Remote sensing and GIS-based prediction and assessment of copper-gold resources in Thailand

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Abstract. Quantitative integration of geological information is a frontier and hotspot of prospecting decision research in the world. The forming process of large scale Cu-Au deposits is influenced by complicated geological events and restricted by various geological factors (stratum, structure and alteration). In this paper, using Thailand’s copper-gold deposit district as a case study, geological anomaly theory is used along with the typical copper and gold metallogenic model, ETM+ remote sensing images, geological maps and mineral geology database in study area are combined with GIS technique. These techniques create ore-forming information such as geological information (strata, line-ring faults, intrusion), remote sensing information (hydroxyl alteration, iron alteration, linear-ring structure) and the Cu-Au prospect targets. These targets were identified using weights of evidence model. The research results show that the remote sensing and geological data can be combined to quickly predict and assess for exploration of mineral resources in a regional metallogenic belt.

1. Introduction
Quantitative integration of geological information is an important method for mineral resources prediction that has benefited greatly from the development of Geographic Information System (GIS) technology. A number of large-scale factors that control the formation and localization of ore, including geological structures and alteration, can be identified using GIS and remote sensing. Many recent studies have used metallogenic prediction methods that combine remote sensing technology with geological data. Here, we use ETM+ images combined with geological data to identify areas of Thailand that are prospective for Cu-Au mineralization, a previously understudied area.

2. Geology of Thailand
Thailand is adjacent to Myanmar and Laos within the Indochina metallogenic belt of Southeast Asia. The Loei area of Thailand contains a number of well-known copper and gold deposits, including the PuLang Cu-Au, Phu Hin Lek Fai Cu, and Phu Thong Daeng Cu deposits. The majority of small Cu-Au deposits and occurrences are located in southeast Thailand, away from the mountainous north and northwest, and the flat-lying northeast of Thailand. Cambrian units occur sporadically in the Chiengmai-Tak area of northwestern Thailand, Cretaceous units are exposed in southern Thailand, voluminous Triassic units crop out within the northeast of the country, and Tertiary units are

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widespread in central and southern Thailand [1] (Fig. 1).

Figure 1. Geological map of Thailand

3. Remote sensing data and preprocessing

3.1. Data selection
Multispectral ETM+ remote sensing images consist of 8 wave bands: bands 1-3 are visible, band 4 is in the near-infrared region, bands 5 and 7 are shortwave bands with a resolution of 30 m, band 6 is a thermal infrared band with a resolution of 60 m, and band 8 is a panchromatic wave band with a resolution of 15 m [2]. The spatial and spectral resolution of ETM+ images means that they are ideally suited for the research undertaken during this study. Given this, we selected 39 ETM+ images with low amounts of cloud cover and good color contrast that cover the entirety of Thailand; additional 30 m Digital Elevation Model (DEM) images were used to extract structural information.

3.2. Image mask processing
Clouds, water, shadows, and vegetation are highlighted in the images used during this study, meaning that alteration-related spectral information may be subject to interference. As such, removal of any interference is an important step in ensuring the accuracy of the alteration information extracted from these images. We use a combination of high-end cutting and use of the band math application within ENVI software to separate and remove possible interferences by identifying the characteristic spectral response of interference within each band.

4. Extraction of geological information
Geological interpretation of remote sensing images during mineral exploration can include the extraction of mineralization, alteration, lithological, and structural information, amongst others, and combines existing geological data with identifiable features within remote sensing images, including textures and tones, that allow the identification and extraction of the geological factors that control the location of mineralization [3]. Here, we use existing geological data and remote sensing images to identify areas with iron staining and hydroxyl alteration, and linear-ring structures, both of which are important guides to mineralization in the study area.
4.1. Iron staining
The spectral characteristics of iron-bearing minerals indicate that iron oxides have a reflection peak in ETM+ band 3 and absorptions within bands 1 and 4 [4]. Areas of anomalous iron staining were identified using bands 1, 3, 4, and 5, as well as a principal component analysis (PCA) approach using ETM+ images that had undergone interference removal. The PCA approach uses a principal component that has band 1 and 3 with contribution coefficients that are opposite in sign, producing images that can identify iron alteration anomalies. The iron-staining-related principal component was then selected in each ETM+ image, and threshold segmentation using de-interfered anomalous principal component values [5] enabled the production of an alteration map (Fig. 2).

