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中南半岛和西太平洋巨型成矿带Cu、Au矿化构造环境与成矿规律对比研究数据集

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摘要：“中南半岛和西太平洋巨型成矿带铜金矿化构造环境与成矿规律对比研究”以中南半岛与西太平洋巨型成矿带为研究区域，以铜、金为主要研究矿种，在前期1∶150万东南亚中南半岛和西太平洋巨型成矿带地质矿产图件编制的基础上，充分利用国际合作，系统开展资料收集，通过对老挝、泰国、缅甸、巴布亚新几内亚等国的研究区典型矿床成矿环境、控矿因素与成矿规律的研究，结合ETM+、Hyperion、ASTER多源遥感解译，深化了成果认知并出版了中英文图件；重点剖析了老挝Cu、Au矿床，在老挝阿文矿区开展了找矿示范和钻探验证并取得了很好的找矿效果；利用MapGIS、ArcGIS技术平台，编制成矿区带成矿规律图，建立不同矿种定量评价模型和东南亚重要成矿区带金铜矿床空间数据库；利用数学建模方法开展研究区的资源潜力评价，圈定老挝、缅甸、泰国、巴布亚新几内亚等研究区不同矿种成矿远景区。该数据集不仅是对已经取得的矿产资源区划和资源潜力评价工作的整理和总结，也为科学地引导国家地质“境外”找矿（“一带一路”倡议）部署工作提供理论基础。

关键词：铜金矿床；构造环境；成矿规律；中南半岛和西太平洋巨型成矿带

数据服务系统网址：http://dcc.cgs.gov.cn

1 引言

中国正在组织实施“一带一路”国家倡议，同时与“一带一路”沿线国家一道积极规划六大经济走廊建设。中国—中南半岛经济走廊是六大走廊之一，泛亚铁路网中国—老挝，中国—泰国段皆于近期宣布相继开工，这将大大加强中国与这些国家的经济贸易往来。东南亚中南半岛和西太平洋巨型成矿带地质矿产研究成果，对推进该经济走廊的矿业勘查开发具有重要意义。

本项目系统展开了老挝、泰国、缅甸、巴布亚新几内亚等国的研究区典型矿床成矿环境、控矿因素与成矿规律的研究，建立了不同矿种定量评价模型和东南亚重要成矿区

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带铜金矿床空间数据库，元数据情况见表 1。利用数学建模方法开展研究区的资源潜力评价，圈定老挝、缅甸、泰国、巴布亚新几内亚等国的研究区不同矿种成矿远景区。

表 1　数据库（集）元数据简表

条目	描述
数据库（集）名称	中南半岛和西太平洋巨型成矿带铜金矿化构造环境与成矿规律数据库
数据库（集）作者	王功文，中国地质大学（北京） 陈永清，中国地质大学（北京） 黄静宁，中国地质大学（北京） 刘胜前，中国地质大学（北京） 吕秀美，中国地质大学 (北京）
数据时间范围	2012—2015 年
地理区域	缅甸，老挝，泰国，巴布亚新几内亚
数据格式	矢量，栅格，表格，文本，gdb 等
数据量	142 GB
数据服务系统网址	http://dcc.cgs.gov.cn
基金项目	中国地质调查局“ 中国大陆周边重要成矿带成矿地质条件对比与资源潜力评价 ”，全球重要成矿带成果集成与综合研究（12120114093001、1212011220912）资助
语种	中文
数据库（集）组成	矢量数据，栅格数据，扫描图件，文档数据，表格数据，工程及其他

2　研究区矿产概况

研究表明，东南亚—西太平洋巨型成矿带 Au-Cu 矿床主要形成于中—晚新生代（25 ~ 1 Ma）岩浆弧，早古生代、中生代具有少量矿床产出（表 2）（卢映祥等，2009）。中南半岛五国已发现矿产 100 余种，具有确切地点和名称的贵金属、有色金属、黑色金属和盐类矿产的矿产地约 720 处（图 1）。其中：特大型和大型矿床 75 处；中小型矿床 356 处（陈永清，2013）。预测储量：钾盐 300 ~ 500 亿 t、铜矿 3 000 万 t 以上、铬铁矿 8 ~ 10 亿 t、铂族金属 100 t 以上、镍矿 150 ~ 200 万 t、铝土矿大于 1 亿 t。近年来，在泰国、缅甸和老挝相继发现普隆（Phu Lon），蒙育瓦（Monywa）（Mitchell A H G，2004）以及塞本（Sepon）（Loader S. E. 1999）和富开（Phu Kham）（Agematsu S，2006）等一系列与中酸性岩浆活动相关的矿产地。矿床类型涵盖斑岩型、矽卡岩型、高—低硫化型、VMS 型以及以沉积岩为容矿岩的浸染型矿床。

根据资料统计，研究区已开采的资源加上现已探明的资源：Au: 15 000 t，Cu: 115 Mt。主要 Cu、Au 资源产在斑岩型（8 742 t，97.1 Mt）、中硫化型（Au：2 659 t）、低硫化型（Au：1 837 t）、矽卡岩型矿床（983 t Au，9.2 Mt Cu）中（赵红娟等，2011）。该区域的岩浆弧具有丰富的贵金属和有色金属资源。印度尼西亚，菲律宾和巴布亚新几内亚的资源量远大于东南亚其他国家。印度尼西亚 Au 47% 和 Cu 52% 来自 Grasberg 斑岩铜矿床（Au：2 604 t，1.05 g/t；Cu：28.02 Mt，1.13%），菲律宾 20% Au 储量来自远南东（Far South East）斑岩系统（Au：973 t，1.42 g/t；Cu：5.48 Mt，0.80%），另外 Au 12% 来自 Baguio 脉状矿床（Au：700t）。Tampakan 斑岩系（Cu：7.70 Mt，0.55%；

Au：336 t，0.24 g/t）占据菲律宾 16% 铜资源（卢映祥等，2009；陈永清等，2013）。在巴布亚新几内亚，Ladolam 矿床（Au：600 t）具有 Au 35%（Kelley et al., 2002），Bougainville 岛 Panguna 矿床（799 t，0.57 g/t）占据 Au 30%。Hishikari 热液脉状矿床占据日本 Au 35%（李方夏等，1995）。

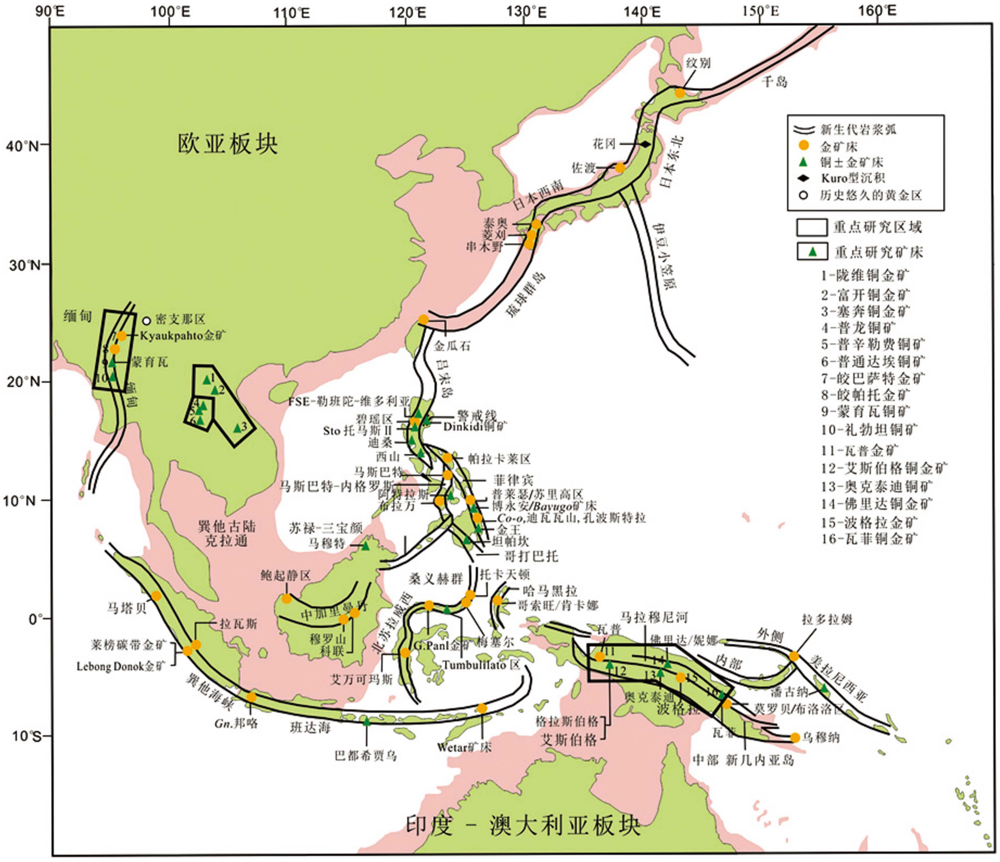

图 1　中南半岛—西南太平洋地质矿产分布图（据李春昱（1982）修）

表 2　研究区成矿规律简表

地质年代	主要矿床	成矿环境	地质单元
新生代（25 ~ 1 Ma）	斑岩 Cu-Au 矿床；高硫化矿床低硫化矿床	火山岛弧环境	西太平洋（中南半岛（缅甸蒙育瓦 Cu 矿）
燕山晚期（99 Ma）	卡林型 Au 矿床	造山环境	中南半岛（老挝帕夯 Au 矿床）
印支期（250 ~ 230 Ma）	石英脉状 Au 矿床	岛弧—造山环境	老挝达克琼 Au 矿床
晚二叠—早三叠世（264 ~ 250 Ma）	矽卡岩型—块状硫化物型 Sn-Cu 矿床	岛弧—造山环境	老挝南八坦 Sn-Cu 多金属矿床
晚石炭世（316 ~ 309 Ma）	斑岩型—矽卡岩型 Cu-Au 矿床	岛弧—造山环境	老挝塞夺斑岩型 Cu-Au 矿床；富开斑岩—矽卡岩型 Au-Cu 矿床；帕立山矽卡岩型 Fe 矿床
早古生代（晚加里东期：570 ~ 409 Ma）	石英脉状 Au 矿床	岛弧—造山环境	老挝阿文 Au 矿床

3　数据采集和处理过程

3.1　数据采集来源

中南半岛和西太平洋巨型成矿带地质矿产系列图件编制所使用的基础图件，主要来源于历年来相关项目的图件；中南半岛的高程数据和遥感影像数据主要来源于 USGS 网站。综合编图使用的主要基础资料如下：

（1）GEOLOGICAL MAP OF CAMBODIA LAOS AND VIETNAM（柬埔寨、老挝、越南地质图），成图比例尺 1∶100 万，英文版第二版，图面资料较完善、标有地理坐标及经纬网。该图由越南地质调查局编制，于 1991 年河内出版，是此次编图使用的主要底图之一。

（2）GEOLOGICAL MAP OF THAILAND（泰国地质图），成图比例尺 1∶100 万，为泰文与英文双语版，该图按地质年代编图，图面资料比较完整、标有地理坐标及经纬网。由泰国矿产资源部编制，于 1999 年出版，是此次编图使用的主要底图之一。

（3）GEOLOGICAL MAP OF THE SOCIALIST REPUCLIC OF THE UNION OF BURMA（缅甸联邦社会主义共和国地质图），成图比例尺 1∶100 万，英文版，图面资料比较完整、标有地理坐标及经纬网。由缅甸联邦地球科学研究局编制，1977 年出版，是此次编图使用的主要底图之一。

