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Detection of hydrothermal alteration zones in a tropical region using satellite remote sensing data: Bau goldfield, Sarawak, Malaysia

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A B S T R A C T

Remote sensing for geology in tropical environments is very challenging, because of the dense vegetation cover and the problem of persistent cloud cover. In this research paper, we have investigated and demonstrated the detection of hydrothermal alteration zones and structural elements associated with intrusion-related gold mineralization using various types of remote sensing data in the Bau gold mining district in the State of Sarawak, East Malaysia, on the island of Borneo. The climate of Bau is tropical with persistent cloud cover and very dense vegetation ground. Geological analyses coupled with remote sensing data were used to detect hydrothermally altered rocks and structural elements associated with gold mineralization in the Bau area. Landsat Enhanced Thematic $Mapper^+$ (ETM^+), Hyperion and Phased Array type L-band Synthetic Aperture Radar (PALSAR) data were used to carry out lithological–structural mapping of the mineralized zones in the study area and surrounding terrain. Hydrothermal alteration zones were detected along the SSW to NNE structural trend of the Tai Parit fault that corresponds with the occurrence of other gold mineralization in the Bau Limestone. The results show that the known gold prospects and potential areas of mineralization are recognizable by the methods used, despite limited bedrock exposure. The approach used in this study is broadly applicable to the detection of gold mineralization using ETM^+, Hyperion and PALSAR data in tropical/sub-tropical regions.

1. Introduction

Numerous remote sensing investigations for mineral exploration and lithological mapping have been conducted in arid and semi-arid terrains, with large exposures of geologic materials, allowing the acquisition of spectral information directly from rock–soil assemblages (Di Tommaso and Rubinstein, 2007; El Desouky et al., 2008; Gabr et al., 2010; Massironi et al., 2008; Pour and Hashim, 2011, 2012a, 2012b, 2013; Rajendran et al., 2012; Sabins, 1999; Van Ruitenbeek et al., 2012; Zhang et al., 2007). However, in tropical environments, the application of remote sensing data for geological mapping has been much more limited (Carranza and Hale, 2002; Galva˜o et al., 2005; Vicente and Filho, 2011), because of the dense, often complete vegetation cover in tropical regions. Moreover, the persistent cloud cover and limited bedrock exposures are other obstacles imposed by tropical environments.

In this study, the identification of hydrothermally altered rocks, faults and fractures associated with hydrothermal mineralization in a tropical environment is examined using Landsat Enhanced Thematic $Mapper^+$ (ETM^+), Hyperion and Phased Array type L-band Synthetic Aperture Radar (PALSAR) remote sensing data sets. The Bau gold mining district in Sarawak province, eastern Malaysia, on the island of Borneo in Southeast Asia serves as the study area (Fig. 1). It is located about the intersection of 1° 25′ N longitude and 110° 10′ E latitude, 25 km southwest of Kuching city, Sarawak (Fig. 2). The climate of Bau is characterized by heavy but seasonal rainfall, uniform temperature, and high humidity. Some 40% of the land is primary rainforest, mostly of the *Dipterocarpaceae* type, restricted to infertile limestone hills and higher mountains (Andriesse, 1972).

Bau is a goldfield similar to the Carlin district of gold deposits (Schuh, 1993; Sillitoe and Bonham, 1990). Gold mineralization at Bau is present from intrusive centers outward to the intrusive peripheries, but principal gold deposits occupy distal to intrusive sites and have the same geological, mineralogical, and geochemical characteristics as Carlin (sediment-hosted) gold deposits in the western United States (Sillitoe and Bonham, 1990). However, the Bau gold mineralization does not fit into today's state of knowledge about Carlin-type gold mineralization. It may be classified as intrusion-related or, using USGS terminology, distal disseminated. Carlin-type gold deposits are disseminated gold deposits hosted by a variety of permeable sedimentary rocks, especially thinly bedded, silty dolomites or limestones, cut by high-angle faults (Bagby and Berger, 1985; Percival et al., 1988; Sillitoe and Bonham, 1990). Nearly all deposits are associated with felsic intrusive rocks, commonly in the form of dikes or sills. Orebodies may be confined to fault zones or may be irregularly-shaped replacements in adjoining rocks. Gold-bearing rocks underwent decalcification, silicification, and argillic alteration, and are associated closely with structurally-localized replacement of carbonate rock by jasperoid (Arehart, 1996; Rockwell and Hofstra, 2008;

