

The Nishinakayama Formation (Toyora Group) exposed along the Era River revisited: Preliminary report on recent outcrop condition and lithology

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Abstract: The Lower Jurassic (upper Pliensbachian to lower Toarcian) Nishinakayama Formation of the Toyora Group, which crops out in the Toyora area of Shimonoseki City, Yamaguchi Prefecture is geologically significant owing to the occurrence of various fossils and the presence of a thick record of the Toarcian Oceanic Anoxic Event (T-OAE). In particular, the Sakuraguchi-dani section in Toyota Town, Shimonoseki City has been heavily investigated because the rocks are exposed nearly continuously. However, sections other than Sakuraguchi-dani have been less well-studied. Thus, to better understand the Toarcian palaeoenvironments recorded in the Nishinakayama Formation, exploration of other sections is required. In this study, we present the preliminary results of recent geological fieldwork at outcrops exposed along the Era River (Era River section). The total thickness of the Era River section is thicker than that of the Sakuraguchi-dani section, although the exposure is relatively less continuous. The lithology of the Era River strata predominantly comprises black silty mudstones, which can be divided into three lithofacies (laminated, bioturbated, thin-bedded). In addition, some minor sandstone and tuff beds are present. Based on our results, it is highly likely that the stratigraphic interval of the Era River section encompasses a thick record of the palaeoclimatologically important T-OAE. As such, further geological investigation of the section, including the use of core drilling to fill exposure gaps, is warranted.

Key words: Toyora Group, Nishinakayama Formation, Era River, Toarcian, oceanic anoxic event

INTRODUCTION

The Lower to Middle Jurassic (Sinemurian to Bathonian) siliciclastic sedimentary rocks of the Toyora Group crop out in the Toyora area of Shimonoseki City, Yamaguchi Prefecture, southwestern Japan (Fig. 1). The group unconformably rests upon pre-Jurassic metamorphic rocks, and it is lithostratigraphically divided into three formations that together comprise a major sedimentary cycle: the Higashinagano Formation, representing a transgressive phase; the Nishinakayama Formation, representing an inundative phase; and the Utano Formation, representing a regressive phase (Hirano, 1971). The Nishinakayama Formation (upper Pliensbachian to lower Toarcian) has been well studied due to its fossiliferous nature, mostly

