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1∶500 万非洲地区遥感地质解译数据集

付长亮 [1]　杨清华 [1]　姜琦刚 [2]
（1. 中国国土资源航空物探遥感中心，北京 100083；
2. 吉林大学地球探测科学与技术学院，吉林 长春 130026）

摘要：该数据集以 Landsat−7 ETM^+ 卫星数据为主要数据源，在已有地质矿产资料分析研究的基础上，采用计算机技术和 GIS 技术相结合的方法，完成了非洲地区约 3020 万 km^2 面积的 1∶500 万遥感地质解译。提取了地层、火山岩、中酸性侵入岩、基性岩或超基性岩、线性构造和环形构造等与成矿有密切关系的地质要素，划分出 7 个重要成矿带。形成了包含非洲地区 Landsat−7 ETM^+ 遥感影像图，非洲地区 1∶500 万遥感地质解译图和非洲地区 1∶500 万重要成矿带划分图在内的数据集，卫星数据分辨率为 30 m，为在非洲地区开展基础地质研究和矿产勘查投资提供重要参考。

关键词：非洲；遥感地质；地质矿产；重要成矿带；1∶500 万
数据服务系统网址：http://dcc.cgs.gov.cn

1　引言

遥感技术作为一种高科技手段，具有视域宽广、信息丰富等特点。遥感图像可以直观、逼真地反映各类地质要素的映像特征及其展布规律，有效地从宏观上反映各级断裂构造，尤其对与成矿关系密切的大量线性和环形构造的反映特别突出，还可以识别不同的岩性地层，对矿化蚀变也有不同程度的光谱异常显示，能够为区域地质调查、矿产资源调查和评价提供有效的信息（荆林海等，2001；杨自安等，2004）。目前，国家启动的境外矿产资源勘查项目中，遥感技术已作为必备技术手段应用于工作的各个阶段，部分项目以遥感为主要技术手段开展了相关工作，已为十多个“走出去”企事业单位的找矿勘探部署及投资决策提供了有价值的信息，取得了显著效果，表明遥感技术是境外矿产勘查开发的重要技术手段之一（付长亮等，2015）。

非洲矿产资源丰富，集中了世界大陆 70% 以上的矿产。非洲的铂、锰、铬、钌、铱等矿藏蕴藏量占世界总储量的 80% 以上，磷酸盐、钯、黄金、钻石、锗、钴和钒等矿藏占一半以上，其中至少有 17 种矿产的蕴藏量位居世界第一（段焕春，2009）。并且与中国矿产资源有较强的互补性，是我国矿产资源勘查开发“走出去”战略的重要地区（宋明国，2004）。

第一作者简介：付长亮，男，1983 年生，高级工程师，主要从事遥感地质研究与应用工作；E−mail：fu_chliang@sina.com。
通讯作者简介：杨清华，男，1964 年生，教授级高级工程师，主要从事遥感技术研究与应用工作；E−mail：466064295@qq.com。

然而，非洲地区地质工作程度低、自然条件恶劣、野外实地调查难，限制了在该大陆的基础地质研究与矿产勘查投资。本次工作充分发挥遥感在境外地质调查中的技术优势（付长亮等，2015），对非洲地区（约 3020 万 km^2）开展了 1：500 万遥感地质解译，形成了由卫星遥感图像、遥感地质解译图和成矿带划分图 3 类数据组成的数据集，包含非洲地区 Landsat−7 ETM^+ 遥感影像图，非洲地区 1：500 万遥感地质解译图和非洲地区 1：500 万重要成矿带划分图。

非洲地区 1：500 万遥感地质解译数据集的基本信息简介见表 1。它包括数据集名称、数据论文作者、数据采集时间、地理区域、空间分辨率、数据量、数据格式、数据出版地址、基金项目、数据库（集）组成等。

表 1　数据库（集）元数据简表

条目	描述
数据库（集）名称	1：500 万非洲地区遥感地质解译数据集
数据作者	付长亮，中国国土资源航空物探遥感中心，fu_chliang@sina.com 杨清华，中国国土资源航空物探遥感中心，466064295@qq.com 姜琦刚，吉林大学地球探测科学与技术学院，jiangqigang@ qq.com
语种	中文
数据采集时间	卫星数据采集时间 2000 年，解译数据采集时间 2009—2010 年
地理区域	非洲
空间分辨率	卫星数据分辨率 30 m，解译数据比例尺 1：500 万
数据量	148 GB
数据格式	wt, wl, wp, msi, jpg
数据服务系统网址	http://dcc.cgs.gov.cn
基金项目	中国地质调查局地质调查工作项目，非洲与拉丁美洲重要成矿带遥感地质解译与战略选区研究（1212010913005）
数据库（集）组成	该数据集主要由卫星遥感图像、遥感地质解译图和成矿带划分图 3 类数据组成，分别为：非洲地区 Landsat7-ETM^+ 遥感影像图；非洲地区 1：500 万遥感地质解译图；非洲地区 1：500 万重要成矿带划分图

2　数据采集和处理方法

2.1　数据来源

本次工作以 Landsat−7 ETM^+(Enhanced Thematic Mapper Plus) 为主要数据源。ETM^+ 是 NASA（美国国家航空和宇宙航行局）于 1999 年 4 月 15 日发射的美国陆地卫星 Landsat−7 携带的对地观测传感器，是一台被动感应地表反射的太阳辐射和散发的热辐射的 8 波段多光谱扫描辐射计，覆盖了可见光—近红外（30 m 分辨率）、短波红外（30 m 分辨率）和热红外（60 m 分辨率）波段等多个波长范围，全色波段空间分辨率为 15 m。Landsat−7 ETM^+ 数据单景面积大、分辨率适中、波段设计合理且可以免费下载 (http://glcf.umd.edu/index.shtml)，是目前我国开展小比例尺基础地质调查和矿产资源勘查工作中使用最多的数据之一。

数据时相以 2000 年左右为主，并根据非洲气候和植被生长情况，尽可能选择 1—5 月份或 10—12 月份；数据的云层覆盖度尽量小于 5%；数据覆盖范围包括整个非洲大陆；

下载的数据总量达 55 GB。

2.2 数据处理

2.2.1 图像处理

1）几何校正：由于无法获取非洲地形图，采用 NASA Global Landsat ETM Mosaic 为参考底图进行遥感图像几何校正，图像配准精度误差不大于 1 个像素，完全能达到 1：500 万解译精度要求。