(4) 中南半岛和西太平洋巨型成矿带地理数据由云南省基础地理信息中心整理提供。原数据为双标准纬线等角圆锥投影（Ψ1=10°，Ψ2=26°，经线 =98°）的 ArcInfo Coverage 格式数据，再经统一坐标基准和参数的投影变换。另采用我国公开出版的相关图件对部分地理信息进行更新、修编；部分陆上、海上交通线路及标注来自云南东方经济地理研究院编印的 1∶200 万南亚东南亚资源交通图（成图时间 2005 年）。此外，还采用了中国地质调查局发展研究中心提供的地理信息数据。

(5) 数据高程 DEM 影像的影响分辨率为 30 m，来源于美国地质调查局（USGS）网站。

(6) 中南半岛和西太平洋巨型成矿带的遥感蚀变信息解译工作数据源主要采用 USGS 网站的 ETM+ 数据，其中，巴布亚新几内亚共有 47 景影像覆盖；老挝共有 7 景影像覆盖；泰国 39 景影像覆盖；缅甸共有 45 景影像覆盖。在研究区内运用 Hyperion 影像作为岩性解译的主要解译影像，数据来源于 USGS 网站。其中，巴布亚新几内亚研究区内获取 1 景 L1GST 级别 Hyperion 影像，在泰国和缅甸研究区内覆盖铜金矿矿点或其附近分别获取了 2 景 1GST 级别 Hyperion 影像和 3 景 1GST 级别 Hyperion 影像。另有 Aster 数据为商业购买数据。

(7) 数据集中的各大矿区、矿点、矿化点，线性、环形构造及制作的图件中的一些信息参考了 Economic Geology 100th Anniversary Volume (Kerrich et al., 2005)。

(8) 在各研究区采集了大量的野外样品，为室内化学实验需要提供必要的素材（表 3）。

3.2　数据处理过程

不同的数据需要进行不同的数据处理过程，以便所收集的信息能够最大化的满足要求，主要的数据处理过程如下：

（1）对每个国家收集到的电子版地质图进行几何校正，以校正好的地质图件作为原始图件，在 ArcGIS 中分别将每一幅地质图进行矢量化。

（2）对云南省地理信息中心整理和中国地质调查局发展研究中心提供的中南半岛地理信息数据进行数据处理，同时将中南半岛部分陆上、海上交通线路图件及标注（1∶200 万南亚东南亚资源交通图，云南东方经济地理研究院编印）进行矢量化。

（3）对收集到的数据中的 MapGIS 格式进行数据转化，将 MapGIS 格式转化成为 ArcGIS 能够使用的 .shp 格式数据。

（4）对数据高程影像（DEM）进行镶嵌、裁剪，进行滤波、拉伸等增强处理，并基于 ArcGIS 平台用 DEM 影像（30 m）提取山体阴影，等高线等。

（5）对于 ETM+ 遥感影像。基于 ENVI 平台，对 ETM+ 影像进行辐射校正、几何精校正等预处理后，运用波段比值法、波段运算，建立掩膜去除植被、水体、云、阴影等干扰信息后，分别对 ETM+ 影像的 ETM1、ETM3、ETM4、ETM5 波段和 ETM1、ETM4、ETM5、ETM7 波段进行主成分分析（PCA），各选取主分量后进行拉伸、阈值分割、滤波后，提取铁染和羟基蚀变信息。将提取的蚀变信息结果与原始影像进行对比分析，将目视解译确定的伪蚀变信息删除。最后将分景的蚀变信息拼接、裁减后编制各个区域蚀变信息分布图（张玉君等，2003）。

（6）对于 Hyperion 遥感影像。基于 ENVI 平台，对 Hyperion 数据进行格式转换、未标定及水气影响波段去除、像元值到绝对辐射值的转换、大气校正、裁剪等预处理后，进行矿物填图。经过最小噪声分离（MNF）、纯净像元指数（PPI）、N 维散度分析（n—D）、波谱分析（SA）后，设定适当的阈值进行波谱角填图（SAM），阈值的选择为综合分析研究区的地质岩性特征、矿点数据库等反复试验确定。最后对研究区内进行 SAM 填图（陈永清等，2009）。

（7）在老挝地区，通过所处研究区区域成矿地质背景、区域成矿条件和遥感异常的显示特征以及区域地球物理、化学等一系列成矿信息的分析、归纳、总结。结合该区铜金矿点分布图、ETM+ 遥感羟基、铁染和线环构造提取致矿异常信息（杨莎莎等，2015 ；陈永清等，2008），利用 GIS 动态聚类法为主要手段，提取了成矿有利的地层、构造和岩体，并在此工作的基础上，进一步开展全区的遥感找矿预测工作，再结合已知矿化事实的成矿作用及区域成矿规律开展研究区圈定靶区预测与评价工作。

（8）在巴布亚新几内亚研究圈定成矿预测靶区时，综合地物化遥的信息，本工作在 MORPASS 3.0 软件中进行。首先利用 MapGIS 对地质图采取图层分离技术，提取出与成矿关系密切的证据因子图层，将图层转成 shape 格式，完成文件格式转换。以 5 km 为单位，在 ArcGIS 软件中做 5 km×5 km 的缓冲区分析。然后，将缓冲后的文件转成 MapGIS 格式，进行赋值和赋属性，提取矿点图层，划分网格单元，生成含矿网格图层，分别将各证据因子图层与含矿网格图层相叠加，进行先验概率及权重值计算，得出先验概率和权重（W+，W-）值，选出合适的证据因子图层，按后验概率划分各级找矿远景区。

（9）在泰国和缅甸地区，在研究区成矿地质背景与典型多金属成矿规律研究的基础上，系统收集、整理了研究区不同尺度、不同类型的地质与 ETM+ 遥感、矿产地等地学数据，根据成矿系列理论和地质异常理论，结合研究区 Cu-Au 矿床成矿模式和找矿标

志，利用 MapGIS、ArcGIS、ENVI 遥感数字图像处理空间分析技术，提取研究区地质（地层、构造和岩体）、遥感致矿异常信息（铁染、羟基和线环构造），运用 GIS 动态聚类法和多重分形阈值分割方法组合，综合开展研究区铜金多金属成矿靶区预测与评价。

表 3　研究区岩石实验分析方法与相应分析数量表

分析方法	数量 / 单位	分析方法	数量 / 单位	分析方法	数量 / 单位
花岗岩全岩分析	116 件	稳定同位素分析	71 件	探针片	180 片
成矿元素分析	602 件	单矿物挑选	160 件	光薄片	102 件
Sr-Nd-Pb 同位素分析	50 件	阴极发光图像	400 张	流体包裹体	24 件
锆石 U-Pb 定年	32 件	包裹体激光拉曼光谱	216 小时	水系沉积物化学分析	755 件

4　研究区编图标准及其数据集

4.1　编图规范标准

建库及编图规范：为了规范项目成果，中南半岛和西太平洋巨型成矿带铜金矿化构造环境数据入库（表 4）以及专题图制作参考最新的相关规范作为标准，具体如下：

（1）SZ1999002-2001《图文地质资料扫描数字化规范（试行)》

（2）全球地质矿产数据库建设指南（20130131 修订稿）

（3）DZT0159-1995《1∶500 000 1∶1 000 000 省（市、区）地质图地理底图编绘规范》

（4）GB_T13923-2006《基础地理信息要素分类与代码》

（5）《PANTONE 国际色卡 CMYK 对应 RGB 对照表》

（6）《标准地层颜色》

（7）《地质矿产图示图例》

（8）DZT0195-1997《物探化探遥感勘察技术规程规范编写规定》

（9）DD2011-06《矿产资源开发遥感监测技术要求》

（10）DD2011-01《遥感影像地图制作规范》

（11）DD2011-02《遥感解译地质图制作规范》

系统精度及投影参数：底图扫描采用美国 VIDAR 公司 Tru Scan TITAN II 真彩色工程扫描仪完成，扫描仪最大扫描幅宽 40 inch（1.016 m），最大进纸幅宽 1.066 m，光学精度 800 dpi，色彩数 36 位，最大扫描精度 1 600 dpi。本次底图扫描精度取 400 ~ 600 dpi，采用手动黑白点色彩校正数字化平台。

东南亚中南半岛和西太平洋巨型成矿带地质矿产系列图件数字化处理在武汉中地数码科技有限公司的 MapGIS（v6.5-v6.7）下完成，为保证系列图件的精度，矢量化采用失真变形最小的折线矢量化方式。

投影系统：北京 1954、Datum：WGS-84

比例尺：1∶1 000 000

4.2　编图原则

根据专题图制作参考规范要求，对不同要求图件制作按实际情况进行针对性的制

图：

（1）中南半岛和西太平洋 4 国的地质矿产图，表示区域地质和矿产资源概况，比例尺为 1∶100 万。

（2）根据项目任务要求，编图工作还涉及到基础地理信息图，铜金成矿预测图，铜金成矿规律图，遥感影像图，遥感影像矿物填图，遥感地质解译推断图，矿业开发图等，这些图件都是围绕铜金矿化工作的预测而建立起来的。

（3）矿产资源产出位置表示在同比例尺的地质底图上，为清楚地反映矿床形成的地质背景，地质底图可做必要的简化。

（4）矿产规模、矿产类型和成矿单元划分等，除参考我国历年来习惯用法外，还必须遵循我国有关部门的规范和规定。

（5）各类图件主要表示中南半岛和西太平洋巨型成矿带陆地的地质和矿产情况，不涉及岛屿和毗邻海域的地质矿产。

（6）编图工作采用 MapGIS 6.7 和 ArcGIS 10.1 计算机软件平台。

表 4　数据库结构具体内容

根目录	一级名称及路径名		二级目录名称及文件名		三级目录文件名及内容		四级目录文件名约定及内容		五级目录文件名约定及内容		说明
	名称	路径名	名称	路径名	名称	路径名	内容	文件名	内容	文件名	
国家代码（国家名称）	矢量数据及相关	Vector	图幅名称简称	同“名称”	ArcGIS库文件	ArcGIS	ArcGIS文档	图幅名称简称.mxd	-----		mxd须包括全要素图Data Frame（包括相关图内外整饰图层）
							地理数据库	图幅名称简称.GDB	-----		
							剖面图、柱状图	H_S_Data	柱状图 剖面图		
							数字化扫描图件及相关	Raster	-----		
					*MapGIS文件	MapGIS	数字化建库成果	Vector	全要素图形文件	Map（中文）	输出的全要素图形数据和工程文件以及图外整饰文件
										Map（英文/原文）	
										经纬度	
										原图投影	MAPGIS各图层文件（包括图内整饰图层\工程文件\系统库）

续表 4

根目录	一级名称及路径名		二级目录名称及文件名		三级目录文件名及内容		四级目录文件名约定及内容		五级目录文件名约定及内容		说明
	名称	路径名	名称	路径名	名称	路径名	内容	文件名	内容	文件名	
					元数据文件	MetaFile	元数据	△△ .txt	-----		
								△△ .mxl	-----		
					矢量数据原始数据	Vector Source	原始数据（如原始数据 .GDB）		-----		包括符号、字体等
							原始数据组织文档（如ArcGIS *.mxd）		-----		
							说明文件 .doc		-----		包括所收集矢量库的相关介绍材料，包括简介、数据模型说明、数据说明及应用情况等
					说明文件	ReadMe	图式图例库说明及图形要素参数说明等	readme.txt	-----		
	影像、扫描图件	RASTER	遥感影像及说明	Image	按照传感器分类命名目录				-----		存放遥感影像数据
			扫描图件及说明	ScanPic	按比例尺分类命名目录				-----		
	表格数据	TABLE	物探	PM			-----		-----		
			化探	CM			-----		-----		
			矿业开发	ME			-----		-----		
			地质矿产资料	GD			-----		-----		