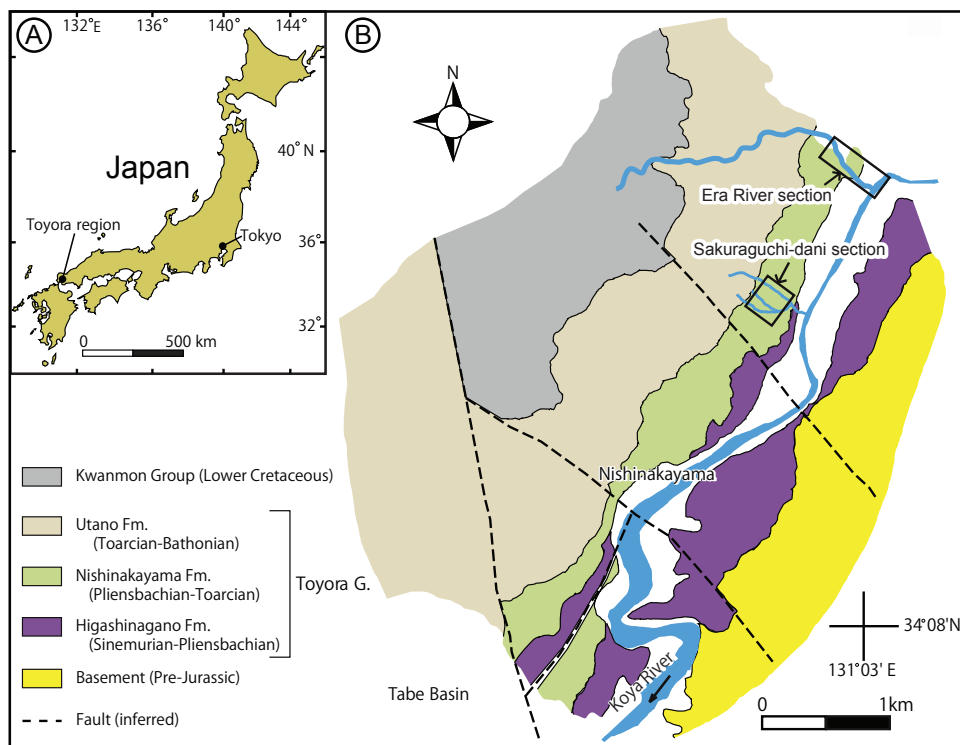


Figure 1. (A) Map of Japan highlighting the location of the Toyora area. (B) Geological map of the Toyora area (Modified after Nakada & Matsuoka, 2011), with the Sakuraguchi-dani and Era River sections highlighted.

characterized by a rich ammonoid assemblage (e.g., Matsumoto & Ono, 1947; Hirano, 1971, 1973a, b; Tanabe, 1991; Nakada & Matsuoka, 2011; Takeda & Tanabe, 2015). The fossil assemblage from the Nishinakayama Formation is not limited to ammonoids but also comprises plants (Kimura *et al.*, 1986; Yamada & Ohno, 2005), insects (Fujiyama, 1974), bivalves (e.g., Hayami, 1960, 1988; Tanabe *et al.*, 1982; Tanabe, 1991), belemnoids (Tanabe *et al.*, 1982; Tanabe, 1991), crinoids (Tanabe *et al.*, 1982; Tanabe, 1991; Hunter *et al.*, 2011), teleost fish (e.g., Tanabe, 1991; Nakada & Matsuoka, 2012), reptiles (Hasegawa *et al.*, 1998; Manabe & Hasegawa, 1998), and invertebrate trace fossils (e.g., Izumi *et al.*, 2012; Izumi, 2014).

In recent years, a series of geochemical studies presented evidence for a $\sim 3.5\%$ excursion in the stable carbon isotope composition of organic matter ($\delta^{13}\text{C}_{\text{org}}$) recorded in the Nishinakayama Formation (Izumi *et al.*, 2012, 2018a; Kemp & Izumi, 2014). This negative $\delta^{13}\text{C}$ excursion is a globally recognizable diagnostic feature of the early Toarcian Oceanic Anoxic Event (T-OAE; ~ 182 Ma, e.g., Hesselbo *et al.*, 2000, 2007; Them *et al.*, 2017). The T-OAE represents one of the most significant palaeoenvironmental perturbations of the Phanerozoic (e.g., Takashima *et al.*, 2006), resulting in marked disruption to both the climate system and the biosphere. Notably, coeval with the negative $\delta^{13}\text{C}$ excursion in a number of localities is associated evidence for abrupt seawater warming, ocean acidification, enhanced hydrological cycling, an increase in global continental weathering rates, and ocean deoxygenation (e.g., Bailey *et al.*, 2003; McElwain *et al.*, 2005; Pearce *et al.*, 2008; Dera *et al.*, 2009; Trecalli *et al.*, 2012; Brazier *et al.*, 2015; Krencker *et al.*, 2015; Fujisaki *et al.*, 2016; Percival *et al.*, 2016; Them *et al.*, 2017). Although some recent studies have presented evidence for the negative $\delta^{13}\text{C}$ excursion and associated palaeoenvironmental perturbations from Toarcian strata deposited at marginal/pelagic settings of the Panthalassic Ocean (e.g., Al-Suwaidi *et al.*, 2010; Mazzini *et al.*, 2010; Caruthers *et al.*, 2011; Fujisaki *et al.*, 2016; Them *et al.*, 2017), most studies of the T-OAE have been concentrated on strata in European countries deposited in the Tethys and Boreal oceans.

