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Discovery of the early Spathian (late Olenekian, Early Triassic) ammonoid *Tirolites* in the Hiraiso Formation, South Kitakami Belt, Northeast Japan

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Abstract. Until now, the Hiraiso Formation was considered to be entirely of Smithian (early Olenekian, Early Triassic) age, but the discovery of the ammonoid *Tirolites* cf. *ussuriensis* in the lower part of the formation on the rocky coast between the Maekawara and Akaushi ports, Motoyoshi Town, Kesennuma City, in the South Kitakami Belt, Northeast Japan, establishes that this portion is actually equivalent to the upper part of the lower Spathian *Tirolites*-*Amphistephanus* Zone (upper Olenekian). The fauna of the Hiraiso Formation, which includes the large bivalve *Eumorphotis iwanowi* and crinoid ossicles, very much resembles the *Tirolites ussuriensis* beds in South Primorye, Russian Far East, suggesting a wide distribution of this shallow marine fauna in the low to middle northern latitudes on the western side of the Panthalassa during the early Spathian. Because pre-Spathian deposits contain only small-sized species of *Eumorphotis* and very rare crinoid ossicles, the appearance of large species of *Eumorphotis* and the flourishing of crinoids in the shallow marine environment during the early Spathian suggest that the Smithian-Spathian boundary marks a major change in the marine ecosystem.

Key words: ammonoid, Hiraiso Formation, South Kitakami Belt, Spathian, *Tirolites*, Triassic

Introduction

The Lower Triassic marine Osawa Formation distributed in the southern part of the South Kitakami Belt, Northeast Japan, is famous for its yield of a primitive ichthyopterygian, *Utatsusaurus hataii* Shikama, Kamei and Murata, 1978 and rich Spathian (late Olenekian) ammonoid faunas as well as coprolites and a thylacocephalan fauna (Bando, 1970; Bando and Shimoyama, 1974; Bando and Ehiro, 1982; Ehiro, 1993, 2016; Nakajima and Izumi, 2014; Takahashi *et al*., 2014; Ehiro *et al*., 2015, 2016). Shallow marine bivalves and crinoid ossicles are found in abundance in the underlying Hiraiso Formation (Kashiyama and Oji, 2004) and amphibian bones have been recently reported (Nakajima and Schoch, 2011), but the rarity of ammonoids has precluded the establishment of a precise biostratigraphic correlation for the formation.

The major ammonoid extinction that occurred at the end of the late Smithian (early Olenekian)–beginning of the Spathian was followed by a rather rapid major evolutionary radiation in the early Spathian (Tozer, 1982; Galfetti *et al*., 2007). One of the families that appeared following this near extinction event, the Tirolitidae Mojsisovics, 1882 includes strongly ornamented, tuberculate taxa, most of which show a narrow or restricted stratigraphic range and a relatively broad geographical distribution. For this reason, they are ideal taxa for precise biostratigraphic correlation within the early Spathian (Balini *et al*., 2010; Jenks *et al*., 2015).

Coauthor Y. Nakajima recently discovered a specimen referable to *Tirolites* cf. *ussuriensis* Zharnikova in Buryi and Zharnikova, 1981 at the type locality of the Hiraiso Formation. We herein document this specimen and discuss the age of the Hiraiso Formation as well as explore the implications for paleobiogeography and the Early Triassic biotic recovery.