续表 4

根目录	一级名称及路径名		二级目录名称及文件名		三级目录文件名及内容		四级目录文件名约定及内容		五级目录文件名约定及内容		说明
	名称	路径名	名称	路径名	名称	路径名	内容	文件名	内容	文件名	
			影像与图片	IP			-----		-----		
			其它	OT			-----		-----		
	文档资料	TEXT	国家概况				-----		-----		
			政治经济基础				-----		-----		
			法律法规				-----		-----		按照法律名称 + 年度命名
			考察报告				-----		-----		
			地质矿产报告				-----		-----		
			矿产矿业开发综合报告				-----		-----		
			其他				-----		-----		
	其他	OTHER	分类别命名				-----		-----		

4.3 编图内容及成果

（1）建立“东南亚中南半岛和西太平洋巨型成矿带铜金矿化构造环境、成矿规律对比研究”的数据库，涵盖泰国、缅甸、老挝和西太平洋巴布亚新几内亚几国，其中编辑属性表 116 个，建立了 30 个 gdb，收集参考文献 313 篇，图表 34 件。

（2）中南半岛—西太平洋巨型成矿带优势矿产地质矿产图编制。其中建立工程文件 56 个。包括成矿规律图 4 幅、成矿预测图 4 幅、专题图 48 幅。专题图中包括基础地理信息图、遥感影像图、地势图、地质图、矿产图、遥感地质推断解译图六大类。

各类专题图表达的要素内容为：

① 基础地理信息图主要内容有行政区划、水系、居民地、交通、境界、等高线等上述内容的相关标示。

② 遥感影像图底图主要为 USGS 网站下载的 ETM+ 影像和 Hyperion 影像，部分为商业购买的 ASTER 影像。

③ 地势图主要内容为该地区的 DEM 影像。

④ 地质图的主要内容有地质界线、构造带、断裂、地层单元、侵入岩体等相关标示。

⑤ 矿业开发图以遥感影像为底图，主要内容为各大矿区、矿点、矿化点以及上述内容的相关标示。

⑥ 遥感地质推断解译图以地质图为底图，主要内容有遥感解译的线性构造、环形构造、羟基蚀变、铁染蚀变。

（3）地质矿产数据库。地质矿产数据库的建立主要遵循全球地质矿产数据库建设指南（20130131 修订稿）及第一次的评审要求，地质矿产数据库建立流程如下（图 2）：

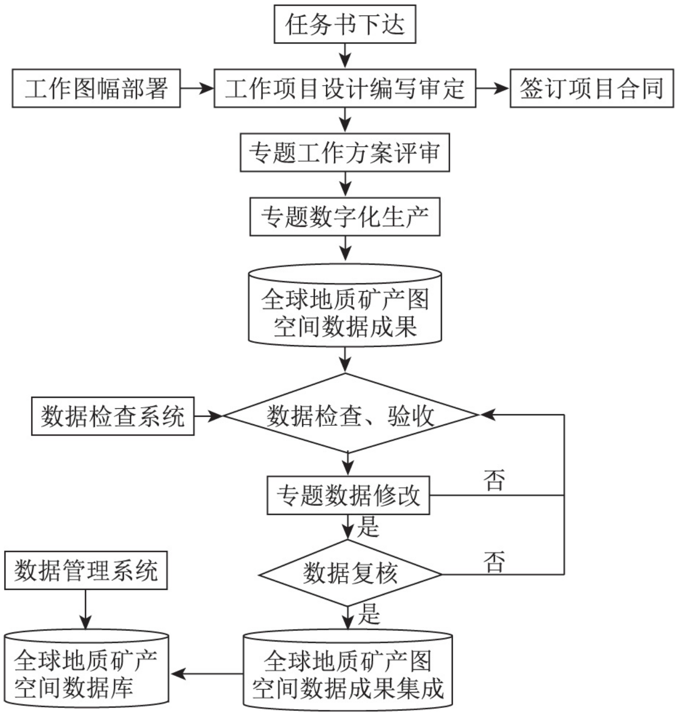

图 2　中南半岛和西南太平洋铜金矿数据库入库与编图流程

（4）建立了中南半岛和西太平洋巨型成矿带铜金矿化构造环境与成矿规律数据库。在此基础上，利用地质、遥感（ETM+，Hyperion）等信息资料，结合 DEM 数据提取出线环构造；利用 Hyperion 影像和波谱角法（SAM）提取了闪锌矿、燧石、蛭石等矿物；利用 GIS 技术和证据权与分形方法组合。优选了老挝（7 景 ETM+、30 景 DEM、1 景 ASTER（爬立山 / 富开地区矽卡岩型铁铜金多金属矿区）），缅甸（45 景 ETM+ 影像、100 余景 DEM、1 景 Hyperion），泰国（39 景 ETM+、120 景 DEM、2 景 Hyperion），巴布亚新几内亚（47 景 ETM+、DEM100 余景、1 景 Hyperion）4 个国家的找矿规律及其找矿远景区。

5　数据质量控制和评估

本次中南半岛和西太平洋巨型成矿带矿化构造环境与成矿规律对比研究数据集来源于历年相关项目所收集的半岛地区和各个国家出版的地质图、矿产图、会议代表交流的资料、图件以及本项目组收集的图件。入库的地理、地质、矿产相关要素一部分是由包括柬埔寨、老挝、越南地质图，泰国地质图，缅甸联邦社会主义共和国地质图，东南亚中南半岛地理数据等相关项目图件矢量化而来，另外中国地质调查局发展研究中心提供的地理信息数据，由云南省基础地理信息中心整理提供的东南亚中南半岛和西太平洋巨型成矿带地理数据。建立“东南亚中南半岛和西太平洋巨型成矿带铜金矿化构造环境、成矿规律对比研究”的数据库，基础地理信息图、遥感影像图、地势图、地质图、矿产图、遥感地质推断解译图六大类专题图。

数字化建库使用的地质、矿产地图为所收集到的国外正规图件。工作底图应优先选择变形小的聚酯薄膜片基，纸介质的次之。聚酯薄膜图，其变形应小于 0.2 ‰。若采用纸质图，根据用户需要精度可适当放宽，且变形要均匀，经仿射变换处理后应能达到相应的精度要求。进行数字化处理图件时，对图件扫描及预处理，图形矢量化，人工质量检查，计算机拓扑检查等流程方法，以保证数字化精度。同时针对地质矿产数据库建设数字化生产过程，建立完善的质量监控制度：

（1）建立工作日志制度：建立完整的工作日志表，每个作业人员每天必须按要求填写工作日志，将每天的工作内容全面、完整的记录下来，并由作业组长签名认可。

（2）建立自互检制：建立完整的自互检表，每个作业人员做每幅图都要进行 100% 的自检，并将自检结果和修改处理结果如实、完整的记录下来，由作业组长签名认可。在自检的基础上，由项目负责人安排其他作业人员进行 100% 以上的互检，并将互检结果和修改处理结果如实、完整的记录下来，由作业组长签名认可。

（3）抽检制度：建立项目组负责人抽检查制度，抽检查比率视年度工作图幅数量可调节，图幅数量较少时，完成 100% 的检查。

（4）阶段性检查制度：对建库的每个阶段性成果要进行严格检查把关，如图件扫描矢量化后的图元检查；属性录入后的图元、属性一致性检查等。

（5）保密及安全措施：数据库建设单位定期对工作数据备份和杀毒，对于国际互联网连接、计算机使用、涉密计算机管理、计算机信息系统使用人员管理、移动存储设备使用管理、数据复制操作管理、涉密设备维修及用途变更等环节的具体操作，按照国家保密局、国务院信息化办公室《关于加强党政机关计算机信息系统安全和保密管理的若干规定》（国保发〔2007〕13 号）统一执行质量监控体系。

6 结论

（1）利用年代学分析（吴锡生，1993），以板块构造理论为指导，建立了东南亚中南半岛大地构造格架；明确了东南亚西太平洋巨型成矿带 Au-Cu 矿床形成的板块构造环境：斑岩、矽卡岩以及高—中硫化物热液矿床与浅成侵入体、火山中心，局部与火山机构具有密切关系；以沉积岩作为容矿岩的浸染状（类卡林型）矿床产在中性或稍微张性环境的侵入中心附近或更远的地方；低硫化型热液矿床与内弧或弧后地堑张性环境相联系。系统论述东南亚西太平洋巨型成矿带 Au-Cu 矿床典型矿床特征。系统总结缅甸蒙育瓦（Monywa）斑岩型 Cu 矿床，泰国普隆（Phu Lon）矽卡岩型 Cu 矿床，老挝赛奔（Sepon）斑岩型 Cu-Au 矿床矿化特征，在此基础上，分别建立上述各类矿床成矿模式。在对印度尼西亚巴布亚 Grasberg 斑岩铜金矿床、巴布亚新几内亚 Ladolam 碱性岩浅成热液金矿床、新西兰怀希玛莎山低温热液硫化物矿床、菲律宾远东南—勒班陀斑岩—高硫化型低温热液型铜金矿床等世界级矿床研究基础上，建立东南亚西太平洋巨型成矿带 Au-Cu 矿床成矿模式与不同勘查阶段的勘查模式。

（2）在老挝阿文地区找到构造蚀变岩型的金矿，在 1∶5 万航磁研究的基础上，运用多元统计方法系统分析了阿文金矿区 1∶5 万水系沉积物测量的 755 个样品的 15 种，成矿相关元素数据：Ag、As、Au、Bi、Co、Cu、Hg、Mn、Mo、Ni、Pb、Sb、Sn、W、Zn。后期加入了 1 万个土壤地球化学测量、槽探工作。在 SPSS 和 Surfer 软件的支撑下，

通过地球物理与地球化学叠加分析，分别圈定了各元素异常和元素组合异常。研究各元素异常强弱、空间分布特征及其与已探明矿体、矿化带、蚀变带、岩浆岩体、构造等地质特征的关系。目前钻孔工程控制储量 5 t，平均品位 3.8 g/t；远景储量达 20 t，平均品位 2.5 g/t。

（3）西太平洋巨型成矿带相对中南半岛，具有众多的大型—超大型铜—金矿床，而中南半岛相对于西太平洋巨型成矿带则表现为铜金成矿的多样性特征。前者铜金矿床类型主要为斑岩型矿床，高硫化型矿床，低硫化型矿床；后者除具有类似的矿床类型外，最典型特征是发育造山带型金矿床。东南亚中南半岛和西太平洋巨型成矿带成矿的一致性表现在：都具有形成斑岩型与硫化型铜金矿床的能力，发育超大型斑岩型铜金矿床（如印度尼西亚巴布亚 Grasberg 斑岩铜金矿床，老挝 Sepon 和 Phu kham 斑岩型—矽卡岩型铜金矿床）和高硫化型铜—金矿床（菲律宾远东南—勒班陀斑岩—高硫化型铜—金矿床和缅甸蒙育瓦斑岩型—高硫化型铜—金矿床）。

（4）东南亚中南半岛与西太平洋巨型成矿带成矿的差异性表现在：

① 矿床类型的差异。中南半岛除发育斑岩型铜金矿床外，还发育造山带型金矿床（如缅甸 ModiTaung-Nankwe 和老挝阿文）。

② 成矿时代的差异。西太平洋巨型成矿带铜金矿床成矿时代为新生代，形成于板块俯冲相关的岩浆岛弧构造环境；中南半岛斑岩型和高硫化型铜金矿床形成于晚古生代（老挝 Sepon 和 Phukham）和新生代（缅甸蒙育瓦）。

