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Sustainable Critical Mineral Resource Development for Energy Transition (ISCMRDET 2026)

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Table of Contents

The Ngoc Linh Complex in Central Kon Tum Massif: an exposed remnant of the Early Paleozoic collisional tectonism in East Central Indochina mainland

Hai Thanh Tran, Truong Tai Nguyen, Hau Vinh Bui, Thanh Xuan Ngo, Monsup Cho, Chi Kim Ngo, Dao Anh Vu, Hiep Huu Nguyen, Binh Van Phan, Hung Quoc Nguyen..... 1

Late Cretaceous Magmatism in the Nui Sam Area (An Giang Province, Southwestern Vietnam): Implications for the Tectono-Magmatic Evolution of the Ankroet Complex

Bui Vinh Hau, Tran Thanh Hai, Nguyen Truong Tai, Ngo Thi Kim Chi, Phan Van Binh, Vu Anh Dao, Nguyen Huu Hiep, Nguyen Quoc Hung, Ngo Xuan Thanh 10

U–Pb zircon geochronology of meta-diorite in the Vit Thu Lu area, northern Quang Tri, central Vietnam

Dinh Trong Tuong, Nguyen Quoc Hung, Tran My Dung, Ha Tri Dung, Dang My Cung, Ngo Xuan Thanh 16

Post-collisional extension during the Early Paleozoic in Northeast Vietnam: Evidence from syenitic complex

Chu Van Dung, Tran My Dung, Ngo Xuan Thanh..... 23

Zircon U–Pb constraints on episodic magmatism of the Hai Van granitoid complex and implications for the Indosinian orogeny in central Vietnam

Dinh Trong Tuong, Ngo Xuan Thanh, Tran My Dung Ha Tri Dung 34

Controlling factors on mineralization in the Tram Tau felsic volcanic formation (Tu Le Basin, North Vietnam)

Tran Thi Huong, Nguyen Hoang, Tran Thanh Hai..... 42

Distribution and Metamorphic Evolution of REE-bearing Minerals in Metapelitic Rocks of the Nam Co Formation, Song Ma Suture Zone, NW Vietnam

Bui Vinh Hau 56

Technology for rare earth ore beneficiation in Vietnam

Thanh Hai Pham..... 63

Structural and tectonic controls on gold mineralization in the northern Kon Tum massif, Vietnam

Vu Tien Thanh, Nguyen Van Vuong, Luong Thi Thu Hoai 73

Potential for Marine Ion-Adsorption Rare Earth Deposits: Sedimentary Facies Controls in Southwestern Vietnam

Nguyen Huu Hiep, Phan Van Binh, Tran Thanh Hai, Bui Hoang Bac 85

Fluvial geomorphology and weathering crust controls on ion-adsorption rare earth element mineralization in Northwestern Vietnam

Dinh Thi Hue, Vu Anh Dao 93

Tectonic – Geomorphology and its relation to geo-hazards in the Southwest region of Vietnam

Nguyen Xuan Nam, Tran Thanh Hai, Ngo Thi Kim Chi, Hoang Ngo Tu Do, Vu Anh Dao, Nguyen Xuan Quang..... 100

Grain-size and mineralogical characteristics of surface sediments in the Con Co Island area and their environmental significance

Distribution and Metamorphic Evolution of REE-bearing Minerals in Metapelitic Rocks of the Nam Co Formation, Song Ma Suture Zone, NW Vietnam

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ABSTRACT

Rare earth elements (REEs) in metamorphic rocks are commonly hosted by accessory minerals whose stability and distribution are strongly controlled by bulk-rock composition, metamorphic grade, and fluid activity. This study investigates the occurrence, textural characteristics, and metamorphic evolution of REE-bearing minerals in metapelitic rocks of the Nam Co Formation within the Song Ma suture zone, northwestern Vietnam. Petrographic observations combined with SEM-BSE and EDS analyses reveal that REEs are mainly concentrated in monazite, xenotime, allanite, apatite, and zircon. These minerals display systematic variations across metamorphic zones, from the biotite zone to the garnet zone and its southwestern margin. Allanite is dominant at lower metamorphic grades, whereas monazite and xenotime become increasingly abundant in higher-grade zones, reflecting prograde metamorphic reactions and redistribution of REEs. Textural relationships indicate both prograde growth and retrograde modification of REE-bearing minerals, locally influenced by fluid-assisted reactions. The results suggest that metamorphic grade and fluid activity play key roles in controlling the stability and transformation of REE minerals, providing important insights into the tectono-metamorphic evolution of the Song Ma suture zone during Indosinian orogenesis.