Because the sedimentary basin of the Toyora Group was located on the northwestern margin of the Panthalassic Ocean (Izumi *et al.*, 2019), the Nishinakayama Formation provides important data for better understanding of the nature of the T-OAE. Evidence for enhanced hydrological cycling and deoxygenation has recently been published from the Nishinakayama Formation (Kemp & Izumi, 2014; Izumi *et al.*, 2018a, b). Those data, coupled with the fact that the T-OAE interval within the Nishinakayama Formation is one of the stratigraphically thickest recorded (cf. Izumi *et al.*, 2018a), means that the formation has the potential to become a key reference site of the T-OAE in the Panthalassic Ocean. Nevertheless, previous palaeoenvironmental studies of the Nishinakayama Formation have been based only on the investigation of a single stratigraphic succession called the Sakuraguchi-dani section, which crops out in ephemeral streambeds in Toyota Town (Fig. 1; Izumi *et al.*, 2012, 2018a, b; Kemp & Izumi, 2014). Furthermore, in this section, there are several exposure gaps that prevent a full reconstruction of continuous and high-resolution palaeoenvironmental records through the T-OAE. Thus, to better understand the nature of the T-OAE at the northwestern margin of Panthalassa, detailed geological investigation of sections other than the Sakuraguchi-dani is required.

From this point of view, rocks of the Nishinakayama Formation that crop out along the Era River (Era River section; Fig. 1) are suitable for investigation. This is because the section is relatively well exposed and is fossiliferous (e.g., Tanabe *et al.*, 1982; Tanabe, 1991). Herein, we present a preliminary report of geological fieldwork at the Era River section. The general lithology and recent outcrop condition are especially highlighted.

GEOLOGICAL SETTING

In the Toyora area, the Nishinakayama Formation comprises the upper Pliensbachian to Toarcian stages based on biostratigraphic studies (e.g., Hirano *et al.*, 1973b; Nakada & Matsuoka, 2011; Fig. 1). The lithology of the formation is predominately shallow-marine mudstone, silty mudstone, and fine-grained sandstone (e.g., Tanabe *et al.*, 1982; Nakada & Matsuoka, 2011). Following Tanabe *et al.* (1982), the formation can be subdivided into three members: Na (silty mudstone, ~90 m thick), Nb (predominantly dark silty mudstone with intercalated fine-grained sandstone and laminated, organic-rich mudstone, ~160 m thick), and Nc (alternating sandstone and mudstone, ~20-60 m thick). The Sakuraguchi-dani section is a key succession with well-exposed outcrops of the Nb member. As such, the section has been thoroughly investigated from biostratigraphical, geochemical, and sedimentological points of view (e.g., Hirano, 1973b; Tanabe *et al.*, 1982; Nakada & Matsuoka, 2011; Kemp & Izumi, 2014; Izumi *et al.*, 2018a).

The biostratigraphic framework of the Nishinakayama Formation was established by Hirano (1973b), who divided the formation into three ammonite zones: the *Fontanelliceras fontanellense* Zone, *Protogrammoceras nipponicum* Zone, and *Dactylioceras helianthoides* Zone. Those ammonite zones have been correlated between many sections in the Toyora area and widely utilized by other researchers (e.g., Tanabe *et al.*, 1982; Fig. 2). More recently, Nakada and Matsuoka (2011) investigated the Sakuraguchi-dani section and established a new biostratigraphic framework consisting of the *Canavaria japonica* Zone, *Paltarpites paltus* Zone, *Dactylioceras helianthoides* Zone, and *Harpoceras inouyei* Zone (Nakada & Matsuoka, 2011; Fig. 2). However, that new biostratigraphic framework has not yet been established at any sections other than Sakuraguchi-dani.

High-resolution $\delta^{13}\text{C}_{\text{org}}$ data from throughout the Sakuraguchi-dani section has revealed a ~3.5 ‰ negative excursion spanning ~35 m, which can unambiguously be interpreted as diagnostic of the T-OAE interval (Kemp & Izumi, 2014; Izumi *et al.*, 2018a, b). The whole excursion ranges from the middle part of the *P. paltus* Zone to the lower part of the *H. inouyei* Zone following the biostratigraphic framework established by Nakada and Matsuoka (2011), or the uppermost part of the *F. fontanellense* Zone through to the top of the *P. nipponicum* Zone following the biostratigraphic framework of Hirano (1973) (Fig. 2). Within the $\delta^{13}\text{C}_{\text{org}}$ excursion interval, pronounced changes of various geochemical and sedimentological proxy data