2）波段组合：主要选择 ETM^+7、4、2/1 波段进行彩色合成，不同地区受植被影响程度不同，可选择不同波段组合方式。重点地区彩色合成图像采用多波段图像与全色 8 波段融合，生成空间分辨率 15 m 的较高分辨率遥感图像。该组合优点在于含有短波红外、近红外及可见光波段信息，组合后色调近似真彩色，信息量丰富，层次感强。

3）图像镶嵌：将前期几何校正和波段组合处理后的多幅图像，按照统一的地理参考坐标，利用直方图匹配法和切割线等方法，使相邻遥感图像依次拼接，最终形成整个非洲地区 Landsat−7 ETM^+ 遥感影像图。

4）信息增强：为了突出图像中目标物信息，区分不同地物特征，扩大不同图像之间亮度值差别，使信息得到补偿，层次丰富，得到一幅影像特征明显的图像，以提高图像的解译及分析能力。主要采用局部反差增强、对数变换、拉伸变换、HIS 彩色空间变换法、均衡化和比值法等方法。

5）坐标参数：兰伯特等面积方位投影坐标系，WGS84 椭球参数，中心投影经度 16°E。

6）软件工具：MapGIS，ENVI，ERDAS。

2.2.2 解译方法

在建立遥感解译标志的基础上，以人机交互式解译方法为主，本着从“已知”到“未知”、先“易”后“难”的原则，主要采用直判法、对比法、邻比法及综合分析法等技术方法完成解译工作（方洪宾等，2010）。

2.3 数据结果

2.3.1 遥感影像图

将获取的 Landsat−7 ETM^+ 卫星数据，在遥感图像处理软件中进行波段组合、数据融合、数据镶嵌和投影变换等处理，最终利用 MapGIS 平台的图像处理模块，将 TIFF/IMG 格式的图像数据转换为 msi 格式，形成非洲地区 Landsat−7 ETM^+ 遥感影像图（图 1），空间分辨率为 30 m，为随后的遥感地质解译提供了影像底图。

2.3.2 遥感解译图

以非洲地区 Landsat−7 ETM^+ 遥感影像图为底图，结合收集的地质矿产资料，以遥感解译标志为基础，遵循规范的遥感解译方法，开展地质矿产信息解译和提取。根据植被和沙漠的分布情况，可解面积占非洲地区的 50% 左右。重点解译了储矿地层、含矿岩体和控矿构造等地质要素，形成非洲地区 1：500 万遥感地质解译图（图 2）。解译内容说明如下：

1）地层：图上用灰色表示，主要分布在北非、西非西部及东南部非洲。

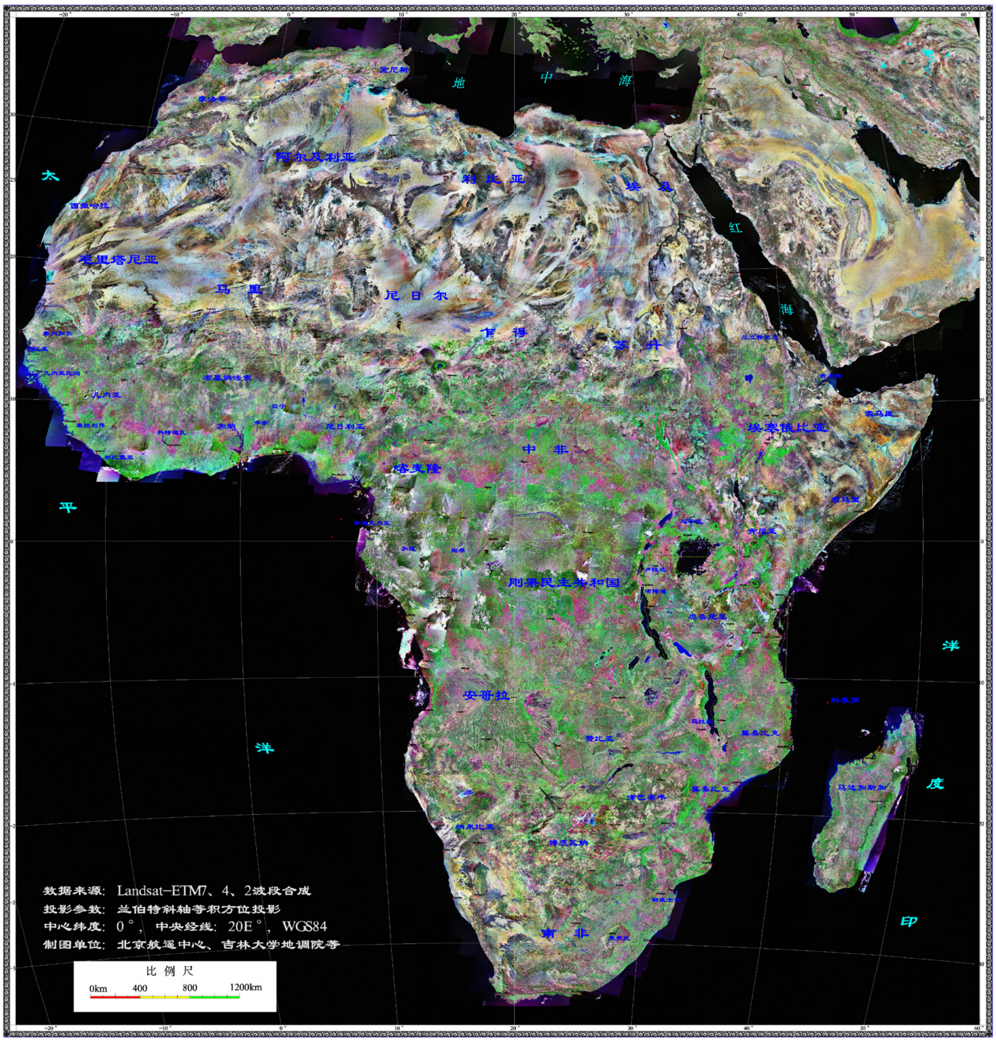

图 1　非洲地区 Landsat-7 ETM^{+} 遥感影像图

2）火山岩地层：图上用淡绿色表示，主要分布在非洲中部，尤其在东非大裂谷附近最为集中，在北非、西非及南非也有零星分布。

3）中酸性侵入岩：图上用肉红色表示，是解译面积最大的一类地质体，主要分布在非洲的东南部及北部地区，单个岩体的出露面积十分巨大。

4）基性岩或超基性岩：图上用紫色表示，由于基性岩的出露面积一般相对较小，因而较难识别，解译出的基性岩主要分布在北非，南非及东非也有少量出露。

5）线性构造：非洲线性构造十分发育，分为一级线性构造（红线）和二级线性构造两类。其中，一级线性构造是指延伸长、明显切割不同大地构造单元或作为不同大地构造单元界线的线性构造，主要呈北东、东西、及北西向展布，在北非、中非及南非均有发育。二级线性构造是指延伸短，仅在构造单元内部延伸的线性构造，以北东、南北向为主，少量为北西及北东向，主要分布在非洲的东南部和西北部，且集中分布在一级线性构造附近，而中部仅有少量东西向和南北向展布的线性构造。同时也识别出了东非大裂谷的具体位置及展布趋势。