③ 成矿与矿床保存能力上的差异。西太平洋巨型成矿带铜金资源潜力远大于中南半岛，这可能因为前者形成年代新，资源保存条件好的缘故。

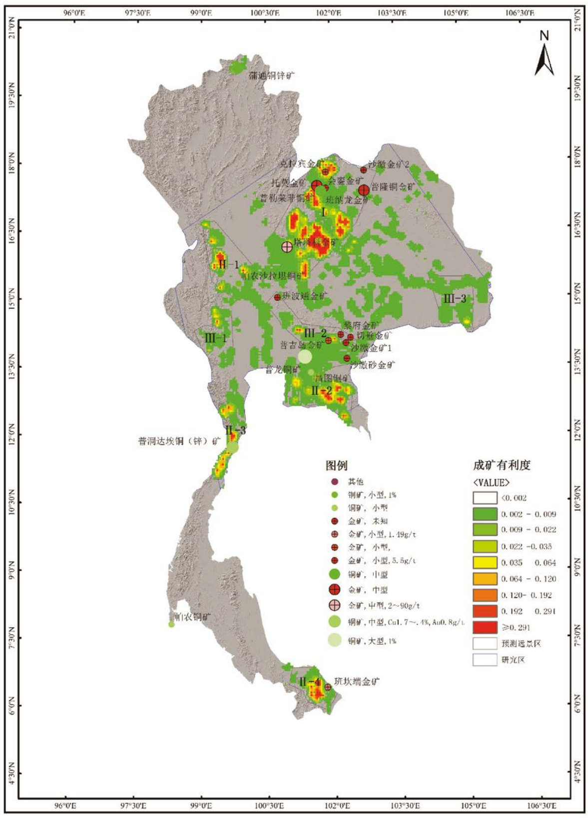

图 3　泰国 Cu、Au 成矿预测图

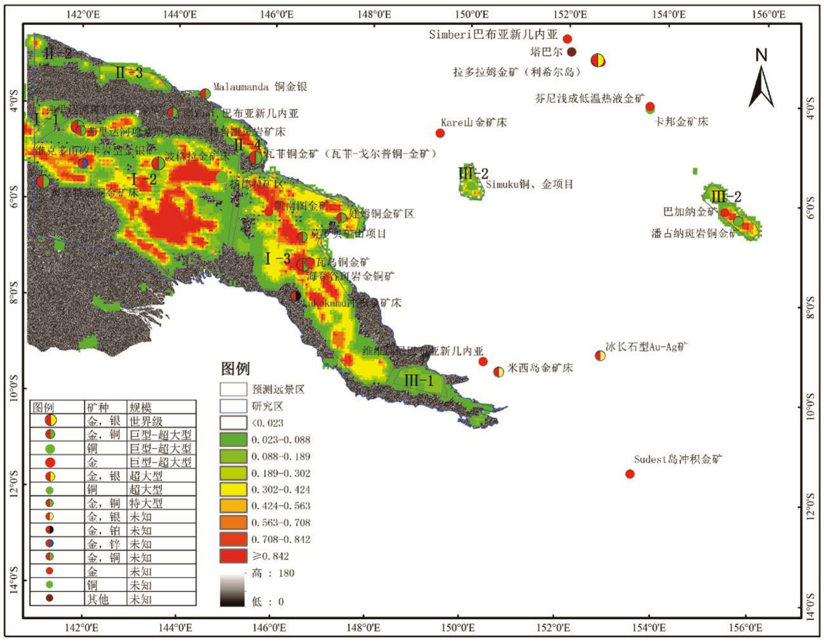

图 4 巴布亚新几内亚 Cu、Au 成矿预测图

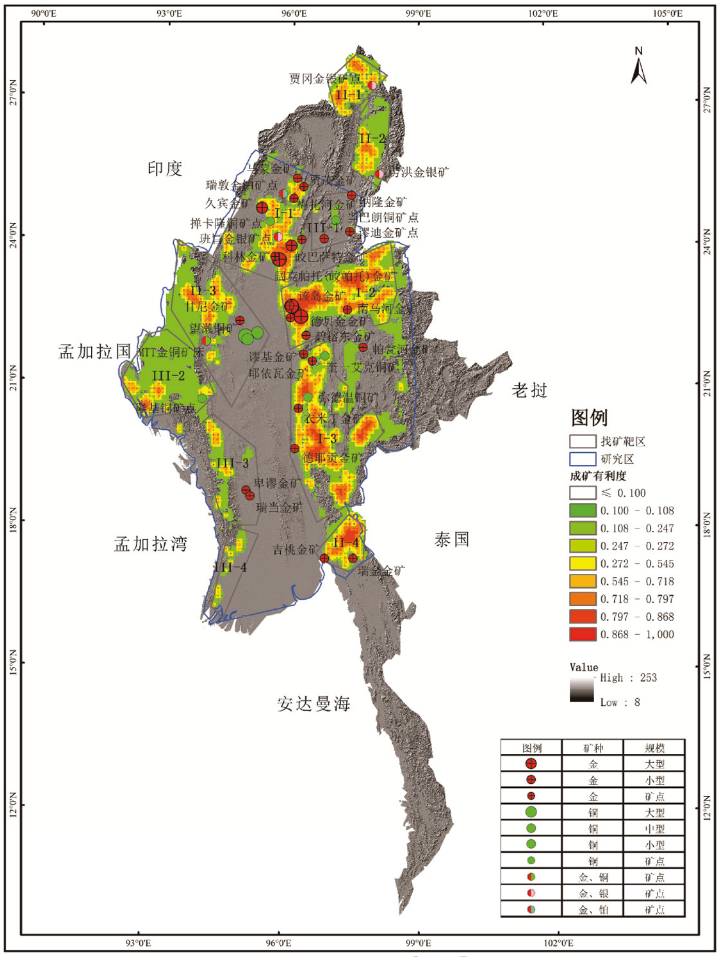

图 5 缅甸 Cu、Au 成矿预测图

（5）建立了中南半岛和西太平洋铜金矿化构造环境与成矿规律数据库，根据上述成因模式和找矿模型，利用 GIS 和数学建模，开展成矿预测并圈定了找矿靶区，主要有：

①泰国 Cu、Au 成矿预测图（图 3）；

②巴布亚新几内亚 Cu、Au 成矿预测图（图 4）；

③缅甸 Cu、Au 成矿预测图（图 5）；

致谢：整个项目实施过程中，得到了中国地质调查局科技外事部、中国地质调查局发展研究中心、云南省地质调查局、中国地质大学 (北京）地质调查院，尤其是得到赵鹏大、翟裕生、莫宣学、张翼飞等老专家，彭齐鸣、严光生、卢民杰、连长云、向运川、刘大文、李文昌、卢映祥、李定平、刘文灿等专家领导的指导和帮助，在此深表感谢！

参考文献

Agematsu S, Sashida K, Salyapongse S, Sardsud A. 2006. Ordovician conodonts from the Thong Pha Phum area, western Thailand[J]. Journal of Asian Earth Sciences, 26(1): 49−60.

Kelley K D, Ludington S. 2002. Cripple Creek and other alkaline−related gold deposits in the southern Rocky Mountains, USA: Influence of regional tectonics[J]. Mineralium Deposita, 37: 38−60.

Kerrich R, Goldfarb R J, Richards J P. 2005. Metallogenic provinces in an evolving geodynamic framework[J]. Economic Geology, One Hunderedth Anniversary Volume (1905−2005): 1097−1136.

Loader S. E. 1999. Supergene enrichment of the Khanong copper resource, Sepon Project, Lao PDR[J]. Australasian Institute of Mining and Metallurgy: CarltonVictoria, 263−270.

Mitchell A H G, Ausa C A, Deiparine L, Hlaing T, Htay N A, Khine. 2004. The Modi Taung−Nankwe gold district, Slate belt, central Myanmar: Mesothermal veins in a Mesozoic orogen[J]. Journal of Asian Earth Sciences, 23(3): 321−341.

陈永清 , 陈建国 , 汪新庆 . 2008. 基于 GIS 矿产资源综合定量评价技术 [M]. 北京 : 地质出版社 , 1−294.

陈永清 , 赵鹏大 . 2009. 综合致矿地质异常信息提取与集成 [J]. 地球科学 , 34(2): 325−335.

陈永清 . 2013. 东南亚中南半岛 (五国) 地质矿产图 [M]. 北京 : 地质出版社 .

李春昱 , 王荃 , 刘雪亚 , 汤耀庆 . 1982. 亚洲大地构造图说明书 [M]. 北京 : 地图出版社 , 1−49.

李方夏 , 赵应龙 , 王卓之 . 1995. 东南亚地质矿产与矿业经济 [R]. 云南 : 云南省地质矿产局 .

卢映祥 , 刘洪光 , 黄静宁 , 张宏远 , 陈永清 . 2009. 东南亚中南半岛成矿带初步划分与区域成矿特征 [J]. 地质通报 , 28(2−3): 314−325.

吴锡生 . 1993. 化探数据处理方法 [M]. 北京 : 地质出版社 , 1−130.

杨莎莎 , 王功文 , 陈永清 , 黄陆雄 , 赵鹏飞 . 2015. 基于遥感信息提取技术的泰国铜金矿成矿预测 [J]. 地质通报 , 4(34): 780−785.

张玉君 , 曾朝铭 , 陈薇 . 2003. ETM+(TM) 蚀变遥感异常提取方法研究与应用——方法选择和技术流程 [J]. 国土资源遥感 . 56(2): 44−49.

赵红娟 , 陈永清 , 卢映祥 . 2011. 老挝长山成矿带与花岗岩有关的铜金铁矿床的成矿模式 [J]. 地质通报 , 30(10): 1619−1627.

中国地质调查局援老挝矿产地质调查项目前期考察组 . 2005. 中国援老挝矿产地质调查前期考察报告 .

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Dataset of the Comparative Study of Tectonic Environment and Metallogenic Laws of Cu–Au Mineralization in Indo-China Peninsula and Western Pacific Giant Metallogenic Belt

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Abstract: The Comparative Study of Tectonic Environment and Metallogenic Laws of Cu–Au Mineralization in the Indo-China Peninsula and Western Pacific Giant metallogenic belt takes the Indo-China Peninsula and the giant Western Pacific metallogenic belt as the study area and targets Cu and Au minerals. Data was systematically collected via international cooperation based on the compilation of 1:1, 500, 000 scale Geological and Mineral Map of Indo-China Peninsula and Western Pacific Giant metallogenic belt, Southeast Asia. Study results were deepened and maps in English and Chinese versions were published after studying the metallogenic environment, ore-controlling factors and metallogenic laws of typical deposits in the study area covering Laos, Thailand, Burma, Papua New Guinea, etc. and combining them with ETM+, Hyperion and ASTER multi-source remote sensing images. Cu–Au deposits mainly in Laos were analyzed, while prospecting demonstration and drilling verification were conducted in the Aven deposit area, Laos. The study achieved positive prospecting effects. Moreover, using MapGIS and ArcGIS technical platforms, maps of metallogenic laws of mineralization zones/regions were compiled, and quantitative evaluation models for different minerals and a spatial dataset of Au–Cu deposits in significant metallogenic zones/regions in Southeast Asia were developed. In addition, using the mathematical modeling method, resource potential assessment was conducted for the study area, and mineralization prospects for different minerals were delineated within the study area. This dataset is not only a summary of mineral resource zoning and resource potential assessment, but also a theoretical basis for scientifically guiding China's prospecting deployment in other countries (the Belt and Road Initiative).

Keywords: Cu–Au deposit; tectonic environment; metallogenic laws; Indo-China Peninsula; Western Pacific Giant metallogenic belt
Data service system URL: http://dcc.cgs.gov.cn

1 Introduction

As China advances the implementation of the Belt and Road (B&R) Initiative, countries along the route are planning the construction of six large economic corridors. The China–

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Indo-China Peninsula Economic Corridor (CICPEC) is one of the six corridors. Therein, China–Laos and China–Thailand segments in the Trans-Asia Rail Network are presently under development. These developments are expected to strengthen China's economic and trade relations with the countries along this route. In this context, research findings in the fields of geology and minerals in the Indo-China Peninsula and Western Pacific Giant metallogenic belt, Southeast Asia are significant to pushing mining exploration and development of this economic corridor.

This paper features a systematic study on the metallogenic tectonic environment, ore-controlling factors and metallogenic laws of typical deposits in the area under study, which covers Laos, Burma, Thailand, Papua New Guinea, etc. In addition, this paper provides quantitative evaluation models for different minerals together with a spatial dataset of Au–Cu deposits in significant metallogenic zones/regions in Southeast Asia. Table 1 lists metadata of the database. Moreover, using mathematical modeling, this paper delineates mineralization prospects of different minerals within the study area.