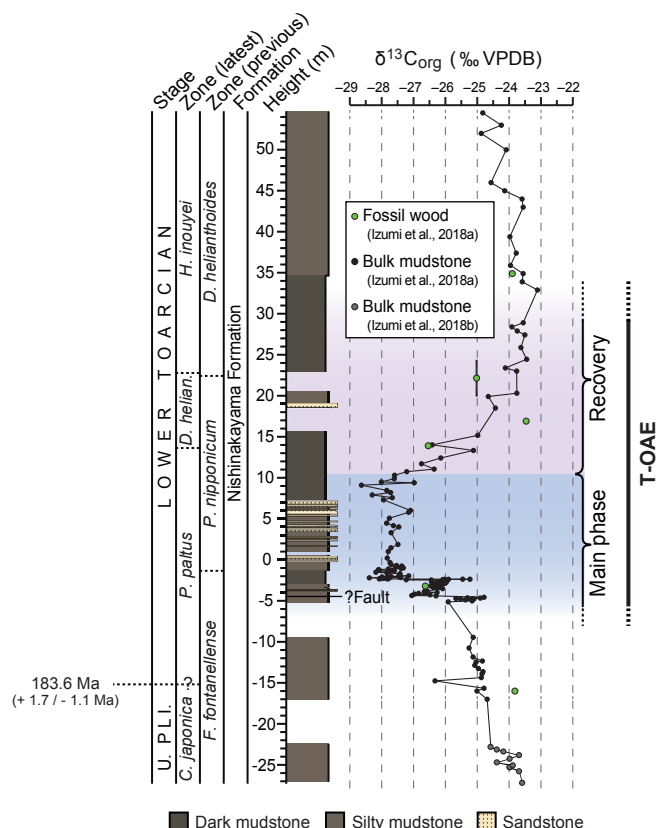


Figure 2. Litho-, bio-, and carbon-isotope stratigraphy of the Sakuraguchi-dani section. Log and carbon-isotope data are after Izumi *et al.* (2018a, b). Previous and latest biostratigraphic frameworks are after Hirano (1973b) and Nakada & Matsuoka (2011), respectively. The Pliensbachian/Toarcian stage boundary is 183.6 ± 1.7 / - 1.1 Ma (Pálffy *et al.*, 2000). U. PLI. represents Upper Pliensbachian.

have been recognized, which indicates that marked palaeoenvironmental perturbations linked to the T-OAE occurred during the interval (e.g., Kemp & Izumi, 2014; Izumi *et al.*, 2018a, b). Importantly, however, neither the $\delta^{13}\text{C}_{\text{org}}$ negative excursion nor any other geochemical and sedimentological changes have been documented from any sections of the Nishinakayama Formation other than Sakuraguchi-dani.

The rocks of the Nishinakayama Formation exposed along the Era River (Era River section) can be biostratigraphically correlated to the Sakuraguchi-dani section (Tanabe *et al.*, 1982; Tanabe, 1991). Although the exposure of rocks at the Era River section is relatively poorer than at Sakuraguchi-dani, the stratigraphic thickness of the *P. nipponicum* Zone is thicker at the Era River section than at the Sakuraguchi-dani (Tanabe *et al.*, 1982; Tanabe, 1991). Thus, it is possible that further geochemical investigations of the Era River section would yield a more expanded record of the T-OAE.

MATERIAL AND METHODS

This study presents the preliminary results of recent geological fieldwork mainly at the Era River section. Fieldwork was carried out several times by the authors from 2016 to 2018. During this fieldwork, outcrops of the Nishinakayama Formation exposed along the Era River and the Koya River near the mouth of the Era River (Fig. 3) were investigated, and new sedimentary logs were produced.

In addition, 136 rock samples were collected, and thin-sections were made for some of these samples in order to observe sedimentary features under optical microscope.