6）环形构造：根据建立的环形构造解译标志，识别出了较多的环形构造，但图像比例尺较小，在非洲东南部和北部发现的许多环形构造或影像，由于规模较小未在图中显

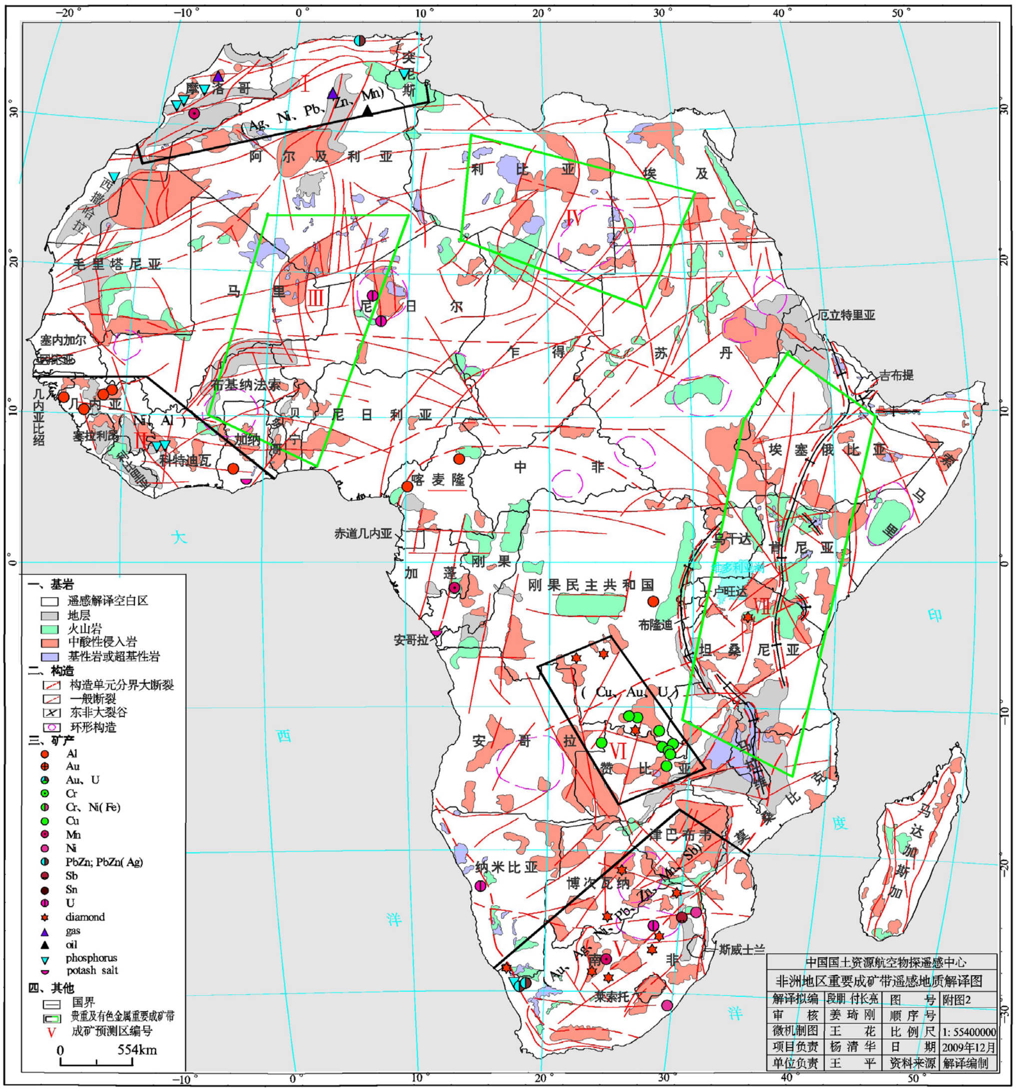

图 2　非洲地区 1∶500 万遥感地质解译及重要成矿带划分图

示，主要为火山口、火山锥、多期火山作用叠加形成的遗迹或圆形、椭圆形侵入体。图上较大的环形构造主要依据影像上出露的大范围的色调异常实心圆形或圆环进行判定，共识别出了 13 个，零星分布在非洲大陆上。

2.3.3　重要成矿带划分

遥感地质矿产综合解译结果表明，非洲地区的线性构造十分发育，在东南部和西北部地区最为集中，存在多处线性构造相对高密区和交点的高密区，且次级断裂往往斜交或平行地集中分布在一级断裂附近；环形构造虽在非洲大陆零星分布，但在东南部和西北部地区较为发育，且多与线性构造产生交切现象。火山岩、中酸性侵入岩、基性岩或超基性岩也多分布在非洲的东南部和西北部，而中部较少，与在这两区发育大量的线环构造相对应，表明东南部和西北部地区热液活动较强烈，大的线环构造为岩浆运移提供了通道，成矿潜力较大。同时，识别出的储矿地层也主要分布在东南部和西北部地区。

因而，笔者认为非洲东南部和西北部地区构造及成矿地层发育，热液活动强烈，在构造有利地段适合赋存矿产资源，可作为成矿带预测的重要区域。基于此，结合相关地

质、矿床资料，通过综合分析，在非洲东南部和西北部地区圈定出7处重要成矿带（图2，表2）。其中，在Ⅰ阿特拉斯成矿带、Ⅱ几内亚—加纳成矿带、Ⅴ卡拉哈里成矿带及Ⅵ赞比亚—刚果（金）成果带中已发现了大量大型超大型矿床。

重要成矿带划分依据：①存在已知的大型、超大型矿床；②大、小线性构造交错伴生，存在线性构造相对高密区和交点的高密区；③环形构造发育；④线环构造存在交切现象；⑤成矿地层发育；⑥成矿岩体发育。