Table 1 Metadata table of Database (Dataset)

Items	Description
Database (dataset) name	Dataset of tectonic environment and metallogenic laws of Cu–Au mineralization in the Indo-China Peninsula and Western Pacific Giant metallogenic belt
Database (dataset) authors	Wang Gongwen, China University of Geosciences Cheng Yongqing, China University of Geosciences Huang Jingning, China University of Geosciences Liu Shengqian, China University of Geosciences Lyu Xiumei, China University of Geosciences
Data acquision time	2012—2015
Geographic area	Burma, Laos, Thailand, and Papua New Guinea
Data format	Vector, raster, sheet, text, gdb, etc.
Data size	http://dcc.cgs.gov.cn
Data service system URL	142 GB
Fund project	Funded by China Geologic Survey's "Geological condition comparison and resource potential assessment of significant metallogenic belts in the periphery of the Chinese Mainland" and Integration and Comprehensive Research of Results of Global Significant Metallogenic Belts (12120114093001 and 1212011220912)
Language	Chinese
Database (dataset) Composition	Vector data, raster data, scanned maps, text data, sheet data, project files, and other

2 Overview of Minerals in Study Area

Research has indicated that Au–Cu deposits in Southeast Asia–Western Pacific Giant metallogenic belt were mainly formed in Middle–Late Cenozoic (25~1Ma) magmatic arcs, while minor deposits were formed in the Early Paleozoic and Mesozoic periods (Table 2) (Lu Yingxiang et al., 2009). More than a hundred mineral species have been discovered in the five countries in the Indo-China Peninsula. Meanwhile, positions and names of about 729 mineral producing areas of precious metal, nonferrous metal, ferrous metal, and salt minerals have been defined (Fig. 1). Among these, there are 75 ultra-large and large deposits and 356 middle and small-sized deposits (Chen Yongqing, 2013).

Predicated reserves include 30~50 billion tonnages sylvite, >30 Mt Cu, 800~1 000 Mt chromite, >100t Platinum Group Metals, 1.5~2 Mt Ni, and >100 Mt bauxite. In recent years, a series of mineral deposits/producing areas, such as Phu Lon, Monywa (Mitchell A H G, 2004), Sepon (Loader S. E. 1999), and Phu Kham (Agematsu S, 2006), which are related to intermediate–acidic magmatic activities, have been successively discovered in Thailand, Burma and Laos. The deposit types include porphyry, skarn, high–low sulfide, VMS and disseminated types (hosted in sedimentary rocks).

Per statistics, extracted and measured resources of the study area amount to 15, 000 t Au and 115 Mt Cu. Main Au and Cu mineral resources are hosted in porphyry type (8 742 t, 97.1 Mt), medium-sulfide type (Au: 2 659 t), low-sulfide type (Au: 1 837 t) and skarn type (983 t Au, 9.2 Mt Cu) deposits (Zhao Hongjuan et al., 2011). Magmatic arcs in the area contain abundant precious and non-ferrous metal resources. Meanwhile, resources of Indonesia, Philippines and Papua New Guinea are much larger than the ones in other Southeast Asian countries. From a reserve perspective, 47% of Au and 52% of Cu reserves in Indonesia are from the Grasberg Porphyry Cu Deposit (Au: 2 604 t, 1.05 g/t; Cu: 28.02 Mt, 1.13%). In addition, 20% of Au reserves in Philippines are from the Far South East Porphyry System (Au: 973 t, 1.42 g/t; Cu: 5.48 Mt, 0.80%), while 12% of Philippines's Au reserves are from the Baguio Veinlike Deposit (Au: 700 t). At the same time, the Tampakan Porphyry System (Cu: 7.70 Mt, 0.55%; Au: 336 t, 0.24 g/t) contains 16% of Philippines' Cu resources (Lu Yingxiang et al., 2009; Chen Yongqing, 2013). In Papua New Guinea, the Ladolam Deposit (Au: 600 t) contains 35% of the country's Au (Kelley et al., 2002), and the Panguna Deposit in Bougainville Island (799 t, 0.57 g/t) contains 30% of Cu reserves. Furthermore, the Hishikari Hydrothermal Vein-Type Deposit houses 35% of all Au reserves in Japan (Li Fangxia et al., 1995).

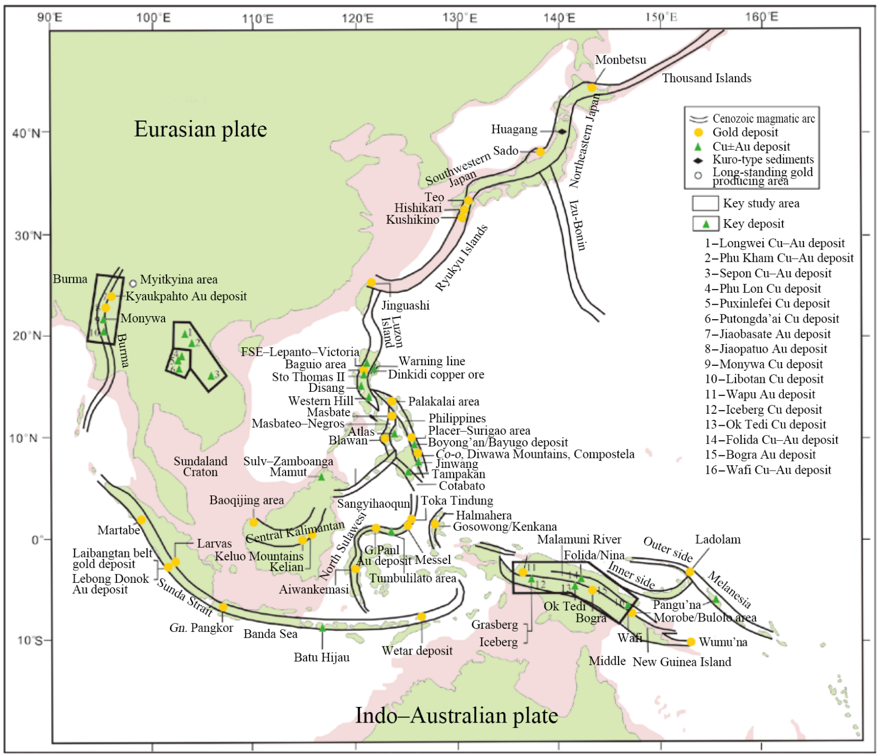

Fig. 1 Geological and Mineral Distribution Map of the Indo-China Peninsula–Southwestern Pacific (Modified after Li Chunyu, 1982)

Table 2 List of Metallogenic Laws of the Study Area

Geologic Age	Key Deposit	Metallogenic Environment	Geologic Unit
Cenozoic (25~1Ma)	Porphyry-type Cu−Au deposit; high-sulfide and low-sulfide deposits	Volcanic island arc	Western Pacific (Indo-China Peninsula(Monywa Cu deposit, Burma)
Late Yanshanian (99Ma)	Carlin-type Au deposit	Orogenic	Indo-China Peninsula(Paben Au deposit in Laos)
Indonesia (250~230Ma)	Quartz vein-type Au deposit	Island arc-orogenic	Dakeqiong Au deposit in Laos
Late Permian–Early Triassic (250~264Ma)	Skarn-VMS type Sn−Cu deposit	Orogenic	Nanbatan Sn−Cu polymetallic deposit in Laos
Late Carboniferous (309~316Ma)	Porphyry-skarn type Cu−Au deposit	Island arc-orogenic	Sepon porphyry-type Cu−Au deposit in Laos; Phu Kham porphyry-skarn type Au−Cu deposit; Palishan skarn-type Fe deposit
Early Paleozoic(Late Caledonian:570~409Ma)	Quartz vein-type Au deposit	Orogenic Island arc-orogenic	Aven Au deposit in Laos

3 Data Collection and Processing

3.1 Data Sources

The basic maps used for compiling a series of geology and minerals maps of the Indo-China Peninsula and Western Pacific Giant metallogenic belt have been mainly sourced from maps and drawings of related projects over the years. Meanwhile, elevation data and remote sensing image data of the Indo-China Peninsula have been mainly sourced from the United States Geological Survey (USGS) website. Comprehensive map compilation mainly uses the following basic data:

(1) The second English edition of Geological Map of Cambodia, Laos and Vietnam, scaled to 1:1, 000, 000, has been used. The map's drawing information is relatively complete, while geographic coordinates, including longitude and latitude, have been marked. This map was compiled by Vietnam Geological Survey and published in Hanoi in 1991. It is one of main base maps of the map compilation presented herein.

(2) The Geological Map of Thailand, scaled to 1:1, 000, 000, has been used. The map is available in Thai and English. This map has been compiled by geologic age and has complete drawing information, marked with geographic coordinates, including longitude and latitude grids. The map was compiled by Thailand Ministry of Mineral Resources and published in 1999. It is one of main base maps of the map compilation presented herein.

(3) Geological Map of the Socialist Republic of the Union of Burma, scaled to 1:1, 000, 000, has been used. This map is in English and has complete drawing information and geographic coordinates, including longitude and latitude grids. It was compiled by the Research Bureau of Geosciences of The Union of Burma and published in 1977. It is one

of main base maps of the map compilation presented herein.

(4) Geographic data of Indo-China Peninsula and Western Pacific Giant metallogenic belt was provided by Yunnan Center for Basic Geographic Information. The original data is ArcInfo Coverage Data featuring conformal conic projection with two standard parallels (Ψ1=10°, Ψ2=26°, longitude =98°). It has undergone projection transformation using uniform coordinate datum and parameters. Besides, related maps published in China were adopted to update and modify partial geographic information. Some of land and sea transport lines and labels are from the 1:2, 000, 000 scale resources and the Transportation Map of South Asia and Southeast Asia, which compiled and printed by the Yunnan Eastern Research Institute of Economic Geography in 2005. In addition, geographic information provided by the Development and Research Center of China Geological Survey (CGS) has been adopted.

(5) Elevation DEM images with a resolution of 30M have been used after being sourced from the USGS website.

(6) Data of remote sensing interpretation of alteration information of the Indo-China Peninsula and Western Pacific Giant metallogenic belt have been sourced from ETM and USGS website data. Among the data, 47 images cover Papua New Guinea, seven cover Laos, 39 cover Thailand, and 45 cover Burma. Within the study area, Hyperion images were adopted as main images for lithologic interpretation. The data have been sourced from the USGS website. One scene of L1GST-level Hyperion image was obtained for the Papua New Guinea study area. Within Thailand and Burma, two scenes of 1GST-level Hyperion images and three scenes of 1GST Hyperion images covering Cu/Au concurrences or their peripheries were respectively obtained. Meanwhile, Aster data was purchased by a commercial mode.

(7) Some information about various deposits, occurrences, mineralized spots, linear and ring-like structures, and maps compiled in the dataset are based on the Economic Geology 100th Anniversary Volume (Kerrich et al., 2005).

(8) Massive field samples were collected from various study sub-areas. They provide necessary materials for indoor chemical testing (Table 3).

Table 3 Laboratory Analytical Methods and Corresponding Analysis Quantities of Rocks in Study Area

Analytical Method	Quantity/ Unit	Analytical Method	Quantity/ Unit	Analytical Method	Quantity/Unit
Whole rock analysis of granite	116 pieces	Stable isotope analysis	71 pieces	Probe section	180 sections
Analysis of ore-forming elements	602 pieces	Selection of single minerals	160 pieces	Polished thin section	102 sections
Sr−Nd−Pb isotopic analysis	50 pieces	Cathodoluminescence image	400 images	Fluid inclusion	24 inclusions
Zircon U−Pb dating	32 pieces	Inclusion laser raman spectroscopy	216 hours	Chemical analysis of stream sediment	755 pieces

3.2 Data Processing

Different data types require different processing methods to maximize information collection. The main data processing methods are described as follows:

(1) Geometric correction was made on electronic geologic maps collected for each country. Corrected geological maps were taken as primary maps, and each geological map was vectorized.