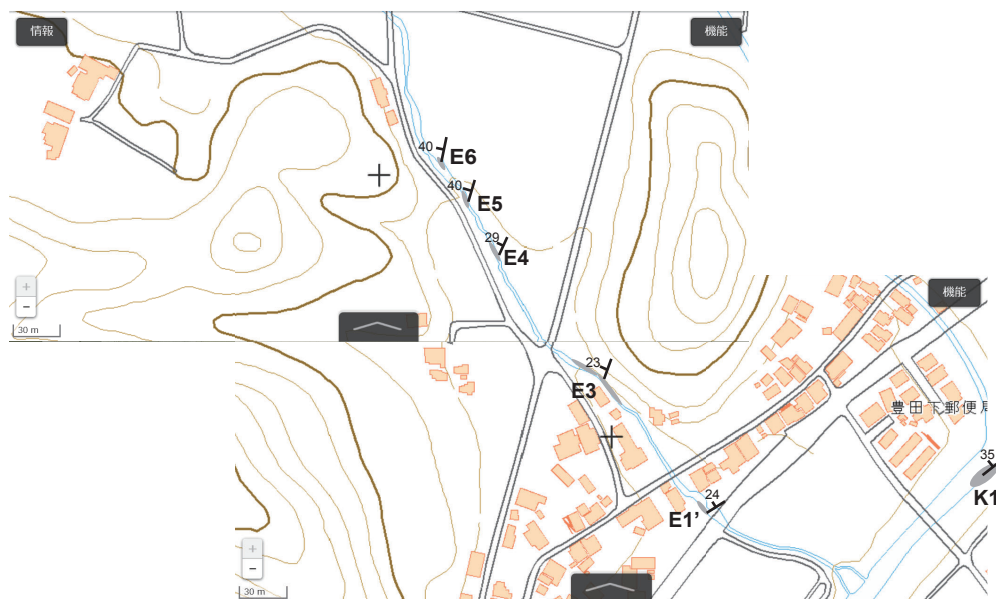


Figure 3. Route map of the Era River section highlighting the detailed locality of each studied outcrop. The background topographic maps are from the Geospatial Information Authority of Japan (<http://maps.gsi.go.jp/>).

RESULTS

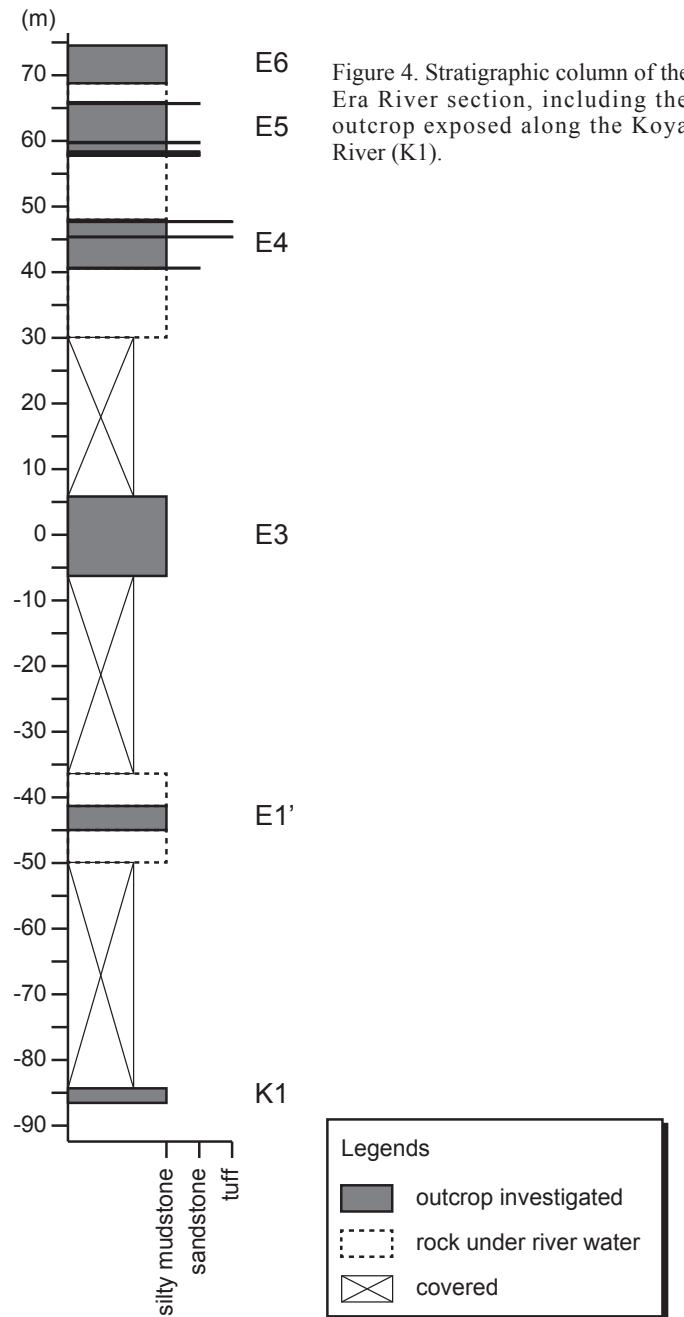
As a result of our fieldwork, it was revealed that a single outcrop along the Koya River (K1), and five outcrops along the Era River (E1'–E5), are easily accessible (Fig. 3). Rocks are also present, though less easily accessible for sampling/investigation, along the streambed (under water) in various places, particularly between outcrops E3 and E6. In general, rocks are fresh and unweathered. These strata generally strike between $\sim N20^{\circ}$ and $65^{\circ}E$ and dip to the northwest, although dips and strikes vary markedly throughout the section (Fig. 3). The whole measured stratigraphic thickness through the studied outcrops is ~ 160 m, although there are several large exposure gaps (Fig. 4).

