



Carbon isotopic excursions and detailed ammonoid and conodont biostratigraphies around Smithian–Spathian boundary in the Bac Thuy Formation, Vietnam



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ABSTRACT

The Smithian–Spathian boundary is indicated by the first occurrence of the ammonoid *Tirolites* cf. *cassianus* in the Olenekian Bac Thuy Formation, northeastern Vietnam. The boundary is intercalated within organic-rich dark gray mudstone that accumulated under anoxic to dysoxic conditions in the An Chau and Nanpanjiang Basins on the South China Block. In Lang Son area, three conodont zones, *Novispathodus* ex gr. *waageni*, *Novispathodus* ex gr. *pingdingshanensis*, and *Icriospathodus collinsoni*, are recognized in the formation. The Smithian–Spathian boundary is intercalated within *N.* ex gr. *pingdingshanensis* conodont Zone. The positive excursion in $\delta^{13}\text{C}$ with values increasing from around -2.3% to $+5.7\%$ was recorded in the uppermost Smithian *Xenoceltites variocostatus* ammonoid beds and *N.* ex gr. *pingdingshanensis* conodont Zone. The $\delta^{13}\text{C}$ values decrease across the Smithian–Spathian boundary. These $\delta^{13}\text{C}$ isotopic patterns are correlated with well-known positive excursions around the Smithian–Spathian boundary globally.

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1. Introduction

Around the Smithian–Spathian (S–S), mid Olenekian boundary in the Early Triassic, drastic change of marine ecosystems are recognized as significant in delaying recovery of marine fauna following the end-Permian mass extinction (Galfetti et al. 2007; Algeo et al. 2011; Payne and Clapham 2012; Sun et al. 2012). At that time, an intense ocean anoxic event characterized by the accumulation of organic-rich black shale, a decrease in U/Th and ΩCe of conodont teeth and pyrite framboid size distributions has been reported (Galfetti et al. 2008; Song et al. 2012; Komatsu et al. 2014a; Shigeta et al. 2014; Tian et al. 2014). The resulting positive carbon isotope excursion is associated with global climate change in both marine and terrestrial ecosystems (Payne et al. 2004; Galfetti et al. 2007, 2008; Horacek et al. 2007; Tong et al. 2007; Saito et al. 2013). These climatic changes and fluctuations of marine productivity had an influence on the global patterns of ammonoid

distribution, and dampened the radiations of ammonoid and conodont faunas in the latest Smithian (Galfetti et al. 2007, 2008; Orchard 2007; Stanley 2009).

The Smithian–Spathian boundary is generally defined by ammonoid and conodont biostratigraphic zones, although the boundary of GSSP isn't designated. The basal Spathian is marked by the appearance of many new ammonoid taxa, including dinaritines, tirolitines and columbitids (Balini et al. 2010); *Tirolites* in particular is a significant age diagnostic ammonoid in the lowest Spathian (Galfetti et al. 2008; Ogg 2012; Shigeta et al. 2014). Among conodonts, the first appearance of *N. pingdingshanensis* (= *N. pingdingshanensis* in Goudemand et al. 2012) has been used as a guide to the S–S boundary in south China (Zhao et al. 2007; Tong et al. 2007; Liang et al. 2011; Chen et al. 2013, 2015). Payne et al. (2004) and Song et al. (2012) correlated south Chinese sections and carbon isotopic excursions on the basis of first appearance of *Neospathodus crassatus* (= *Icriospathodus? crassatus* in Orchard 1995).

We recovered abundant collections of ammonoids and conodonts, including the basal Spathian age diagnostic species, in the Olenekian