(2) Geographic information data handled by the Yunnan Center for Geographic Information and provided by the Development and Research Center of CGS were processed. Some of land and sea traffic route maps and labels (1:2, 000, 000 Scale Resources and Traffic Map of South Asia and Southeast Asia, compiled and printed by Yunnan Eastern Research Institute of Economic Geography) of Indo-China Peninsula were vectorized.

(3) MapGIS data was transformed into .shp data used for ArcGIS.

(4) Mosaic, cutting, and enhancement processes, such as filtering and stretching, were conducted on elevation images (DEM). Based on the ArcGIS platform, DEM images (30M) were adopted to extract mountain shadows, contour lines, etc.

(5) Firstly, based on the ENVI platform, ETM+ remote sensing images were pre-processed through radiation correction and geometric correction. Secondly, using band ratio and band calculation methods, masks were built to remove vegetation, waters, clouds, shadows, and other disturbances. Later on, principle component analysis (PCA) was conducted on ETM1, ETM3, ETM4, ETM5, ETM1, ETM4, ETM5, and ETM7 images. After the selection of principal components, stretching, threshold segmentation and filtration were carried out to extract iron-stained and hydroxyl alteration information. The extracted alteration information results and primary images were compared and analyzed. False alteration information determined by visual interpretation was deleted. Finally, alteration information of different scenes were joined and cut, and alteration information distribution maps of various regions/zones were compiled (Zhang et al., 2003).

(6) Firstly, based on the ENVI platform, Hyperion remote sensing images were pre-processed, involving format conversion, removal of bands that are not calibrated and exposed to steam influences, conversion from pixel values to absolute radiation values, and atmospheric correction and cutting. After that, minerals mapping was conducted. Secondly, after conducting Minimum Noise Fraction (MNF), Purity Pixel Index (PPI), N-dimensional divergence analysis (n−D), and Spectrum Analysis (SA), an appropriate threshold was set to perform Spectral Angle Mapping (SAM). For the purpose, the selected threshold was determined by repeated tests of geologic lithologic characteristics, occurrence dataset, etc. of the study area under comprehensive analysis. Finally, SAM was conducted within the study area (Cheng et al., 2009).

(7) In Laos, a series of ore-forming information, such as regional metallogenic geologic setting, regional metallogenic conditions and characteristics of remote sensing anomalies, and regional geophysical and geochemical characteristics of the study area were analyzed and summarized. Later on, ore-forming anomaly information was extracted using the distribution map of Cu−Au occurrences/spots in the area, ETM+ remote sensing hydroxy, iron-stained information, and linear-ring-like structures (Yang, 2015; Cheng, 2008). At the same time, strata, structures and intrusions that are favorable for mineralization were extracted using GIS dynamic clustering procedures, and accordingly, further remote sensing prospecting was conducted for the entire area. Lastly, target delineation, prediction and evaluation were conducted for the study area in light of mineralization and regional

metallogenic laws of known mineralization cases.

(8) When predicted mineralization targets were delineated within Papua New Guinea, geological, geophysical, geochemical and remote sensing information was synthesized in Software MORPASS3.0. Firstly, geological map layers were separated by using MapGIS to extract evidence factor layers closely related to mineralization. After that, layers were transformed into shape format and format conversion was completed. With 5 km as the unit, 5 km×5 km buffer zone analysis was conducted in Software ArcGIS. Secondly, buffer files were converted into MapGIS format to enable value and attribute assignment, occurrence layer extraction, grid cell division, and ore-bearing grid layer generation. Later on, various evidence factor layers were respectively overlapped with ore-bearing grid layers to calculate prior probability and weighted values, obtain prior probability and weighted values (W+, W−), select appropriate evidence factor layers, and divide mineralized prospects of variable levels by posterior probability.

(9) Geoscience data, including ETM+remote sensing data, and mineral producing sites of variable scales and types, among others, were systematically collected and processed in Thailand and Burma on the basis of the study on metallogenic geologic setting and typical polymetallic metallogenic laws. In line with metallogenic series and geological anomaly theories combined with mineralization models and prospecting indicators of Cu−Au deposits in the study area, geological (strata, structures and intrusions) and remote sensing ore-forming anomaly information (iron-stained, hydroxyl and linear-ring-like structures) were extracted using image digitalization processing spatial analysis techniques of MapGIS, ArcGIS and ENVI remote sensing. Moreover, comprehensive prediction and evaluation of Cu−Au polymetallic mineralization targets of the study area was conducted using the combined GIS dynamic clustering and multifractal threshold segmentation method.

4 Map Compilation Criteria and Dataset

4.1 Map Compilation Criteria

Dataset Establishment and Map Compilation Criteria: In order to standardize project results, refer to the following latest specifications/standards for the tectonic environment dataset and special map compilation of Cu−Au mineralization of the Indo-China Peninsula and Western Pacific Giant metallogenic belt (Table 4):

(1) SZ1999002−2001 Specifications for Scanning and Digitalization of Geological Image-Text Information (Trial)

(2) Establishment Guidelines for Global Geology and Minerals Dataset (revised in 2013)

(3) DZT0159−1995 Specifications for Compilation of Geographic Base Maps of 1:500, 000 and 1:1, 000, 000 Scale Provincial (Municipal, Regional) Geological Maps

(4) GB_T13923−2006 Fundamental Geographic Information Features Classification and Code

(5) Comparison Table of CMYK Vs RGB of PANTONE International Color Cards

(6) Stratigraphic Color Codes

(7) Graphs and Legends for Geology and Minerals

(8) DZT0195−1997 Specifications for Compilation of Technical Regulations of

Geophysical, Geochemical and Remote Sensing Surveys

(9) DD_2011−06 Regulation on Remote Sensing Monitoring of Mining Exploration

(10) DD2011−01Standard for Production of Remote Sensing Photomap

(11) DD2011−02 Standard for Production of Geological Map Interpreted With Remote Sensing Image (1:250, 000)

System Precision and Projection Parameters: Base map scanning was completed using American VIDAR's Tru Scan TITAN II true color engineering scanner, with maximum scanning width of 40 inch (1.016 m), minimum paper feed width of 1.066 m, optical precision of 800 dpi, 36 colors, and maximum scanning precision of 1, 600 dpi. This base map scanning was set to be within 400 dpi-600 dpi in precision. It adopted the manual digitalization platform of black/white point color correction.

Digitalization of geological and mineral map series of the Indo-China Peninsula and Western Pacific Giant metallogenic belt, Southeast Asia was completed in MapGIS (v6.5−v6.7) developed by Wuhan Zondy Cyber. Meanwhile, broken line vectorization mode with minimum distortion was adopted to ensure the precision of the map series.

Projection System: Beijing 1954, Datum: WGS−84

Scale: 1:1, 000, 000

4.2 Principles of Map Compilation

Maps of variable classes were produced according to actualities and in line with the reference standards for special map production.

(1) Geological and mineral maps of four countries in Indo-China Peninsula and Western Pacific, scaled at 1:1, 000, 000, provide an overview of regional geology and mineral resources.

(2) According to the project tasks, map compilation also involves basic geographic information maps, Cu−Au metallogenic prognosis maps, Cu−Au metallogenic laws maps, remote sensing photomaps, remote sensing mineral maps, remote sensing geological interpretation maps, mining development maps, etc. These maps are all based on Cu−Au mineralization work.

(3) Occurrence locations of mineral resources are expressed on the same scale geological base map, so as to clearly reflect the geologic setting of deposit formation. The geological base map can be simplified if necessary.

(4) Division of mineral scale, mineral type and metallogenic unit, etc. ought to obey China's regulations and specifications issued by related organizations in addition to China's idiomatic usage over the years.

(5) Various classes of maps mainly show the geological and mineral resources of Indo-China Peninsula and Western Pacific Giant metallogenic belt land. They do not involve geology and minerals in islands and adjacent seas.

(6) Map compilation adopts computer software platforms MapGIS6.7 and ArcGIS10.1.

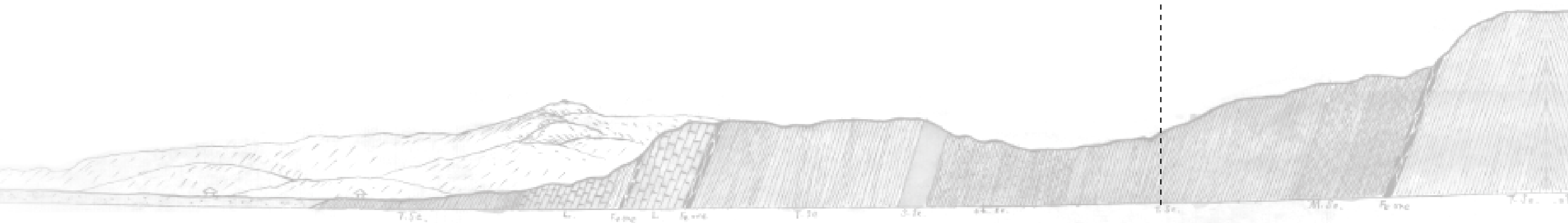

Table 4 Detailed Contents of Dataset Structure

Root directory	First-level name and pathname		Second-level directory name and filename		Third-level directory file name and contents		Fourth-level directory filename convention and contents		Fifth-level directory filename convention and contents		Instruction
	Name	Pathname	Name	Pathname	Name	Pathname	Contents	File name	Contents	File name	
Country code (Country name)	Vector data and related	Vector	Abbreviation for map sheet name	Same as “name”	ArcGIS Library file	ArcGIS	ArcGIStext	Abbreviation for mapsheet name.mxd	—————		mxd should include total- factor Data Frame (including related inside- and outside-map decoration layers)
							Geographic databset	Abbreviation for mapsheet name.GDB	—————		
							Column and section	H_S_Data	Column		
									Section		
					*MapGISfile	MapGIS	Digitalized scanning map and related	Raster	—————		
							Digitalized dataset establishment results	Vector	Total-factor graphic file	Map (Chinese)	Output total-factor graphic data and project files and outside-map decoration file
										Map(English/ original language)	
									Latitude and longitude		
									Original map projection		Various layer files of MAPGIS (including inside-map decoration layer\project file\system library)
					Metafile	MetaFile	Metadata	△△.txt	—————		
								△△.mxl	—————		
					Vector data original data	Vector Source	Original data (e.g. original data.GDB)		—————		Include symbols and character styles
							Original data organization text (e.g. ArcGIS *.mxd)		—————		
							Instruction file.doc		—————		Include collected related introduction information of vector library, including introduction, data model instruction, data instruction and application, etc.
					Instruction file	ReadMe	Pattern and legend base instruction graphic element and parameter instruction	readme.txt	—————		
	Image and scanned map	RASTER	Remote sensing image and instruction	Image	Directory of classification and naming by sensor				—————		Store remote sensing image data
			Scanned map and instruction	ScanPic	Directory of classification and naming by scale				—————		
	Table data	TABLE	Geophysical measurement	PM			—————		—————		
			Geochemical measurement	CM			—————		—————		
			Mining development	ME			—————		—————		

Continued table 4

Root directory	First-level name and pathname		Second-level directory name and filename		Third-level directory file name and contents		Fourth-level directory filename convention and contents		Fifth-level directory filename convention and contents		Instruction
	Name	Pathname	Name	Pathname	Name	Pathname	Contents	File name	Contents	File name	
			Geological and mineral data	GD			————		————		
			Image and graphic	IP			————		————		
			Other	OT			————		————		
	Text	TEXT	Country profile				————		————		
			Political and economic basis				————		————		
			Laws and rules				————		————		Name by legal name and year
			Investigation report				————		————		
			Geological and mineral report				————		————		
			Mineral and mining development comprehensive report				————		————		
			Other				————		————		
	Other	OTHER	Classification and naming				————		————		

4.3 Map Compilation and Results

(1) Dataset of the Comparative Study of Tectonic Environment and Metallogenic Laws of Cu−Au Mineralization in Indo-China Peninsula and Western Pacific Giant metallogenic belt, Southeast Asia was established. The dataset covers Thailand, Burma, Laos and Papua New Guinea in Western Pacific, wherein 116 attribute tables were edited, 30 gdbs were established, 313 references were collected, and 34 figures and tables were produced.