4.2. Hydroxyl alteration
Hydroxyl minerals have strong absorptions in ETM+ band 7 and strong reflections in band 5. These absorptions, combined with the fact that visible bands are sensitive to the presence of iron oxides, meant that bands 1, 4, 5, and 7 were used for PCA; only one of these bands is in the visible range, meaning that iron oxide interferences are reduced. The resulting PCA used an approach where the contribution coefficient of band 5 is opposite to that of bands 4 and 7, producing images that identify areas of anomalous hydroxyl alteration; subsequent threshold segmentation yielded a hydroxyl alteration map (Fig. 3).

4.3. Extraction of linear-ring structures
The identification of linear and ring structures is an important tool for mineral exploration within Thailand; these structures can be identified by changes in texture, tone, vegetation, and hydrology that can be directly or indirectly interpreted from remote sensing images. The approach used here combines remote sensing image and a DEM-based shaded topographic map to identify linear-ring structures at a scale of 1:1,000,000 (Fig. 4).

5. Metallogenic prediction based on weights-of-evidence modeling
Weights-of-evidence modeling is commonly used to determine prospective areas for mineral exploration during the assessment of metallogenic potential [6]. This type of modeling uses GIS technology and identifies the weights of evidence for mineralization-related factors (e.g., structure, alteration) for prospective areas using a metallogenic probability-based approach. The modeling
undertaken during this study used the location of linear-ring structures, iron staining, hydroxyl alteration, prospective geological units, and the location of known Cu-Au deposits and occurrences. All of these evidential themes were gridded at a scale of $1 \times 1$ km, yielding a map that identifies three tiers of prospect targets according to the probability of metallogenesis (Fig. 5).

**Figure 5.** Map of mineral potential targets

**Figure 4.** Map of linear and ring structure

6. Conclusion
An approach that combines remote sensing data with weights-of-evidence modeling and the analysis of existing data has enabled the definition of highly prospective areas of Thailand, yielding the following conclusions.

- Weights-of-evidence modeling allows the quantitative integration and analysis of metallogenic factors, removing the subjectivity that is inherent within traditional prediction methods, and therefore yielding objective results. The prospective areas outlined here are corroborated by existing data, proving the feasibility of this approach. These highly prospective areas should be considered priority areas for future mineral exploration.

- The accuracy of evidential themes is directly related to the reliability of the results of this modeling. Although remote sensing can provide a significant amount of information for use during mineral exploration, these data are easily affected by interference (e.g., by vegetation and cloud cover) that reduces the accuracy of the information extracted from the images. Consequently, the combination of geological mapping and other data, such as DEMs, with remote sensing images is a sound method to ensure the accuracy of metallogenic modeling.

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References

[1] Wu Liangshi 2011 The geological structure and mineral resources of Thailand J. Mineral Deposits. 30 571-574
[2] Qin Yaozu and Liu Liangming 2010 Extraction of information on structure, rock and alteration by ETM+ remote sensing at west Beishan mountain, Gansu province J. Southern Metals. 177 40-43
[3] Yang Desheng, Cheng Gang and Lu Xiaoping 2010 Application of geological interpretation and mineralization information extracting by remote-sensing in mineral resource evaluating J. Editorial Board of HPU (National Science). 29 184-189
[4] Zhang Yujun, Yang Jianmin and Chen Wei 2002 A study of the method for extraction of alteration anomalies from the ETM+(TM) data and its application: geologic basis and spectral precondition J. Land Resource Remote Sensing. 4 30-36
[5] Jing Feng and Chen Jianping 2005 The review of the alteration information extraction with remote sensing J. Remote Sensing Information. 2 62-65
[6] Li yike and Sun gang 2009 Application of Evidence Weight Model in Copper and Gold Metallogenic Prediction of Northeastern Jiangxi Province J. Gold Science and Technology. 17 29-33