The lithology of the Era River section is mainly black silty mudstone, with minor sandstone and tuff beds also present (Figs. 4, 5). Three primary mudstone lithofacies can be identified within the succession (Fig. 5): 1) laminated (ranging from well laminated to weakly laminated), 2) bioturbated, and 3) thin-bedded. Bioturbated silty mudstones often contain the ichnofossil *Phycosiphon*. Silt beds with basal scour and thin muddy layers with homogeneous internal structure, which can be interpreted as compacted fluid-mud deposit layers (cf. Izumi *et al.*, 2018a), are often recognized in thin-bedded mudstones (Fig. 5). These are similar to the mudstone lithofacies recognizable from the Sakuraguchi-dani section (Izumi *et al.*, 2018a). However, any stratigraphic variation in these lithofacies is still unclear owing to the limited exposure (Fig. 4).

Mineral veins are commonly recognized within the silty mudstones. Fossil plants are common in the silty mudstone throughout the Era River section, and a few poorly preserved ammonoids (at least *Cleviceras chrysanthemum* and *Harpoceras inouyei*) were also discovered.

DISCUSSION

The overall stratigraphic thickness of the Era River section (~ 160 m; Fig. 4) is greater than that of the Sakuraguchi-dani section (~ 80 m; Fig. 2), although the continuity of the outcrop is less than the Sakuraguchi-dani section. Based on the previous studies



(Tanabe *et al.*, 1982; Tanabe, 1991), the Era River section outcrops (E1' to E6) correspond to the *P. nipponicum* Zone to *D. helianthoides* Zone in Hirano (1973b)'s biostratigraphic framework. In more detail, the outcrops E1' and E3 correspond to *P. nipponicum* Zone, and outcrops E4 to E6 correspond to the *D. helianthoides* Zone (cf. Tanabe *et al.*, 1982; Tanabe, 1991).

Following Tanabe *et al.* (1982) and Tanabe (1991), the stratigraphic position of the K1 outcrop presumably corresponds to the *F. fontanellense* Zone in the traditional biostratigraphic framework of Hirano (1973b). However, previous studies did not investigate the outcrop along the Koya River (K1 outcrop in this study). In addition, no outcrops were recognized between K1 and E1' owing to the presence of vegetation and concrete (Fig. 4). Because this interval is presumed to be geochemically

important (especially from the viewpoint of the recognition of the T-OAE $\delta^{13}\text{C}_{\text{org}}$ negative excursion), further geological investigation (i.e., taking drill cores) is required.