(2) Geological and mineral maps of superior minerals of the Indo-China Peninsula−Western Pacific Giant metallogenic belt were compiled, wherein 56 project files were established, including four metallogenic laws maps, four metallogenic prognosis maps, and 48 special maps which include six classes: basic geographic information map, remote sensing photomap, topographic map, geological map, mineral map, and remote sensing geological interpretation map.

Contents of various classes of special maps are as follows:

① The basic geographic information map mainly contains administrative division, water systems, settlement places, traffic, borders and contour lines, and related marks of the aforementioned contents.

② The base map of a remote sensing photomap mainly comprises ETM+ and Hyperion images downloaded from the USGS website, with some ASTER images purchased in a commercial mode.

③ The topographic map mainly includes DEM images of the area.

④ The geological map mainly includes geological boundaries, tectonic belts, faults, stratigraphic units and intrusions, and related marks of the aforementioned contents.

⑤ The mining development map takes remote sensing images as the base map. It mainly includes related various deposit areas, occurrences, mineralized spots, and marks of the aforementioned contents.

⑥ The remote sensing geological interpretation map takes the geological map as its base map. It mainly contains remote sensing interpreted linear structures, ring-like structures, hydroxyl alteration, and iron-stained alteration.

(3) Establishment of geological and mineral dataset mainly follows the Establishment Guidelines for Global Geological and Mineral Dataset (revised in 2013) and the first review requirements. The flowchart explaining the process of geological and mineral dataset's establishment is show in Fig 2.

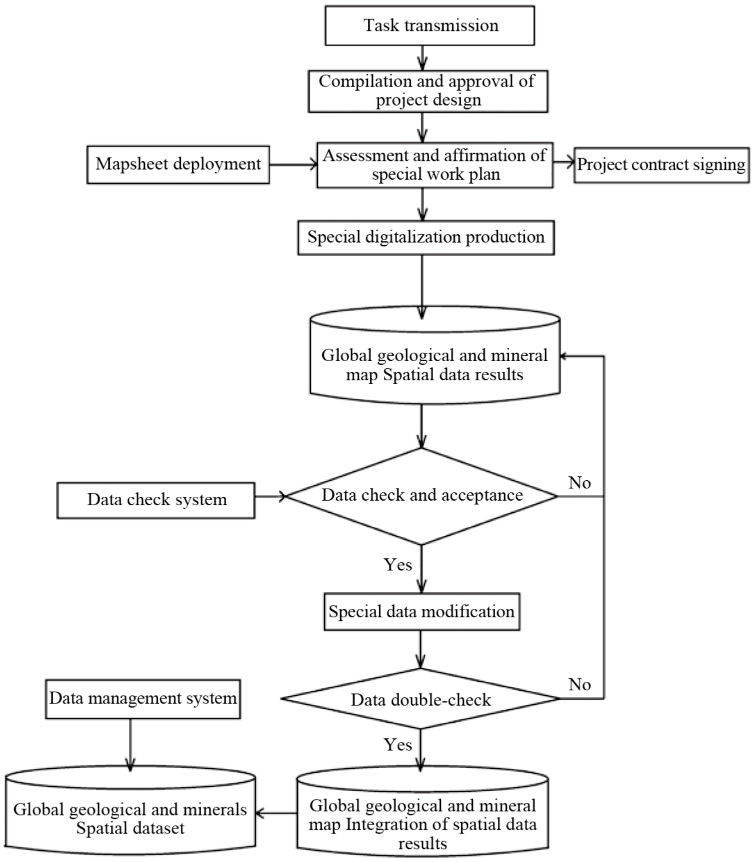

Fig. 2 Flowchart for Dataset Storage and Map Compilation of Cu−Au Deposits in Indo-China Peninsula and Western Pacific

(4) Dataset of tectonic environment and metallogenic laws of Cu−Au mineralization of Indo-China Peninsula and Western Pacific Giant metallogenic belt was established. Therein, linear and ring-like structures were extracted using geological, remote sensing (ETM+ and Hyperion) information, etc. in combination with the DEM data. Minerals, such as sphalerite, flint, and roseite, were extracted using Hyperion images and SAM. Moreover, metallogenic laws and mineralization prospects were optimized for Laos (seven scenes of ETM+, 30 scenes of DEM, and one scene of ASTER, including Palishan/Phu Kham skarn Fe−Cu−Au polymetallogenic deposit area), Burma (45 scenes of ETM+, above 100 scenes of DEM, and one scene of Hyperion), Thailand (39 scenes of ETM+, 120 scenes of DEM, and two scenes of Hyperion) and Papua New Guinea (47 scenes of ETM+, above 100 scenes of DEM, and two scenes of Hyperion) using combined GIS and weight evidence and fractal method.

5 Data Quality Control and Evaluation

Sources of the Dataset of the Comparative Study of Tectonic Environment and Metallogenic Laws of Cu–Au Mineralization in the Indo-China Peninsula and Western Pacific Giant metallogenic belt are as follows: collected geological and mineral maps of the Peninsula region published by various countries, information and drawings/maps from conventioneers' exchange, and maps collected by the project group. Meanwhile, some of geographic, geological and mineral elements contained in the dataset are from vectorization of related projects, e.g., Geological Maps of Cambodia, Laos, and Vietnam, Geological Map of Burma, and Geological Map of the Socialist Republic of the Union of Burma. In addition, they have been sourced from geographic data of Indo-China Peninsula in Southeast Asia and geographic information data, provided by the Development and Research Center of CGS, and geographic data of Indo-China Peninsula in Southeast Asia and Western Pacific Giant metallogenic belt, provided by the Yunnan Center for Basic Geographic Information. Moreover, a dataset was built for the Comparative Study of Tectonic Environment and Metallogenic Laws of Cu–Au Mineralization in the Indo-China Peninsula and Western Pacific Giant metallogenic belt, Southeast Asia. At the same time, basic geographic information map, remote sensing photomap, topographic map, geological map, mineral map and remote sensing geological interpretation map were compiled.

Furthermore, digitalized dataset establishment adopted foreign geological and minerals maps. Work base maps given selection priority include polyester film bases with weak distortion, and secondary paper media. It was ensured that the distortion of polyester film maps is less than 0.2%. If paper maps are adopted, the precision can be lowered according to users' needs. At the same time, distortion should be even and in line with precision requirements after affine transformation. Moreover, map scanning and pre-processing, graphic vectorization, manual quality check, computer topology check, etc. were conducted to ensure precision in map digitalization. Meanwhile, a digitalized production process and a suitable quality control system were developed for the geological and mineral dataset.

(1) Job Log System: Complete job log sheets were produced. Each operation personnel filed job log sheets as per requirements to record daily work contents completely and submit them to the operation team leader for signing and recognition.

(2) Self and Mutual Check System: A complete self and mutual check system was established. Each operation personnel made 100% self-check for each mapsheet, completely recorded actual self-check and modification results, and submitted them to the operation leader for signing and recognition. Based on self-check, the project leader arranged other operational personnel through 100% mutual check. The leader completely recorded actual mutual check and modification results, which were re then signed and recognized by the correspondent operation leader.

(3) Spot Check System: A project leader spot check system was used. The proportion of spot check can be regulated based on annual work mapsheets, and when the number of mapsheets is low, 100% check is needed.

(4) Stage Check System: Results of each stage of dataset establishment were checked strictly, including pixel check after map scanning vectorization, and consistency check of pixels and attributes after attribute input, etc.

(5) Confidentiality and Safety: The dataset establishment party ensured backup

and killed viruses in work data periodically. For steps including international internet connection, computer usage, computer management involving security, management of users of computer information system, portable storage device operation management, data copy operation management, and security involved equipment maintenance and usage change, a quality control system was formed per the Several Regulations on Strengthening Safety and Security Management of Computer Information System for Party and Government Offices issued by the National Administration for Protection of State Secrets and the Informatization Office of the State Council.

6 Conclusions

(1) In line with the Plate Tectonics Theory, the geotectonic framework of the Indo-China Peninsula in Southeast Asia has been established using chronological analysis (Wu, 1993). The plate tectonic environment for forming Au−Cu deposits in Western Pacific Giant metallogenic belt, Southeast Asia has been identified as porphyry. Meanwhile, Skarn and high−medium sulfide hydrothermal deposits have been found to be related to hypabyssal intrusions and volcano centers, and closely related to volcanic edifices. Moreover, disseminated (carlin-type) deposits hosting in sedimentary rocks developed near or a little further from the intrusion centers of intermediate or slightly extensional environments. Low-sulfide hydrothermal deposits have been found to be correlated to inner arc or backarc garben extensional environments. At the same time, characteristics of typical Au−Cu deposits in Western Pacific Giant metallogenic belt, Southeast Asia have been described and discussed. Mineralization characteristics of the Monywa Porphyry Cu deposit in Burma, the Phu Lon Skarn Cu deposit in Thailand, and the Sepon Porphyry Cu−Au deposit in Laos have been systematically summarized. Accordingly, metallogenic models have been established for the aforementioned deposits. Metallogenic models of Au−Cu deposits and exploration models for different exploration stages in Western Pacific Giant metallogenic belt, Southeast Asia were developed on the basis of studies on the Grasberg Porphyry Cu−Au deposit in Papua, Indonesia, the Ladolam alkaline rock epithermal gold deposit in Papua New Guinea, the Huaiximasha Mountain epithermal sulfide deposit in New Zealand, the Far Southeast−Lepanto porphyry−high sulfide epithermal Cu−Au deposit in Philippines, and other such world-level deposits.

(2) Tectonic altered rock type gold deposits were discovered in Aven, Laos. On the basis of 1:50, 000 scale aeromagnetic surveying, the multi-element statistic approach was adopted to systematically analyze 15 types of 755 samples from the 1:50, 000 scale water stream sediments survey over the Arwen gold deposit area. Therein, the mineralization-related elements included Ag, As, Au, Bi, Co, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Sn, W, and Zn. In the late stage, additional 1:10, 000 scale soil geochemical surveying and trenching were carried out. Under the support of SPSS and Surfer, geophysical and geochemical superimposed analyses respectively delineated anomalies of individual elements and element combinations. Meanwhile, the intensity, spatial distribution, and relationships with measured ore bodies, mineralized zones, alteration zones, magmatic intrusions, and structures, of individual element anomalies were investigated. The current indicated reserve by drilling is 5t, with an average grade of 3.8g/t and the prospective reserve reaching 20t, with an average grade of 2.5g/t.

(3) This competitive study shows that the Western Pacific Giant metallogenic belt has numerous large to ultra-large Cu–Au deposits, while the Indo-China Peninsula has variable Cu–Au mineralization features. Cu–Au deposit types of Western Pacific Giant metallogenic belt mainly include porphyry, high-sulfide and low sulfide types. As for the types of deposits in the Indo-China Peninsula, in addition to the aforementioned types, they include orogenic gold deposits with the most typical characteristics. Moreover, mineralization consistency between the Indo-China Peninsula and Western Pacific Giant metallogenic belt, Southeast Asia is expressed as follows: both have the capacity to form porphyry and sulfide type Cu–Au deposits, and contain ultra-large sized porphyry-type Cu–Au deposits (e.g., the Grasberg porphyry Cu–Au deposit in Indonesia, the Sepon and Phu kham porphyry-skarn type Cu–Au deposits in Laos), and high-sulfide Cu–Au deposits (the Lepanto porphyry-high sulfide Cu–Au deposit in Philippines and the Monywa porphyry-high sulfide type Cu–Au deposit in Burma).