表2 划分的非洲7处重要成矿带

序号	名称	简介	主要矿种	预测依据
Ⅰ	阿特拉斯成矿带	位于非洲的最北端，包括摩洛哥、突尼斯及阿尔及利亚北部区域，构造位置处于阿特拉斯褶皱带内	磷矿、重晶石、石油与天然气等	①②⑤⑥
Ⅱ	几内亚—加纳成矿带	位于西非的太平洋沿岸，主要包括几内亚、塞拉利昂、利比亚里、马里西南部、科特迪瓦及加纳南部，构造位置处于西非克拉通的西南部	铁、金、金刚石、铝土矿、石油与天然气等	①②⑤⑥
Ⅲ	马里—贝宁成矿带	位于西非的北部，包括马里大部分地区、布基纳法索、尼日尔西南部、加纳北部、多哥及贝宁，构造位置处于西非克拉通的北部	铀、锰、磷、金矿等	②③④⑤⑥
Ⅳ	利比亚—埃及成矿带	位于北非中部，主要包括利比亚、尼日尔东北部、乍得北部和埃及。构造位置处于西尼罗活动带上	铁、磷、石油与天然气	②③④⑥
Ⅴ	卡拉哈里成矿带	位于非洲南部，主要包括南非、博茨瓦纳东南部、津巴布韦和莫桑比克南部，处于卡拉哈里克拉通之上	铬铁、金、铂镍、铀、金刚石等	①②③④⑤⑥
Ⅵ	赞比亚—刚果（金）成矿带	位于中非与南部非洲的交汇部位，主要包括赞比亚和刚果（金）西南部，位于刚果克拉通上	铜、钴、金刚石、金、石油与天然气等	①②⑥
Ⅶ	东非成矿带	位于东非地区，主要包括埃塞俄比亚、乌干达、肯尼亚、坦桑尼亚、赞比亚东北部及马拉维，处于东非裂谷带一线，其南部处于坦桑尼亚克拉通上	金、金刚石、磷、钾碱、铌钽、煤等	②⑤⑥

3 数据质量控制与验证

由于遥感图像上的地质体或地物具有同物异谱和异物同谱的特征，造成解译结果存在不确定性，需要通过实地调查，解决室内遥感图像解译过程中发现的新问题，检查地质和矿产解译标志的准确性、可靠性和稳定性，以提高成果精度。然而，非洲地区面积巨大，无法对解译成果一一核查，并且在境外开展野外工作的难度大、成本高，因此，本次工作主要以实际收集的图件和报告等资料进行交叉验证，对部分地区配合使用SPOT5等高分辨率卫星数据进行解译验证，少量重点区开展实地野外调查验证。

3.1 野外调查验证

前往埃塞俄比亚开展了为期20天的野外调查验证工作，调查了埃塞俄比亚西部和南部主要成矿带，野外考察路线1250 km左右，观测点34个、有地质意义照片240张。野外调查期间，收集第一手资料，采集适量样品。通过野外调查，对工作区主要岩石类

型、构造特征及成矿类型有了进一步认识，特别是校正了遥感解译标志与实际地质体对应关系，有效地提高了成果的解译质量。

3.2 高分辨率影像验证

利用空间分辨率为 2.5 m 的 SPOT5 卫星数据，通过图像处理技术，对部分地区重点区进行大比例尺的解译验证，进一步修正地质体类型不明确和界线模糊不清等问题，可有效提高解译质量，加快工作进度。

3.3 已有地质矿产资料交叉验证

广泛收集非洲地区的地质和矿产等有关资料，充分阅读和消化吸收，在对非洲地区地质矿产情况有一定认识的基础上，再开展遥感地质解译工作。在遥感解译过程中最大限度地利用所收集的资料成果，对比研究，去粗取精，去伪存真，通过已有地质矿产资料与遥感影像特征的交叉验证，最大限度地提高解译成果质量。

4 结论

本数据集由卫星遥感图像、遥感地质解译图和成矿带划分图 3 类数据组成，包含非洲地区 Landsat−7 ETM^+ 遥感影像图，非洲地区 1∶500 万遥感地质解译图和非洲地区 1∶500 万重要成矿带划分图。制作了一张完整的非洲地区卫星遥感影像底图，解译提取了地层、火山岩、中酸性侵入岩、基性岩或超基性岩、线性构造和环形构造等与成矿有密切关系的地质要素，在此基础上，结合已有地质矿产资料，在非洲地区划分了 7 个重要成矿带。

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参考文献

段焕春，林晓辉．2009. 非洲地质经济：纪念天津华北地质勘查局“走出去”10 周年论文集 [M]. 北京：地质出版社 .

方洪宾，赵福岳，黄洁，张瑞江，张振德，杨清华．2010. 1∶250000 遥感地质解译技术指南 [M]. 北京：地质出版社 .

付长亮，杨清华，姜琦刚，王梦飞，蒋校．2015. 遥感技术在境外地质调查中的应用——以津巴布韦大岩墙为例 [J]. 国土资源遥感，27(4): 85−92.

荆林海，沈远超，蔺启忠，曾庆栋，邹为雷．2001. 胶莱盆地北缘遥感信息提取及解译分析 [J]. 地质与勘探，37(1): 91−94.

宋明国．2004．非洲矿业投资指南 [M]．北京：地质出版社 .

杨自安，徐国端，邹林，张普斌 . 2004. 遥感与多元地学信息综合找矿定位预测 [J]．矿产与地质，18(4): 343−345.

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1:5000000 Remote Sensing Geological Interpretation Datasets in African Regions

FU Changliang[1], YANG Qinghua[1], JIANG Qigang[2]

(1. China Aero Geophysical Survey & Remote Sensing Center for Land & Resources, Beijing 100083*, China; 2. College of Geo-exploration Science and Technology, Jilin University, Changchun* 130026*, Jilin, China)*

Abstract: Based on the analysis results of existing geological and mineral data and using computer technology and GIS technology, we completed a 1:5000000 remote sensing geological interpretation in Africa over an area of 30.2 million km^2. The dataset used in this work takes Landsat−7 ETM$^+$ data as its main resource. The geological elements, such as strata, volcanic rocks, intermediate acid intrusive rocks, basic or ultrabasic rocks, linear structures and ring structures which are closely related to mineralization were extracted, and seven important metallogenic belts were recognized. The dataset with the Landsat−7 ETM$^+$ remote sensing image in Africa, the 1:5000000 remote sensing geological interpretation map in Africa and the 1:5000000 division map of important metallogenic belts in Africa were generated, the satellite data resolution is 30m, providing an important reference to carry out basic geological research and mineral exploration investment in Africa.

