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Geology, mineralogy, geochemistry and $\delta^{34}S$ of sedimentary rock-hosted Au deposits in Song Hien structure, NE Vietnam

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ABSTRACT

The Song Hien rift basin is considered to be one of the most important regions of gold mineralisation in North East Vietnam. A number of gold deposits in the Song Hien rift basin are hosted in Triassic and Devonian sedimentary formations of the basin. The largest among them are the Bo Va, Tham Riem and Khung Khoang deposits. The Bo Va deposit is hosted in carbonaceous sedimentary rocks of Triassic age, whereas the Tham Riem and Khung Khoang deposits are hosted in carbonaceous sedimentary rocks of Devonian ages. Based on the mineral composition of the ores, the deposits can be divided into to two types: (i) pyrite dominated and (ii) pyrite-arsenopyrite dominated. The Khung Khoang is of the first type and the Bo Va and Tham Riem deposits belong to the second type. The isotopic composition of pyrite and arsenopyrite in the Tham Riem deposit however, is close to that for the ores of the Bo Va deposit. The $\delta^{34}S$ value for pyrite ranging from −3.7‰ to −7.4‰ and for arsenopyrite ranging from −3.2‰ to 7.4‰. The $\delta^{34}S$ of pyrite in the ore from the Khung Khoang deposit however, has a much heavier isotopic composition of +18.9 to +20.2‰. A narrow range of the variation of sulfur isotopic composition of pyrite and arsenopyrite, the presence of visible gold as inclusions, the presence of chalcopyrite, sphalerite and other inclusions in arsenopyrite and pyrite, the large size of the grains of major ore minerals allow us to assume that the primary gold ores of the Bo Va and Tham Riem deposits underwent metamorphic transformations. The absence of arsenic, antimony, mercury and other characteristic elements in the ores of the Khung Khoang deposit, and substantially heavier isotopic composition of sulfur similar to the sulfur isotopic composition of marine sulfates in the Devonian, allow us to assume another source of the ore components, not connected with the Triassic sedimentary rocks of the Song Hien rift.

1. Introduction

A specific ensemble of precious metals deposits including orogenic gold deposits, Carlin type, and epithermal Au-Sb-Hg mineralization occurs in sedimentary basins containing carbonaceous sediments in many gold provinces of the world (West and Southern Tyan Shan, Eastern Kazakhstan, Verkhoyansk province, the Yenisei Ridge, South-Western China and many others) (Berger et al., 2014; Gold deposits of Russia, 2010; Goldfarb et al., 2014; Goryachev, 2006; Goryachev and Yakubchuk, 2008; Konstantinov et al., 2009; Morelli et al., 2007; Novozhilov and Gavrilov, 1999; Nozhkin et al., 2011; Peters et al., 2007; Spiridonov, 1996; Yakubchuk et al., 2002).

One area that is considered important for metallogenic studies is the Song Hien rift basin in Northeastern Vietnam. The basin consists mainly of Triassic sulfide-rich black shale beds, which play a role as a sedimentary host for various mineral systems such as antimony, mercury and gold-sulfide deposits (Hoa et al., 2008). Gold deposits (of the pyrite-arsenopyrite type) in carbonaceous sedimentary rocks are also known; such deposits include the Bong Mue and Ta Nang ore clusters in Central Vietnam and Southern Vietnam, respectively, as well as the Lang Neo, Lang Vai, Na Pai, Hat Han and other deposits in the northern part of the country (Anh et al., 2015; Hoa et al., 2008; Nguyen, 2008; Tran et al., 2016a,b).

The Triassic Song Hien sedimentary basin extends towards the northwest to the boundary with China and has been interpreted