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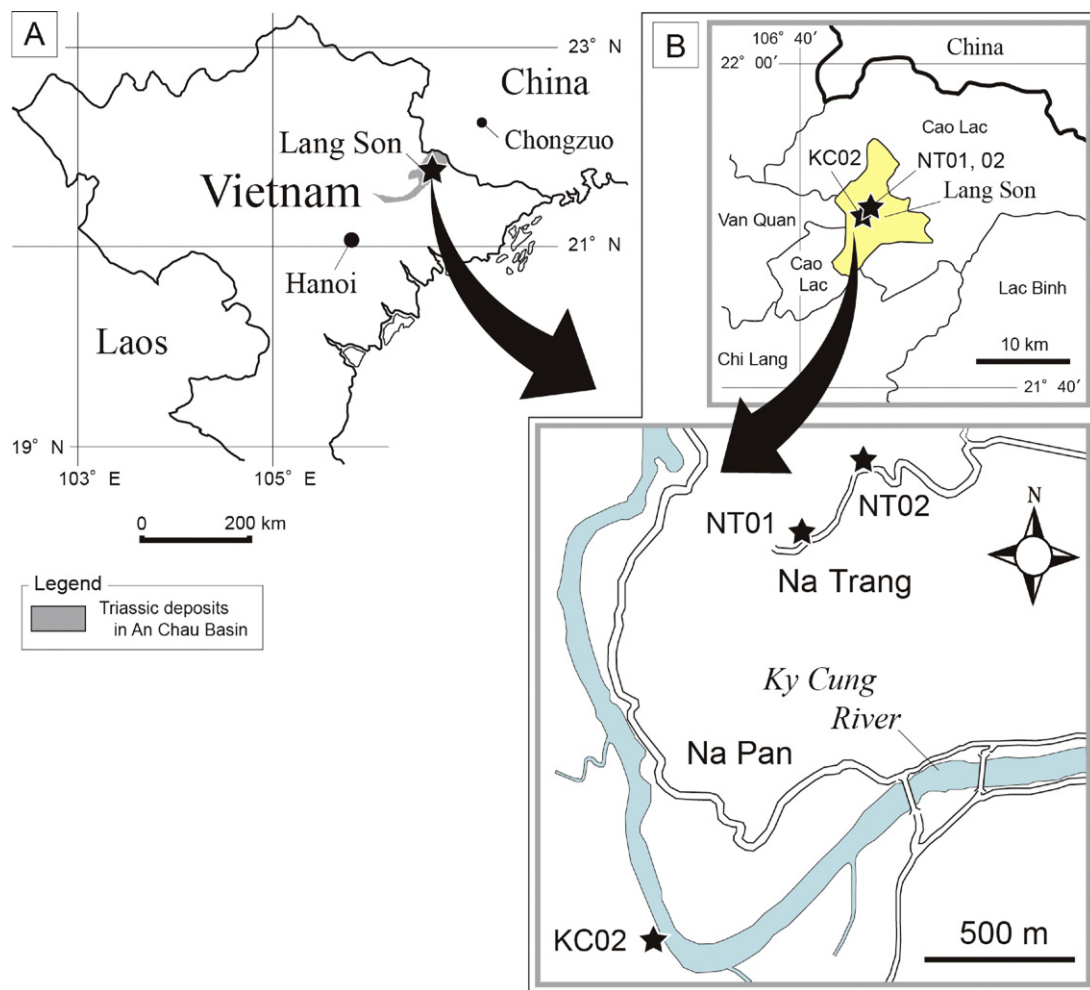


Fig. 1. (A) Map showing the An Chau Basin located primarily in Lang Son Province, Vietnam. (B) Location of the study area. Black stars representing the locations of the studied sections (NT01, KC02).

sections of northeastern Vietnam (Fig. 1; Shigeta et al. 2014). In this study, we report additional collections of ammonoid and conodont specimens from the middle part of the Bac Thuy Formation, and calibrate detailed ammonoid and conodont biostratigraphic data and carbon isotopic excursions around the S–S boundary. The total organic carbon content (TOC) from the latest Smithian to earliest Spathian organic-rich dark-gray limestone and black mudstone was also measured.

2. Geologic setting

In the An Chau Basin of Vietnam (Fig. 1), the Lower Triassic is composed of siliciclastics of the Induan to lower Olenekian Lang Son Formation, and the Olenekian Bac Thuy Formation characterized by carbonates (Dang and Nguyen 2005; Komatsu and Dang 2007; Maekawa et al. 2015). The Bac Thuy Formation is approximately 40 to 200 m in thickness (Dang 2006; Komatsu et al. 2014a; Shigeta et al. 2014; Maekawa et al. 2016), and consists mainly of fossiliferous carbonates, limestone breccia, and hemipelagic basinal marl and mudstone (Fig. 2). This formation conformably overlies the Lang Son Formation, and is unconformably overlain by the Middle Triassic (Anisian–Ladinian) Khon Lang Formation, which consists mainly of volcanic and siliciclastic rocks (Dang 2006; Shigeta et al. 2014).

In the Lang Son area (Fig. 1), the Bac Thuy Formation is divided into lower, middle and upper parts, and is characterized by a typical transgressive succession ranging from tide- and wave-influenced

shallow marine carbonate platform, through slope, and finally marginal basin plain environments (Komatsu et al. 2014a).

The lower part of the formation consists mainly of thick limestone breccia, bedded limestone, thin-bedded lime mudstone, and hemipelagic greenish gray mudstone. Thin shallow marine carbonate platform deposits crop out along a tributary of the Ky Cung River near Na Pan (Fig. 1, section KC01 in Komatsu et al. 2014a; Shigeta et al. 2014). The bioclastic shallow marine platform limestone and slope deposits of the lower Bac Thuy Formation commonly yield early Olenekian (Smithian) ammonoids *Owenites koeneni* and *Submeekoceras hsiiyüchieni* (Shigeta et al. 2014).

The middle part of the Bac Thuy Formation is characterized by alternating dark gray organic-rich limestone and mudstone yielding abundant radiolarians, the bivalve *Crittendenia*, the uppermost Smithian ammonoid *Xenoceltites variocostatus*, and the lowermost Spathian *Tirolites* cf. *cassianus* (Komatsu et al. 2013, 2014a; Shigeta et al. 2014). Komatsu et al. (2014a) reported that the Smithian–Spathian boundary, which embedded in anoxic to dysoxic facies characterized by organic-rich mudstone, is intercalated in the middle part of the formation.

The upper part of the Bac Thuy Formation is dominated by thick greenish gray hemipelagic mudstone intercalating with thin calciturbidite layers, bedded limestones, and limestone breccias. The mudstone is locally overlain by alternating siliciclastic sandstone and mudstone. The hemipelagic mudstone and calciturbidite layers commonly contain Spathian ammonoids *Columbites* and *Tirolites*, and the bivalves *Crittendenia*, *Leptochondria*, and *Bositra*. These thick

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