Keywords: Africa; remote sensing geology; geology and mineral resources; metallogenic belt; 1:5000000
Data service system URL: http://dcc.cgs.gov.cn

1 Introduction

High-tech remote sensing technology allows a broad overview with abundant content. The remote sensing images can visually and vividly reflect the characteristics and distribution of various geological features. Faults can be reflected effectively at macro levels, and linear and circular structures that have close relationships with mineralization can be reflected especially prominently. Moreover, different lithologies can be identified by it, and the mineralizing alteration shows different degrees of abnormal spectral displays, which can provide effective information for the investigation and evaluation of mineral resources and regional geological surveys (Jin Linhai et al., 2001; Yang Zian et al., 2004). Currently, remote sensing technology has been applied as a necessary tool at various stages of work, among the overseas mineral resources exploration projects that the country has launched. Some of the projects have carried out related work using remote sensing technology as the main means and the technology has provided valuable information on

About the first author: FU Changliang, male, born in 1983, senior engineer, mainly engages in research and application of remote sensing geology; Email: fu_chliang@sina.com.
The corresponding author:YANG Qinghua, male, born in 1964, professor, mainly engages in research and application of remote sensing technology; Email: 466064295@qq.com.

decision making about investment and deployment in geological prospecting for more than 10 “Going Out” enterprises. This has achieved remarkable results and has shown that remote sensing technology is one of the most important techniques in overseas exploration and exploitation of mineral resources (Fu Changliang et al., 2015).

There are abundant mineral resources in Africa, with perhaps over 70% of the world’s mineral resources. The manganese, chromium, platinum, ruthenium, iridium and other mineral reserves in Africa account for more than 80% of the total global reserves. Furthermore, the phosphate, palladium, gold, diamond, germanium, cobalt and vanadium deposits account for more than half of total reserves in the world. Among them, there are at least 17 kinds of mineral reserves ranking as the first in the world (Duan Huanchun and Ling Xiaohui, 2009). It has a strong complementarity with China’s mineral resources, and should be an important area for China’s mineral resource exploration and development as a “Going Out” strategy (Song Mingguo, 2004).

However, the low level of geological research in Africa and the poor natural conditions as well as the difficulties in field investigations have limited investment in basic geological research and mineral exploration in this continent. This overseas geological survey allows full play to the technological advantage of remote sensing (Fu Changliang et al., 2015). The remote sensing geological interpretation was carried out at a scale of 1:5000000 over an area of Africa of ca. 30.2 million km^2, and formed a dataset consisting of three kinds of data: satellite remote sensing images, a remote sensing geological interpretation map and a metallogenic belt map, containing Landsat−7 ETM$^+$ remote sensing image, 1:5000000 remote sensing geological interpretation map of Africa and 1:5000000 important metallogenic belt map of Africa.

The basic information about the 1:5000000 remote sensing geological interpretation data in Africa is shown in Table 1.

2 Data acquisition and processing method

2.1 Data Sources

This research is based on Landsat−7 ETM$^+$ (Enhanced Thematic Mapper Plus) as the main data source. ETM$^+$ is an earth observation sensor carried by NASA (National Aeronautics and Space Administration), launched by Landsat−7 on April 15, 1999. It is an 8-band-multispectral scanning radiometer that passively induced solar radiation from surface reflection and emission of thermal radiation, covering a multi-wavelength range from the visible light to near infrared (resolution 30 m), shortwave infrared (resolution 30 m) and thermal infrared (resolution 60 m) wave bands, and the panchromatic spatial resolution is 15 m. Landsat−7 ETM$^+$ data are among the most widely used data for small-scale geological surveys and mineral exploration in China because of its large single scene, moderate resolution, reasonable band design, and can also be downloaded for free (http://glcf.umd.edu/index.shtml).

Data phase is primarily around the year 2000. According to the climate and vegetation growth in Africa, January to May or October to December were chosen as far as possible; the coverage percentage of data cloud is less than 5% as far as possible; the data coverage area includes the entire African continent; the amount of downloaded data reached 55 GB.

Table 1 Metadata table of dataset(s)

Items	Description
Database (dataset) name	1∶5000000 Remote Sensing Geological Interpretation Datasets in African Regions
Database authors	Fu Changliang, China Aero Geophysical Survey & Remote Sensing Center for Land & Resources, fu_chliang@sina.com YangQinghua, China Aero Geophysical Survey & Remote Sensing Center for Land & Resources, fu_chliang@sina.com JiangQigang, College of Geo-exploration Science and Technology, Jilin University, fu_chliang@sina.com
Language	Chinese
Data acquisition time	Satellite data acquisition in 2000, interpretation data collection from 2009 to 2010
Geographic area	Africa
Spatial resolution	Satellite data resolution is 30 m, data interpretation scale is 1∶5000000
Data size	148 GB
Data format	wt, wl, wp, msi, jpg
Data publishing URL	http://dcc.cgs.gov.cn
Foundation items	Geological Survey Project of China Geological Survey, remote sensing geological interpretation and strategic constituency study of important metallogenic belts in Africa and Latin America (1212010913005)
Database (dataset) composition	Three kinds of data: satellite remote sensing images, remote sensing geological interpretation map and metallogenic belt map, containing Landsat−7 ETM^+ remote sensing image, 1∶5000000 remote sensing geological interpretation map of Africa and 1∶5000000 important metallogenic belt map of Africa.

2.2 Data Processing

2.2.1 Image Processing

(1) Geometric correction: Due to a lack of access to African topographic maps, geometric correction of remote sensing images was finished using NASA Global Landsat ETM Mosaic as a reference map, with an image registration error of less than 1 pixel, which can easily reach the requirements for 1∶5000000 interpretation accuracy.

(2) Band combination: The color combinations mainly chosen were the ETM^+7, 4 and 2/1 bands. Different areas with different vegetation affect the results, so different band combinations can be selected. The color combined images in the key areas are fused with multi-band images and panchromatic 8 bands to generate high-resolution remote sensing images with spatial resolution of 15 m. This combination has the advantages of containing information of short wave infrared, near infrared and visible light bands, and the combined tone is similar to true color, with abundant information and strong sense of hierarchy.