In addition, to reconstruct the palaeoenvironment of the Era River section and correlate it with the Sakuraguchi-dani section (Izumi *et al.*, 2018a), stratigraphic variations in the three recognized mudstone lithofacies also need to be investigated. Furthermore, at least two tuff layers were identified in the outcrop E4, and these tuffs could be important for future geochronological studies that would further constrain the age of the Era River stratigraphy.

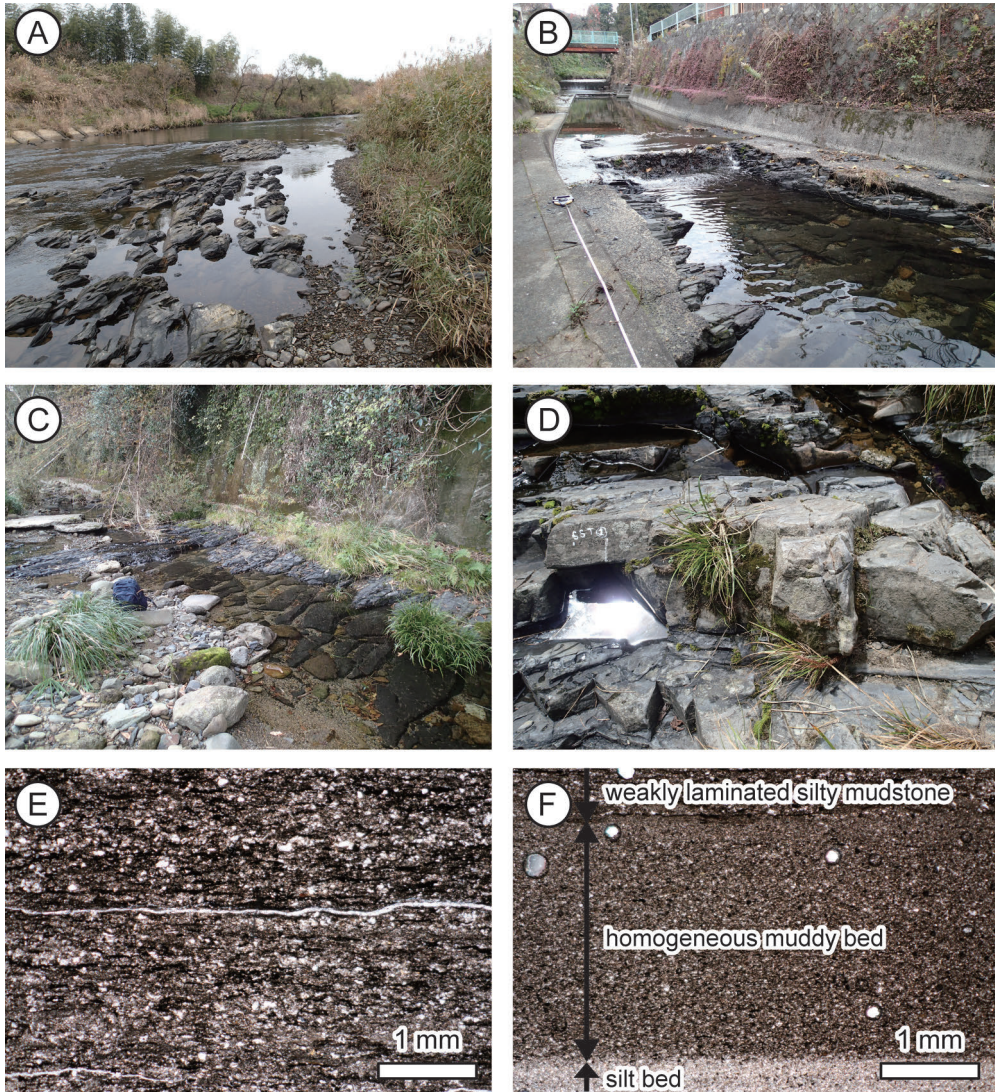


Figure 5. Selected photographs and thin section photomicrographs showing the lithofacies of the silty mudstone facies from the studied outcrops. (A) Field photograph of the K1 outcrop. (B) Field photograph of the E1' outcrop. (C) Field photograph of the E3 outcrop. (D) Magnified field view of the outcrop E5, highlighting the presence of a sandstone bed. (E) Thin-section photomicrograph of the laminated silty mudstone (Sample ID: 2018-E1' -8.6; -36.38 m in the stratigraphic column of Fig. 4). (F) Thin-section photomicrograph of the thin-bedded mudstone (Sample ID: 2018-E6-m0.8; 71.98 m in the stratigraphic column of Fig. 4). Note the presence of a silt bed and a homogeneous muddy bed that is interpreted as a compacted fluid-mud deposit layer.

CONCLUSIONS

This study represents a preliminary account of recent (2016 to 2018) geological fieldwork in the Nishinakayama Formation (Toyora Group) exposed along the Era River (Era River section). Although the exposure of rocks along the Era River section is poorer than that of the Sakuraguchi-dani section, the total stratigraphic thickness of the Era River section is greater. The lithology of the Era River section mainly comprises black silty mudstones, with some minor sandstone and tuff beds also present. The silty mudstones can be further divided into three lithofacies: 1) laminated (ranging from well laminated to poorly laminated), 2) bioturbated, and 