in this study, it includes geochemical, ecological, field surveys, experimental analysis, planting test, simulating test and comprehensive methods. The pollution history, actuality and evolution tendency and the primary influential factors of the environment in this mining area were studied in this book. Mining area of environmental pollution control and chemical treatment plants were proposed.

Achieved the following main results:

(1) Geochemical background of this mining area was surveyed and studied based on the rock geochemical characteristic. The results show that the contents of toxic elements, such as As, Cd, Cu, Hg, Cr, Pb and Zn, in the intrusive rocks of this mining area are generally higher than their whole background level in Hainan intrusive rocks. These toxic elements, except for Pb, of the mesoproterozoic granite gneiss were higher in this mining area. The abundance of these toxic elements of the sedimental- metamorphic rocks in this area has similar parting properties. Moreover, Shilu Group, the host rocks of the iron-ore and Copper-Cobalt ore bodies contains the highest contents of As, Co, Cr, Cu, Mn, Ni, and Fe in this mining area. For the main bodies, the iron-ore and Copper-Cobalt ore, exploited in this mine, many elements except for iron are generally low in the iron-ore, and however, the contents of Hg, Ni and so on are very high in its host rocks. Contrarily, the contents of toxic elements, such as As, Cd, Hg, Ni, Pb and Zn in the Copper-Cobalt ore, are high with ore-forming elements Cu and Co. Therefore, the exploitations of both iron and Copper-Cobalt

ores are quite possibly to bring the environment pollution with ore–forming elements, such as Fe, Cu, Co and the accompanying elements, such as As, Cd, Hg, Ni, Pb, Zn and Mn, etc.

(2) Environment geochemistry study were also carried on several environmental media, such as soils, tailings, waters, stream sediments and plants, etc. and summarized the following results.

1) From the whole soils in Hainan, to the regional soils in Shilu region, to the local soils closely affected by the exploitation in the mining area, and to the upriver and the downriver soils of the tailings dam, the contents of the forementioned toxic elements are getting higher and higher. Especially, the abundances ratios (enrichment) of these toxic elements in the two latter soils are far higher than one. It indicates that the tailings are the possible source of these toxic elements polluted the downriver soils. According to the explains for the geochemical abnormality of the toxic element enrichment factors in the regional surface soils, the cause of the pollution was possibly farther deduced to the human action, i.e. the mine exploitation.

2) The contents of these toxic elements are quite high in the tailings and waste rocks for every period of tailing dam and dumping sites. The toxic element contents in the Cu–Co tailings are higher than that in the Fe tailings. Chromium is the most stable element in the tailings, and the organic combination is a quite usual occurrence form for these toxic elements in the tailings. The organic combinations of these toxic elements are higher in the surface layers than that in the down layers. The contents of the organic combinations and the potential activities of these toxic elements in the Cu–Co tailings are much higher than that in the Fe tailings.

3) From a comparison study on the toxic elemental characteristic of the present and the last century' s stream sediments in this mining area, it was found that the contents of the toxic elements in these stream sediments have an increasing tendency. Comparing the toxic elements contents of these two stages in this mining area, we found that for the stream sediments, there was a time delay on the alteration of the toxic elements by the tailings dam and the iron dumping sites. This delay is factually the geochemical evolution of the tailings dam.

4) During the surface water flowing along the river, it happen a series of physical, chemical and biological interactions and absorption with the rocks, soils and stream waters in the riverbed. By this way some toxic elements such as Fe, Mn and heavy metals were dissolved into the water, and their contents in river water increase. So the contents of Fe, Mn and other elements of the river water are general enriched in Shilu mining region, especially much higher in the distributaries of iron (Fe1) tailings dam and Copper–Cobalt (Cu–Co2) tailings dam. It is also related to the interchange process between the leach water from the iron tailings dam, sewage from the ironworks and the complex tectonic rocks. Affected by the infiltration of the tailings dam, the metal elements such as Fe, Mn and sulfides, etc. of the tailings were dissolved into the groundwater on the sections of the tailings dam in this mining area, therefore, the contents of heavy metal elements of the groundwater are rapidly increase as a whole in this mining area.