(3) Image mosaic: According to unified geographical reference coordinates, using the histogram matching method and line cutting method, adjacent remote sensing images that have been processed through early geometric correction and band combination can be spliced together and ultimately this forms the Landsat−7 ETM^+ remote sensing image of Africa.

(4) Information enhancement: In order to highlight the object information in the image to distinguish surface features between different items and expand the brightness of different image differences and enable the information to be compensated as a multileveled, characteristic image. The local contrast enhancement, logarithmic transformation, stretching transformation, HIS color space transformation, equalization and ratio method are mainly used to improve the capability of image interpretation and analysis.

(5) Coordinate parameter: Lambert equal azimuthal projection coordinate system, WGS84 ellipsoid parameter, central projection longitude 16°E.

(6) Software: MapGIS, ENVI, ERDAS.

2.2.2 Interpretation method

Based on the man-machine interactive interpretation method with the principle from "known" to "unknown", "easy" after "difficult", in the establishment of the remote sensing interpretation signs, the interpretation has been completed mainly using the direct judgment method and the comparative method, adjacent ratio method and comprehensive analysis method. (Fang Hongbin et al., 2010).

2.3 Data Result

2.3.1 Remote sensing image map

The Africa Landsat−7 ETM$^+$ remote sensing image with spatial resolution 30 m (Fig. 1)

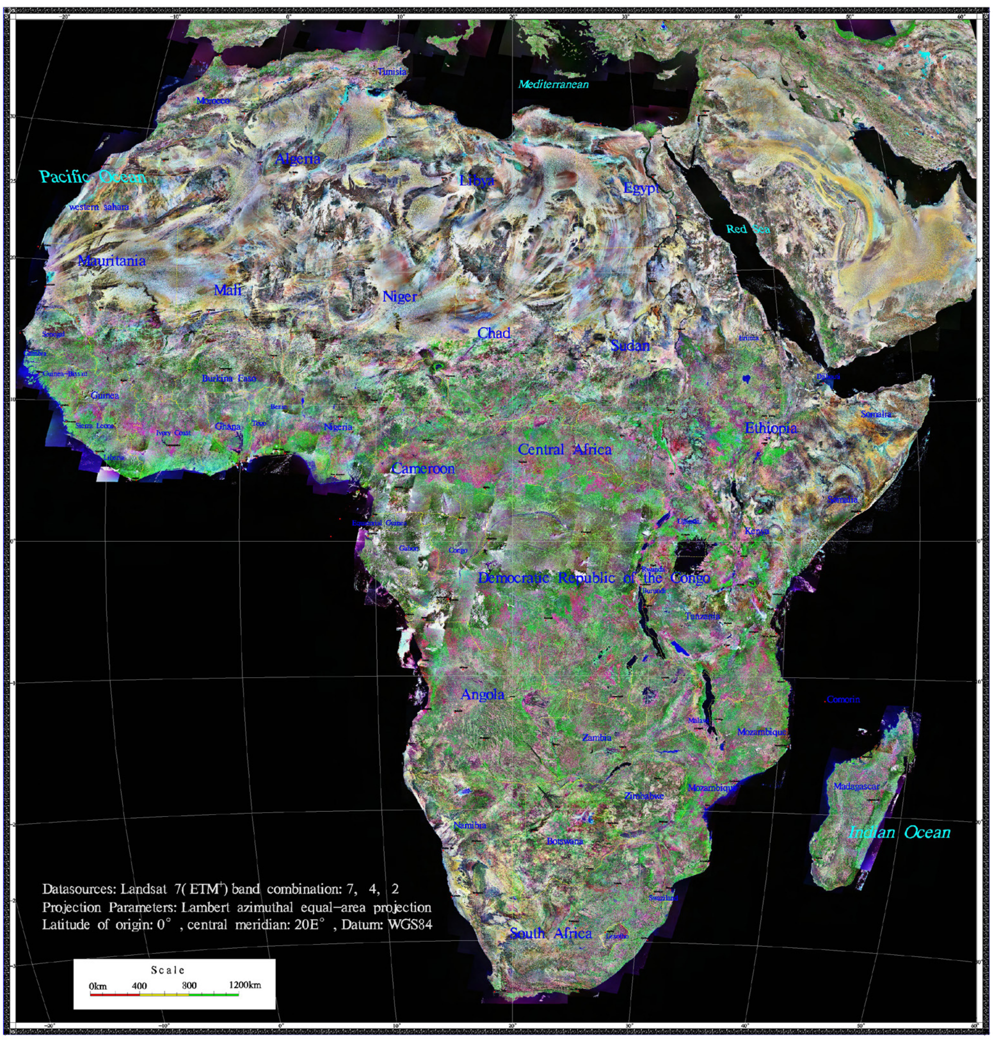

Fig.1 The remote sensing image map of Landsat−7 ETM+ in Africa

was formed by processing the acquired Landsat−7 ETM$^+$ satellite data through band combination, data fusion, data mosaic and projection transform by remote sensing image processing software. It was finally processed by the image processing module of the MapGIS platform to transform the image data from TIFF/IMG format into MSI format, which provides the image base map for subsequent remote sensing geological interpretation.

2.3.2 Remote sensing interpretation map

The geological and mineral information interpretation and extraction has been carried out using Landsat−7 ETM$^+$ remote sensing image map in Africa as a base map, combining the collection of geological data, based on the remote sensing interpretation signs, following the method of remote sensing interpretation standard. According to the distribution of vegetation and desert, the resolvable area accounts for about 50% of the African region. The geological elements such as ore-hosting strata, ore-bearing rocks and ore-controlling structures are interpreted in detail to form the 1:5000000 remote sensing geological interpretation map in Africa (Fig. 2). The interpretation is as follows:

(1) Stratum: This is represented by gray on the graph, and distributed mainly in North Africa, West Africa and southeast Africa.

(2) Volcanic strata: These are represented by pale green on the graph, and distributed mainly in Central Africa, particularly gathered in the East African Rift Valley. They are also scattered more disparately in North Africa, West Africa and southern Africa.

(3) Intermediate-acid intrusive rock: This is represented by red on the graph, has the largest geological area in the interpretation area, and is mainly distributed in the southeastern and northern parts of Africa, and the exposed area of individual rock mass is very large.

(4) Mafic or ultrabasic rocks: This is represented by purple on the graph, and is difficult to identify because the exposed area of the basic rock is generally relatively small. The interpreted basic rock is mainly distributed in North Africa, and scattered in southern Africa and East Africa.