Keywords: *REE-bearing minerals; Metapelite; Nam Co Formation; Song Ma suture zone; Metamorphic evolution*

1. Introduction

Rare earth elements (REEs) are critical tracers of geological processes due to their coherent chemical behavior and sensitivity to mineralogical controls. In metamorphic rocks, REEs are predominantly hosted by accessory minerals such as monazite, xenotime, allanite, zircon, and apatite, whose stability is strongly dependent on bulk-rock composition, pressure-temperature (P-T) conditions, and fluid activity. Consequently, the study of REE-bearing minerals provides valuable constraints on metamorphic evolution and tectonic processes.

Metapelitic rocks are particularly suitable for investigating REE behavior during metamorphism, as they commonly contain a diverse assemblage of REE-hosting minerals and undergo progressive mineralogical changes with increasing metamorphic grade. Numerous studies have demonstrated that prograde metamorphism can induce reactions such as allanite breakdown and monazite growth, accompanied by redistribution and fractionation of light and heavy REEs (Pyle et al., 2001; Janots et al., 2008).

The Song Ma suture zone represents a major tectonic boundary in northwestern Vietnam, marking the collision between the Indochina and South China blocks during the Indosinian orogeny. Within this zone, the Nam Co Formation comprises metapelitic sequences that record multistage metamorphism and deformation. However, the distribution and metamorphic evolution of REE-bearing minerals in these rocks remain poorly documented.

This study aims to (1) characterize the types and textural features of REE-bearing minerals in metapelitic rocks of the Nam Co Formation, (2) evaluate their systematic variations

across metamorphic zones, and (3) discuss the implications for metamorphic processes and tectonic evolution of the Song Ma suture zone.

2. Geological Setting

2.1. Song Ma Suture Zone

The Song Ma suture zone is a NW–SE-trending tectonic belt extending across northwestern Vietnam and adjacent regions of Laos. It represents the boundary between the Indochina Block to the southwest and the South China Block to the northeast. The zone is characterized by high-strain deformation, ophiolitic remnants, high-pressure metamorphic rocks, and widespread magmatic activity related to Paleozoic–Mesozoic tectonism (Figure 1a, Metcalfe, 2006; Nakano et al., 2010; Tri and Khuc, 2011; Thanh et al., 2011; Liu et al., 2012; Vuong et al., 2013; Zhang et al., 2013, 2014; Hieu et al., 2017; Hau et al., 2018, 2026)

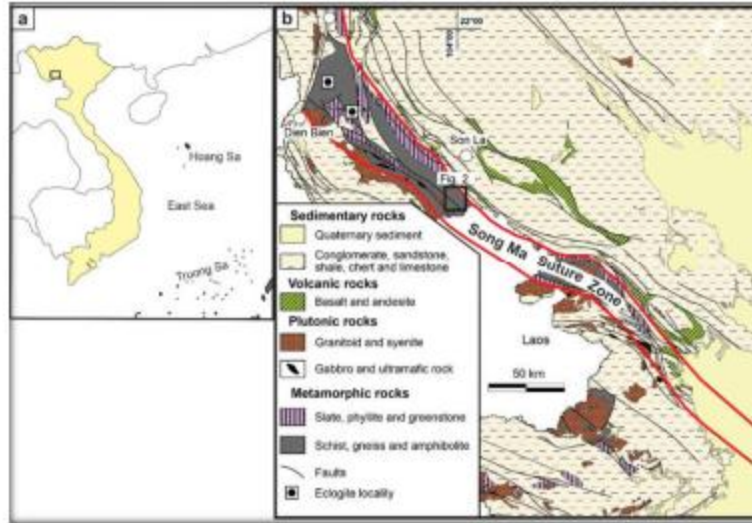


Figure 1. Simplified geological map of northwestern Vietnam (After Luong and Bao, 1988, Hau et al., 2018), with approximate location of the study area

2.2. Nam Co Formation

The Nam Co Formation consists predominantly of metasedimentary rocks, including metapelite, metapsammite, and minor carbonate layers. These rocks have undergone regional metamorphism and deformation associated with the Indosinian Orogeny. Metapelitic lithologies are widespread and contain abundant index minerals suitable for metamorphic zoning.

2.3. Metamorphic Zoning

Based on mineral assemblages, the Nam Co metapelites can be subdivided into a biotite zone and a garnet zone, with further variations observed between the core and the southwestern margin of the garnet zone (Figure 2; Hau et al., 2018, 2026). These zones record progressive metamorphism from lower- to higher-grade conditions and provide an ideal framework for examining the distribution of REE-bearing minerals.

3. Materials and Methods