5) The absorption of the toxic elements in soils by Brassica Chinensis in different growing backgrounds shows that the adsorb ability decreases from roots to leaves and to stems. However, every part of the Brassica Chinensis is sensitive to the geochemical property of the soils. So the

toxic elements have positive relations between their contents in Brassica Chinensis and in the soils. Some metal elements in soil such as Cd, Pb, Zn, and Hg, etc. are liable to be absorbed by Brassica Chinensis.

(3) The toxic elemental compositions of the soils, surface water, and groundwater were changed by the exploitation, tailings and waste rocks in the mining area. Consequently, the environmental quality of the soils and waters was also deteriorated in the mining area, and was quite distinctive from the soils outside this mine. Finally this environment deterioration is getting a dangerous effect to the crops planting. Most of contents of As, Cd, Cu, Hg and Zn, etc. from the soils in this mining area are beyond the 1st level of the national soil standard. The environment quality was much worse for the downriver soils of the tailings dam and the refuse dumps, and some elements were especially beyond the 3rd level of the national soil standard. According to NMR' s index, in Shilu mining area, the surface water in the tailing dam reach of Shilu river is badly polluted; surface water of the downriver is secondarily polluted; and they are evidently different from the outside surface water; the groundwater around the tailing dams is also badly polluted. Brassica Chinensis planted in the downriver soils of the tailing dams were polluted, the contents of As, Cd, Hg and Pb in these Brassica Chinensis were beyond the national standard. Totally, the environment quality in this mining area is bad. The primary influential factors are the pollutions from the tailings in the tailing dams and waste rocks in the refuse dumps.

(4) The environmental quality evolution of the soil in the mining area was surveyed and evaluated. The result shows that the exploitation and tailing dams and so on have bad affected the environment in this mine, and the environmental quality has a worsen tendency in general. In the coming period of 30 to 35 years, the contents of Fe, Mn and other toxic elements and sulphate and nitrate compositions contained in the whole Shilu river will exceed the drinking water standard. The toxic element contents of stream water in this area will be continuously increasing. Anyway, the environmental qualities of different environmental media in this mining area will go along with a worsen evolution tendency. The environmental pressure is increasing with the industrial scale exploitation and smelting of Cupper–Cobalt in Shilu mining area.

(5) In order to find out some effective plants to treat the pollutions in the tailings, a survey on the natural vegetation was done in the area of tailings dams. We found that there were more than forty of natural plants growing about this tailings dams; and fortunately that, one of Typhaceae angustifolia was first found in Hainan province; the dominant plants are Typhaceae angustifolia , Polygonum hydropiper , Phragmites. Karka, Imperata cylindrica , Saccharum arundinaceum , etc. in this area of tailings dams. Polygonum hydropiper, Phragmites. Karka and Typhaceae angustifolia have strong absorbing capacity and tolerance to the toxic elements, such as Fe, Mn, Cu, Pb, Zn, As and Hg, etc. The plant species, plant coverage, and variety are closely correlated with the storage time of tailings, and the nutrient contents of Nitrogen, Phosphorus, and Potassium, etc. The longer the storage time of tailings, the higher the contents of these nutrients, and the more the plant species, coverage, and variety.

(6) A pilot study was done on the planting of the natural dominant plants, such as Polygonum

hydropiper, Typhaceae angustifolia , Phragmites. Karka are the tropic plants in Hainan. The planting study was focused on the absorption and tolerance of the toxic elements into these plants in the area of tailings dams. We have got the following important conclusions.

1) Polygonum hydropiper and Typha Orientalis have strong ability to decontaminate the toxic elements such as Cu, Pb, Zn, Mn, etc. from the tailings. Polygonum hydropiper has a very high capacity of absorption, enrichment, and tolerance to Manganese. Both transfer and cumulation coefficients of Mn in Polygonum hydropiper are higher than one. The contents of Mn in it's over ground parts can accumulate to 13 681.5 mg/kg, moreover, during the absorption of Mn, it has no antagonistic action; so it is totally the strongest super–accumulating plant for Mn absorption.