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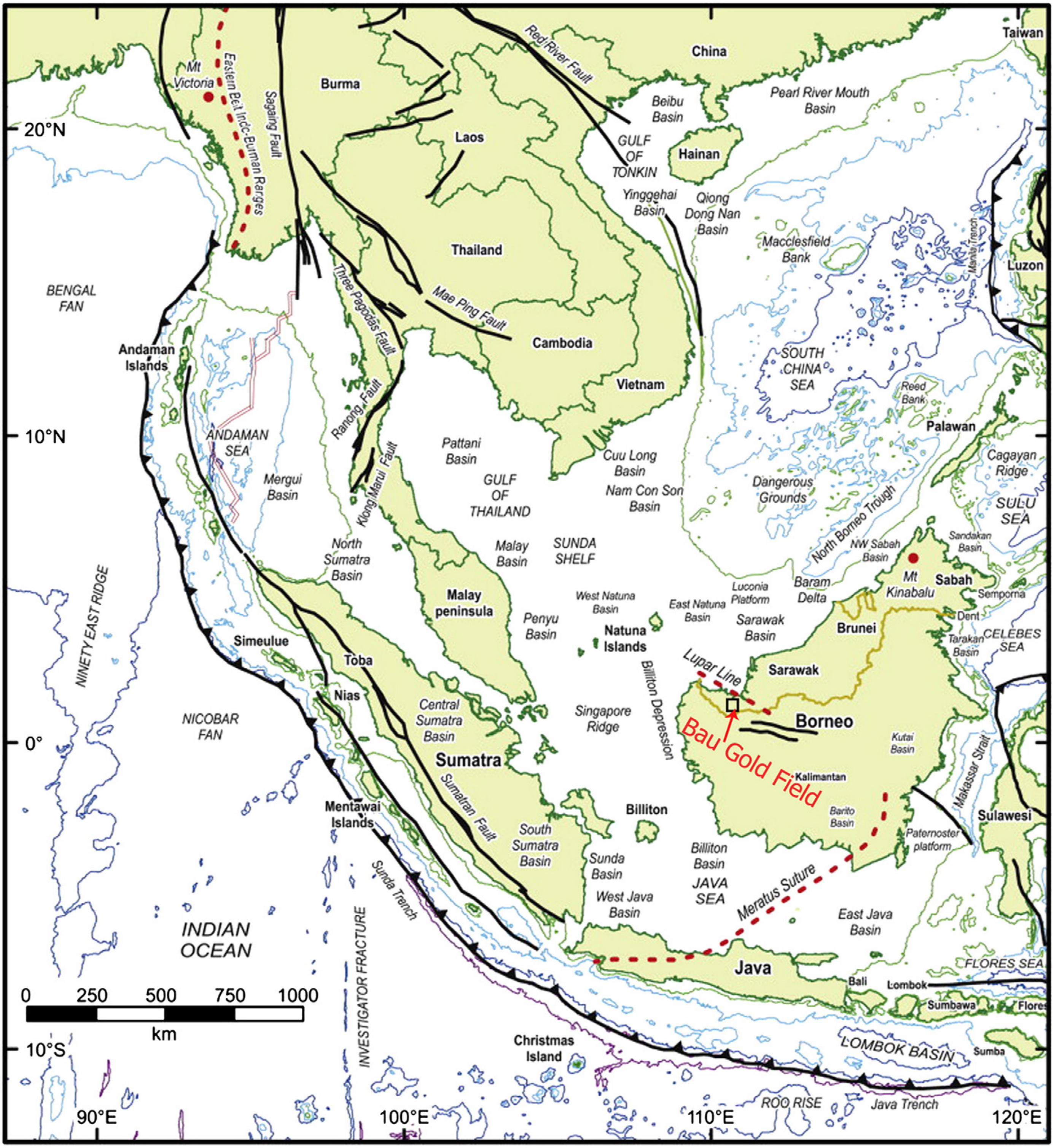

Fig. 1. Location of the study area in Southeast Asia. The Bau gold mining district is in westernmost Borneo. It is located in the state of Sarawak, which is part of Malaysia. Modified from Hall (2012).

Sillitoe and Bonham, 1990; Zhu et al., 2011). These geological characteristics can be detected as indicators in the reconnaissance stages of exploration for intrusion-related gold mineralization using remote sensing data.

Gold was first discovered in the Bau goldfield in the 1870s, but there was very little production until 1909, and only about 22,000 oz was produced through 1964 (Dill and Horn, 1996; Hon, 1981; Schuh, 1993). In comparison, by 2008, the intrusion-related mineralization trend in Sarawak had produced over 70 million ounces of gold (Stevens and Fulton, 2010). The Bau goldfield is located in this mineralization trend where a variety of mineralization styles ranging from mesothermal to low-temperature deposits were recognized. Six distinct types of ore deposits occur in the Bau mining district, including porphyry-copper deposits (Gunong Ropih, Gunong Juala), contact metasomatic Cu–Au skarn deposits (Arong Bakit), Cordilleran vein-type mesothermal precious metal and Pb–Zn–Ag sulfide deposits (Sarabau Mine, Bekajang,