(5) Linear structures: There are abundant linear structures in Africa, which can be divided into two types: the first-order linear structure (red line) and the second-order linear structure. First-order linear structure are those linear structures with extended prolongation and clearly cut the different tectonic units, or as a boundaries of different geotectonic units, and mainly occur in N—E, E—W, and N—W directions. Second-order linear structures are linear structures with short extensions and found wholly within a tectonic unit. They occur mainly in N—E and N—S orientations but a few of them are in N—E and N—W directions. They are mainly distributed in the southeast and northwest of Africa, and are concentrated in the vicinity of first-order linear structures. There are only a few linear structures in the E—W and N—S directions. The specific location of the East African Rift Valley and its distribution trend has been also demarcated.

(6) Circular structures: According to the established circular structures interpreting signs, some of circular structures have been identified, but due to the small scale images, some small-size circular structures or images found in southeastern and northern Africa are not shown in the graph. These are mainly the volcano vents, volcanic cones, or the remains of several stages of superimposition of volcanoes and round intrusive bodies. The

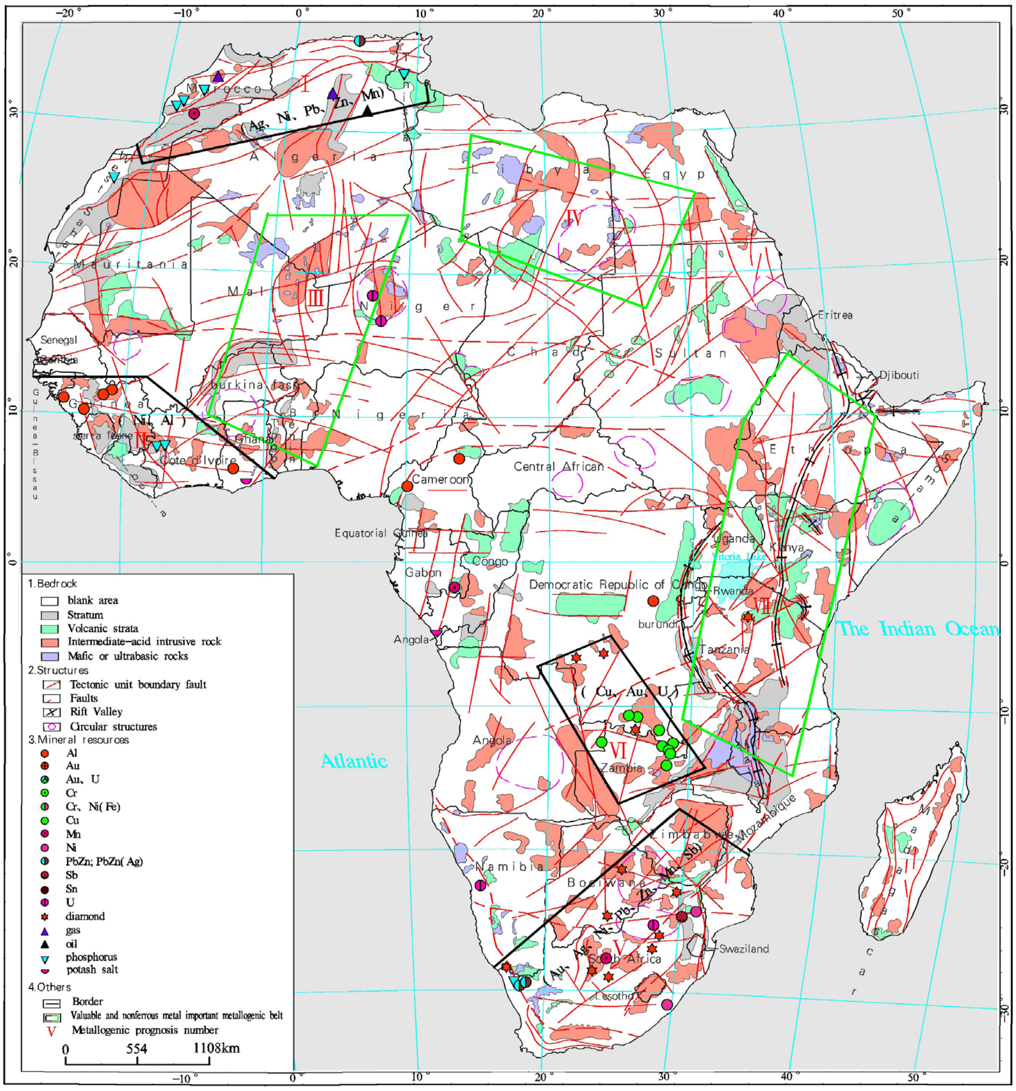

Fig.2 The remote sensing geological interpretation and important metallogenic belt in Africa (1: 5000000)

recognition of larger circular structures on the map is based on the large range of solid circles or rings that appear on the image with tonal anomalies. In total there are 13 circular structures identified, scattered widely over the African continent.

2.3.3 Division of important metallogenic belts

Remote sensing of geology and mineral resources comprehensive interpretation results show that linear structures in Africa are well developed, with most concentrated in the southeast and northwest areas in high density and with intersection of multiple linear structures. Secondary faults often obliquely or parallelly concentrate in the vicinity of primary fractures. Although circular structures are scattered throughout the mainland of Africa, they are better developed in the southeast and northwest areas, and showed cross cutting with linear structures. Volcanic rocks, intermediate-acid intrusive rocks, and mafic or ultrabasic rocks are mainly located in the southeast and northwest Africa, with a few in Central Africa, which corresponds to well-developed linear-circular structures in these two areas. This indicates that hydrothermal activity is intense in the southeast and northwest areas, and large linear-circular structures provide a channel for magma migration with great metallogenic potential. At the same time, ore-bearing strata that are mainly distributed in the southeastern and northwestern regions have been identified.

Therefore, it is inferred that the tectonic and metallogenic strata in the southeastern and northwestern parts of Africa are well developed and hydrothermal activity is strong, so the mineral resources should be more concentrated in tectonic areas, which should be considered as an important area for the prediction of metallogenic belts. Based on this, combined with related geological and mineral data, through comprehensive analysis, seven important metallogenic belts are delineated in the southeast and northwest of Africa (Fig. 2, Table 2). Among them, a huge number of large and ultra-large deposits have been found in the Atlas, Guinea−Ghana, Kalahari and Zambia−Congo (Au) metallogenic belts.