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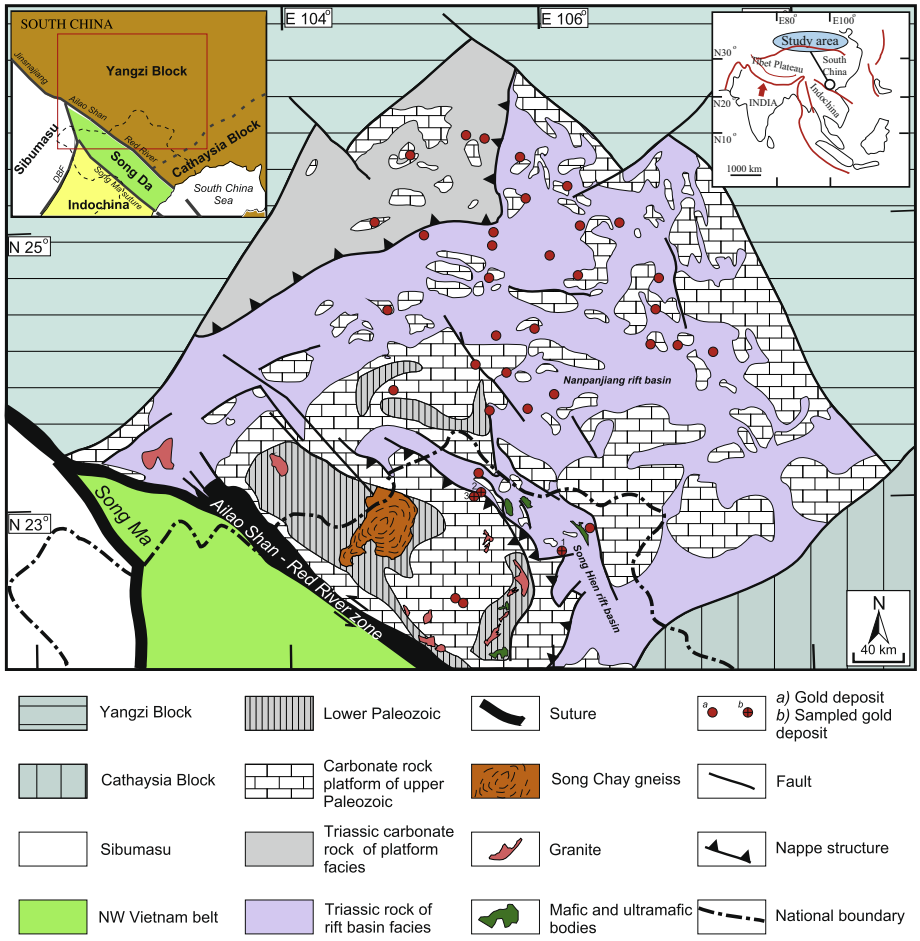

Fig. 1. Regional geological map showing the location of the sampling sites in the gold deposits of Song Hien structure and Yunnan–Guizhou–Guangxi "golden triangle" area (modified from Cai et al., 2014; Chen et al., 2011, 2015a,b; Chen et al., 2014; Lepvrier et al., 2011; Peng et al., 2014; Roger et al., 2012; Svetlitskaya et al., 2015; Yang et al., 2012). *Sampled gold deposit: 1 – Bo Va, 2 – Khung Khoang, 3 –Tham Riem.*

as an intracontinental rift structure related to the Emeishan LIP (Hoa et al., 2008; Izokh et al., 2005; Polyakov et al., 2009; Vladimirov et al., 2012). To the northwest, in the Guangxi and Yunnan provinces of China, the Nanpanjang (Youjiang Basin) sedimentary basin is analogous to the Song Hien (Galfetti et al., 2008; Guangxi BGMR, 1985). Because it hosts a number of gold deposits, Nanpanjang is included in a metallogenic province that is called the "golden triangle" (Chen et al., 2011; Peters et al., 2007; Zhong et al., 2002; Zhou et al., 2002) (Fig. 1).

This paper summarizes the results of investigations in the Song Hien structure that were part of a joint collaborative agreement between the Institute of Geology and Mineralogy (SB RAS) and the Geological Institute (VAST) to study Au deposits hosted in sedimentary rocks in Vietnam. The paper contains descriptions and the results of field and laboratory studies of the Au deposits. In this study, we report for the first time on the ore minerals' compositions, their geochemical characteristics and the sulfur isotopic compositions of the sulfide minerals. We also investigate the relationship between gold mineralization and the tectonic-magmatic evolution of the region.

2. Geological background

2.1. Regional geology

The geological development of South-Eastern Asia began in the Precambrian and continues today. The territory of Vietnam includes parts of two major tectonic blocks (Faure et al., 2014), which are the Indochina Block in the south-west and North Vietnam-South China Block in north-east (Hoa et al., 2008; Zhang et al., 2013). The timing of collision between these blocks is assumed to be mainly Triassic (Lepvrier et al., 1997, 2008, 2011; Liu et al., 2012).

The Red River fault zone is the major structure of northern Vietnam. It is Cenozoic left-lateral shear zone that accommodated the extrusion of Sundaland due to Indian collision (Leloup et al., 1995; Tapponnier et al., 1990;). This zone separates the northern part of the country into two structural tectonic zones – NW and NE fold belts (Faure et al., 2014; Hoa, 2007).

Structural zones or terrains are distinguished within each folded system. The most important structural elements in the north-western part of Vietnam are early Precambrian basement uplifts, which include the Phan Si Pan elevation and the P-T Song Da – Tu Le intracontinental rift system. The structures identified in the north-east include Song Chay Dome, which represents a part of the basement of the Yangzi platform that was remobilized during the Triassic, and the surrounding Lo Gam and Phu Ngu structures that border on the Mesozoic-age Song Hien and An Chau depressions in the east and the arched Yen Minh-Ngan Son fault system in the west (Faure et al., 2014; Hoa et al., 2008; Lepvrier et al., 2011; Tran et al., 2016b).

Terrigenous and volcanogenic-terrigenous Triassic series that are locally interbedded with felsic lavas and their tuffs dominate in the modern erosion section within the Song Hien zone (Faure