3) thin-bedded. Because the stratigraphic interval of the Era River section presumably includes the $\delta^{13}\text{C}_{\text{org}}$ negative excursion characterizing the globally important T-OAE, further geological investigation (i.e. taking drill cores) of the section is warranted.

ACKNOWLEDGEMENTS

K. I. was financially supported by JSPS grant (15J08821), Fujiwara Natural History Foundation, and Asahi Group Foundation. D.B.K. acknowledges support for fieldwork from the Daiwa Anglo-Japanese Foundation and the Great Britain Sasakawa Foundation, as well as a UK NERC Fellowship. B.T.B. received support for fieldwork funding from the American Philosophical Society (Lewis and Clark Fund for Exploration and Field Research), the Geological Society of America (Graduate Student Research Grant), and the University of Utah Department of Geology & Geophysics (The David S. and Inga M. Chapman Fund). This study contributes to IGCP 655. We would like to thank M. Inui, Y. Aoki, N. Kumagai, R. Sakaguchi, S. Suzuki, T. Ohta, and K. Kawano for assistance in the field and/or helpful discussion. In addition, we thank R. Sakaguchi and S. Suzuki for thin section preparations.

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江良川沿いに分布する豊浦層群西中山層への再訪：近年の露頭状況及び岩相について

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要約：山口県下関市の豊浦地域に分布する下部ジュラ系豊浦層群西中山層（上部プリンスバッキアン階～下部トアルシアン階）は、豊富な化石が産出すること、およびトアルシアン期の海洋無酸素事変を特徴付ける炭素同位体比の負異常が検出されていることから、地質学的に重要な地層である。特に、桜口谷の露頭（桜口谷セクション）は連続性が良いことから、これまで重点的に研究されてきた。しかし、桜口谷以外のセクションは、相対的に研究が進んでいない。したがって、西中山層に記録されたトアルシアン期の古環境情報をより良く理解するためには、桜口谷以外のセクションを調査研究することが必要である。本論では、江良川沿いの露頭（江良川セクション）において著者らが近年行ってきた地質調査の予察的な結果を報告する。江良川セクションは桜口谷セクションに比べて、露頭の連続性は悪いが全体層厚は厚いことが分かった。江良川セクションは主に黒色のシルト質泥岩から構成され、シルト質泥岩には三種類の岩相が認識された。また、江良川セクションでは何枚かの砂岩層や凝灰岩層も存在する。江良川セクションは、トアルシアン期の海洋無酸素事変を特徴付ける炭素同位体比の負異常の層準を含んでいる可能性が高く、したがって今後はドリルコアの掘削等、さらなる地質調査が望まれる。

キーワード：豊浦層群、西中山層、江良川、トアルシアン期、海洋無酸素事変