An important metallogenic belt division is based on: ① the existence of known large and ultra-large deposits; ② areas with high density and intersection of multiple linear structures, associated with staggered large and small linear structures; ③ well developed circular structures; ④ the linear-circular structures cross-cut one another; ⑤ well developed metallogenic strata; ⑥ well developed metallogenic rock.

Table 2 The seven important metallogenic belts in Africa

Num.	Name	Brief Introduction	Main Minerals	Prediction basis
Ⅰ	Atlas metallogenic belt	Located in northernmost Africa, including Morocco, Tunisia and Northern Algeria area, structure is located in the Atlas fold belt.	Phosphorite, barite, petroleum and natural gas, etc.	①②⑤⑥
Ⅱ	Guinea–Ghana metallogenic belt	The Atlantic coast in West Africa, including Guinea, Sierra Leone, Libya, Mali and the Ivory Coast southwest, southern Ghana, structure is located in the southwest of the West African craton.	Iron, gold, diamonds, bauxite, oil and gas, etc.	①②⑤⑥
Ⅲ	Mali–Benin metallogenic belt	Located in the northern part of West Africa, including most of Mali, Burkina Faso, southwest Niger, northern Ghana, Togo and Benin, the structure is located in the North West African craton.	Uranium, manganese, phosphorus, gold, etc.	②③④⑤⑥
Ⅳ	Libya–Egypt metallogenic belt	Located in Central Africa, mainly including Libya, northeastern Niger, northern Chad and Egypt. The structure is located in the West Nile active zone.	Iron, phosphorus, oil and gas	②③④⑥
Ⅴ	Kalahari metallogenic belt	Located in southern Africa, mainly in South Africa, southeastern Botswana, Zimbabwe and southern Mozambique, on Cara and Harry Craton	Chromium, iron, gold, platinum, nickel, uranium, diamond, etc.	①②③④⑤⑥
Ⅵ	Zambia–Congo (Au) metallogenic belt	The junction of Central Africa and southern Africa, comprising the southwestern part of Zambia and Congo (gold), located on the Congo craton.	Copper, cobalt, diamond, gold, petroleum and natural gas, etc.	①②⑥
Ⅶ	East African metallogenic belt	Located in the East African region, mainly including Ethiopia, Uganda, Kenya, Tanzania, northeastern Zambia and Malawi, located in the East African Rift Valley line, the south of it is in the Tanzania craton.	Gold, diamond, phosphorus, potash, niobium and tantalum, coal, etc.	②⑤⑥

3 Data quality control and verification

There is uncertainty in the interpretation of results geological bodies or objects on the remote sensing image may have different or the same spectra. Therefore on-the-spot investigation is required to solve new problems found through interpretation of remote sensing images in the process of inspection, checking the accuracy, reliability and stability of the geology and mineral interpretation signs to improve the precision of results. However, it is difficult to verify the interpretion of results due to the huge area of Africa and the difficulty and high cost of carrying out field work. Therefore, cross validation through actual collected maps and reports was mainly used in this work and interpretation and verification with SPOT5 high resolution satellite data was used in some areas, with field investigation and verification having been carried out in a small amount of key areas.

3.1 Field investigation and verification

Field investigation and verification has been carried out in Ethiopia over a period of 20 days, investigating the main metallogenic belt of western and southern Ethiopia over 1,250 km route, incorporating 34 observation points, with 240 photographs of features with geological significance. During the field investigation, first-hand data and appropriate samples were collected. Through field investigation, there is a further understanding of the main rock types, tectonic features and metallogenic types, especially the correction of the corresponding relationship between remote sensing interpretation signs and the actual geological body, which effectively improved the quality of the interpretation results.

3.2 High resolution image verification

Large scale interpretation and verification has been carried out in some key areas, using the SPOT5 satellite data with 2.5 m spatial resolution, through image processing technology, which has further modified the unclear geological body type and blurred boundaries. The quality of interpretation has been effectively improved through this method.

3.3 Cross validation of existing geological and mineral data

Remote sensing geological interpretation should be carried out based on a certain understanding of the geology and mineral resources in the African region with extensive collection, fully read and absorb relevant information about geology and mineral resources in the African area. Maximizing the use of the collected data in the remote sensing process with comparative study, discarding the dross and selecting the essential, discarding the false and retaining the true, through cross validation of existing geological data and the characteristics of the remote sensing image, which could highly improve the interpretation quality.

4 Conclusion

The dataset consists of three kinds of data: satellite remote sensing images, a remote sensing geological interpretation map and a metallogenic belt map, containing Landsat–7 ETM^+ remote sensing images, a 1:5000000 remote sensing geological interpretation map of Africa and a 1:5000000 important metallogenic belt map of Africa. A complete satellite remote sensing geological image map has been finished, extracting the geological elements of strata, volcanics, volcanic intrusive rock, mafic or ultramafic rocks, and linear and circular structures, which have a close relationship with mineralization interpretation. On this basis, seven important metallogenic belts have been distinguished in Africa, combined with the existing geological and mineral data.

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References

Duan Huanchun, Lin Xiaohui. 2009. African Geological Economy: Commemorate the 10th Anniversary Collection of "Going out" of Tianjin North China Geological Prospecting Bureau [M]. Beijing: Geological Publishing House.

Fang Hongbin, Zhao Fuyue, Huang Jie, Zhang Ruijiang, Zhang Zhende, Yang Qinghua. 2010. Technical Guide for Remote Sensing Geological Interpretation of 1:250000[M]. Beijing: Geological Publishing House.

Fu changliang, Yang Qinghua, Jiang Qigang, Wang Mengfei, Jiang Xiao. 2015 .Application of remote sensing technique to geological survey abroad: A case study of Great Dyke,Zimbabwe [J]. Remote Sensing for Land and Resources,27(4) :85−92.

Jing Linhai, Shen Yuanchao, 2001. Lin Qizhong, Zeng Qingdong, Zou Weilei. Extraction and interperation for the northern marigin of the jiaolai basin with remote sensing [J]. Geology and Prospecting, 37(1):91−94.

Song Mingguo. 2004. African Mining Investment Guide [M]. Beijing:Geological Publishing House.

Yang Zian, Xu Guoduan, Zou Lin, Zhang Pubin. 2004. Prospecting prediction with remote sensing and integrative geochemical information [J]. Mineral Resources and Geology, 187(104):343−345.