2) Typhaceae angustifolia has strong absorption and tolerance capacities to the toxic elements, such as Cu, Pb, Zn, etc. The max tolerant capacity to these toxic elements is 2000 mg/kg, 350 mg/kg and 10 000 mg/kg, respectively, which is far higher than that in the soil.

3) Agave Sisalana has strong tolerance and accumulation ability to the toxic elements such as Pb and Cd. It can stand up and tolerate high levels of these toxic elements, although the contents of Pb and Cd are as high as 15 900 mg/kg, 400 mg/kg, 4000 mg/kg, and 1000 mg/kg, respectively. The contents of these toxic elements in its over ground parts are respectively 2220.26 mg/kg, 321.87 mg/kg, 2702.6 mg/kg, and 2348.08 mg/kg, while the contents in its underground parts are respectively 2544.78 mg/kg, and 16 620.52 mg/kg. Both parts contain high contents of Pb and Cd. Although the transfer coefficients of these toxic elements in Agave Sisalana are less than one, its biomass is much large in this area, so it has an effective function to decontaminate the toxic elements of Pb and Cd. During the planting test of Agave Sisalana in the tailing dams, we found that one variety of Agave Sisalana, H.11648, has a stronger absorptive ability to these toxic elements, and can decrease their organic combinations, so it is a better variety to treat the tailings.

(7) To search out a possible chemical method for treating the tailings, simulating test was carried. The eluting of the tailings using EDTA, and hydrochloric acid shows that, in acid or complex condition, the toxic metal elements are unstable in the tailings, especially, in the fresh tailings. These toxic metal elements were easily to leach out from the tailings. The simulating results indicate that usage of lime, organic manure, and biological fertilizer is ineffective to improve the stale tailings, although it has effect to the fresh tailings to some extent. A mixture of lime of 0.1% and organic manure of 1% is possible the most effective to improve the fresh tailings.

(8) Main pollution sources in this mining area are from tailings filled in the tailing dams and from waste rocks in the refuse dumps. The important effective measure for the recondition of this mine is planting plants, and associated with chemical disposal method. The selection principle of plants for environmental recondition should follow the natural law, "the survival of the fittest" . The dominant plants naturally growing in this area are the primary and effective selection. The treating project for different pollution sources should be different for different sections in the mining area. An innovative project was developed in this study; and it is effective to the tropic environmental recondition of Fe–Cu–Co mine.

1) For the environmental recondition of dry sections in the tailings dams, a combined and

synergistic project should be effectively taken. Planting of Agave Sisalana is the primary measure, and the chemical treat, with lime and organic manure, is an accessorial measure. The proportion of lime used to treat the new tailing dams is 0.1%, and organic manure used to plant Agave Sisalana is 1%. The planting distance of 3.6m × 1.2m in girding is efficient enough to the environmental recondition. By the 2nd level of the national soil standard, the rehabilitating terms of Cd in the old tailings dams is 2 years, and the terms of Cd in the Cu–Co tailings dams are respectively 2 years, while the terms of Cd in the new tailings dams is 4 years. The planting and processing of Agave Sisalana in the tailings dams has notable economical benefit, it can get an annual production value of 72.9 thousands Yuan per hectare of tailings dam.

2) For the environmental recondition of the marshes with wastewater in the tailings dams, a primary project is planting plants. In the wastewater sections, Orientalis Presl should be planted; Polygonum hydropiper and Phragmites Karka should be planted in the intermediate zones, while let the other plants grow naturally; and then the phytobiocoenose was forming by the planting and naturally growing plants. The toxic elements absorbed into Typhaceae angustifolia and Phragmites Karka can't transfer to human and other bodies by food chain. These two of plants can be also used to make art ware and produce economic values.

3) For the environmental recondition of the refuse dump, an engineering measure should be first taken to prevent the landslide and mud–rock flow; and secondly, basing on the tree planting and re–cultivating, the interplant of Agave Sisalana should be a helpful measure.

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