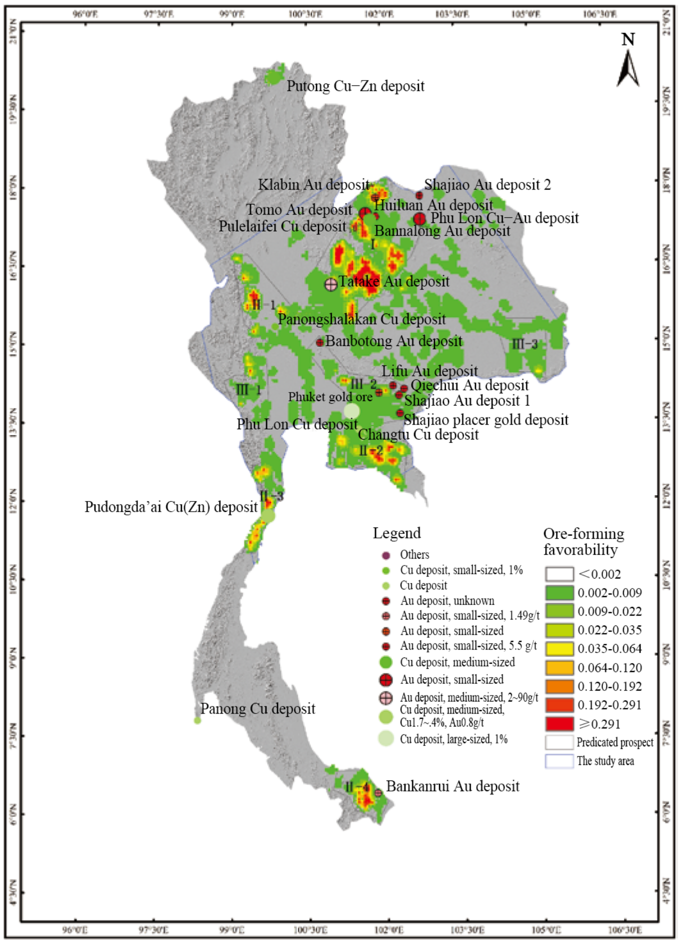

Fig. 3 Cu and Au Metallogenic Prognosis Map of Thailand

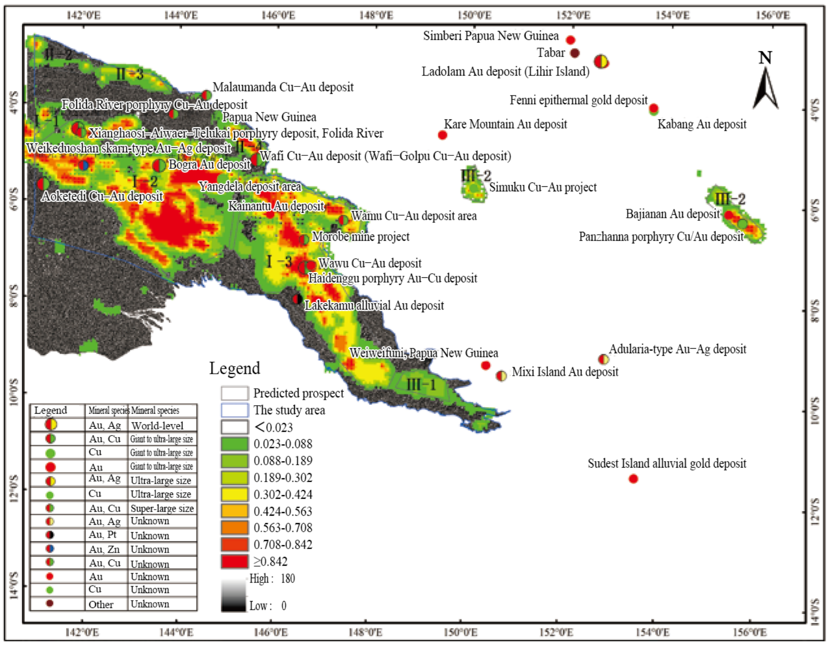

Fig. 4　Cu and Au Metallogenic Prognosis Map of Papua New Guinea

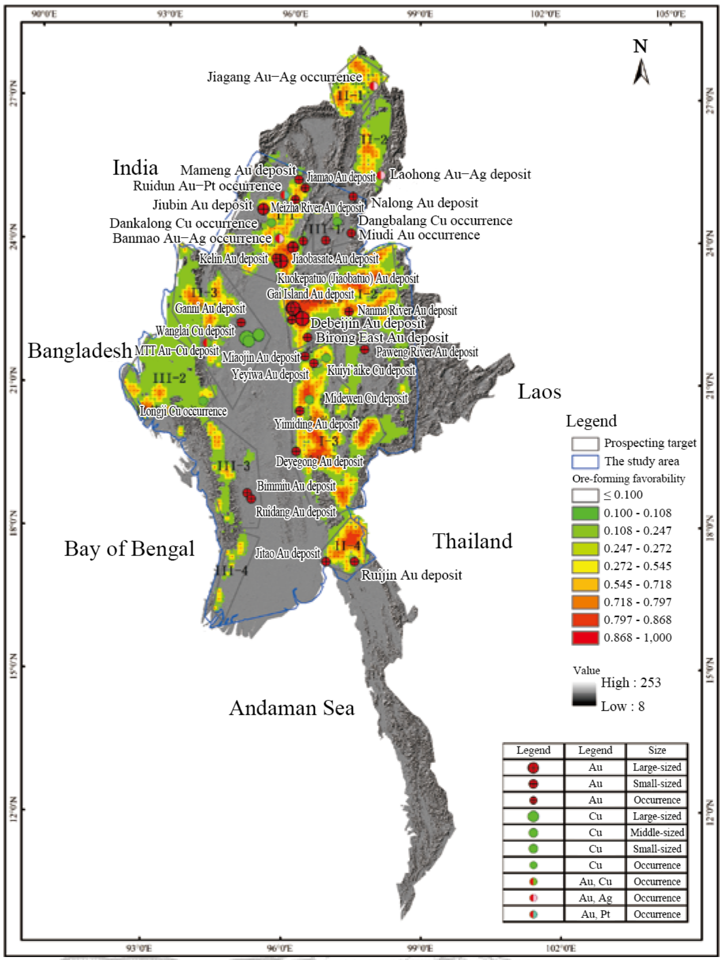

Fig. 5　Cu and Au Metallogenic Prognosis Map of Burma

(4) Metallogenic differences between the Indo-China Peninsula and Western Pacific Giant metallogenic belt, Southeast Asia are as follows:

① Difference in Deposit Type: The Indo-China Peninsula houses orogenic gold deposits, such as ModiTaung–Nankwe in Burma and Aven in Laos, in addition to porphyry type Cu–Au deposits.

② Difference in Ore-Forming Age: Cu–Au deposits in Western Pacific Giant metallogenic belt were formed in the Cenozoic period in a magmatic island arc tectonic environment related to plate subduction. Porphyry and high-sulfide Cu–Au deposits in the Indo-China Peninsula were formed in the late Paleozoic (Sepon and Phukham in Laos) and Cenozoic (Monywa in Burma) periods.

③ Difference in Mineralization and Deposit Preservation Capacity: Cu–Au resource potential of Western Pacific Giant metallogenic belt is much higher than that of the Indo-China Peninsula. It is possibly attributable to younger formation age and favorable resource preservation conditions of the former.

(5) The Dataset of Tectonic Environment and Metallogenic Laws of Cu–Au Mineralization in Indo-China Peninsula and Western Pacific Giant metallogenic belt was established. According to the aforementioned genesis and prospecting models, metallogenic prognosis and prospecting target delineation were conducted using GIS and mathematical modeling, mainly including:

Cu and Au metallogenic prognosis map of Thailand (Fig. 3)
Cu and Au metallogenic prognosis map of Papua New Guinea (Fig. 4)
Cu and Au metallogenic prognosis map of Burma (Fig. 5)

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References

Agematsu, S, Sashida K, Salyapongse S, Sardsud A. 2006. Ordovician conodonts from the Thong Pha Phum area, western Thailand[J]. Journal of Asian Earth Sciences, 26(1): 49–60.

Chen Yongqing, Chen Jianguo, Wang XIinqing. 2008. Comprehensive Quantitative Evaluation Technology of Mineral Resources Based on GIS[M]. Beijing: Geological Publishing House, 1–294 (in Chinese).

Chen Yongqing, Zhao Pengda. 2009. Extraction and Integration of Geoanomal ies Associated with Mineral ization[J]. Earth Science, 34(2): 325–335 (in Chinese with English abstract).

Chen Yongqing. South East Asia South-South Peninsula (five countries) geological and mineral map[M]. Beijing: Geological Publishing House (in Chinese).

Kelley K D and Ludington S. 2002. Cripple Creek and other alkaline–related gold deposits in the southern Rocky Mountains, USA: Influence of regional tectonics[J]. Mineralium Deposita, 37: 38–60.

Kerrich R, Goldfarb R J, Richards J P. Metallogenic provinces in an evolving geodynamic framework[J]. Economic Geology, One Hunderedth Anniversary Volume (1905–2005): 1097–1136.

Li Chunyu, Wang Quan, Liu Xueya, Tang Yaoqing. 1982. Asian Earth Structure Diagram [M]. Beijing: Map Publishing House, 1−49 (in Chinese).

Li Fangxia, Zhao Yinglong, Wang Zhuozhi.1995. Southeast Asia Geology, Minerals and Mining Economy [M]. Yunnan: Bureau of Geology and Mineral Resources of Yunnan Province (in Chinese).

Loader S. E. 1999. Supergene enrichment of the Khanong copper resource, Sepon Project, Lao PDR. Australasian Institute of Mining and Metallurgy: CarltonVictoria, 263−270.

Lu Yingxiang, Liu Hongguang, Huang Jingning, Zhang Hongyuan, Chen Yongqing. 2009. Preliminary division of the metallogenetic belts in the Central South Peninsula of Southeast Asia and their regional ore−forming characteristics[J]. Geological Bulletin of China, 28(2−3): 314−325 (in Chinese with English abstract).

Mitchell A H G, Ausa C A, Deiparine L, Hlaing T, Htay N A, Khine. 2004. The Modi Taung−Nankwe gold district, Slate belt, central Myanmar: Mesothermal veins in a Mesozoic orogen[J]. Journal of Asian Earth Sciences, 23(3): 321−341.

Wu Xisheng. 1993. Geochemical data processing method[M]. Beijing: Geological Publishing House, 1−130 (in Chinese).

Yang Shasha, Wang Gongwen, Chen Yongqing. 2015. Prediction and assessment of copper and gold resources based on in−formation extracted from remote sensing images in Thailand[J]. Geological Bulletin of China, 34(4): 780−785 (in Chinese with English abstract).

Zhang Yujun, Zeng Zhaoming, Chen Wei.2003. The methods for extraction of alteration anomalies from the ETM+(TM) data and their application: method selection and technological flow chart[J]. Remote Sensing for Land & Resources, 56(2): 44−49 (in Chinese with English abstract).

Zhao Hongjuan, Chen Yongqing, Lu Yingxiang. 2011. Ore-forming model for Cu-Au-Fe ore deposits associated with granites in the Truongson ore- forming belt of Laos[J]. Geological Bulletin of China, 30(10): 1619−1627 (in Chinese with English abstract).

China Geological Survey Aided Laos Mineral Geological Survey Preliminary Investigation Team. 2005. A preliminary inspection report on China's assistance to the Lao Mineral Geological Survey (in Chinese).