Notes on stratigraphy

The Lower–Middle Triassic Inai Group (*ca.* 3000 m, maximum thickness) is widely distributed in the southern part of the South Kitakami Belt, Northeast Japan. This

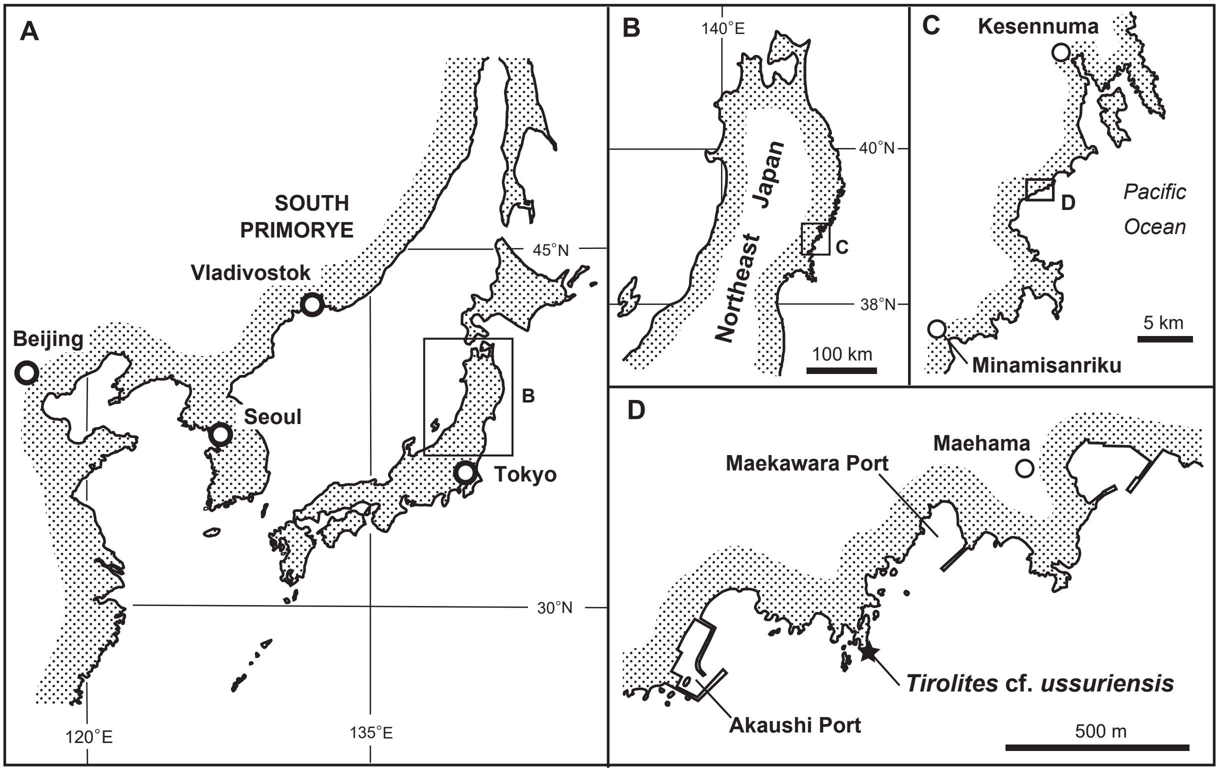

Figure 1. Index maps (**A–C**) showing the locality (**D**) from which *Tirolites* cf. *ussuriensis* Zharnikova in Buryi and Zharnikova (1981) was collected.

area is regarded as a fragment of continental origin (= South Kitakami Terrane; Kobayashi, 1999) and the Triassic strata in the area are divided into four formations, the Hiraiso, Osawa, Fukkoshi and Isatomae formations in ascending order (Onuki and Bando, 1959). The Hiraiso Formation (max. 300-m thick), which unconformably overlies the uppermost Permian Toyoma Formation (Onuki, 1969; Kambe, 1963), consists of a basal conglomerate, overlain by sandstone with intercalations of siltstone beds (Kamada, 1992; Kashiyama and Oji, 2004). The sandstone contains many disarticulated bivalve shells (*Eumorphotis*, *Entolium*, *Bakevellia* (*Maizuria*), *Unionites* and *Neoschizodus*) and crinoid ossicles belonging to *Holocrinus* (Kashiyama and Oji, 2004) as well as amphibian bones (Nakajima and Schoch, 2011). Bando (1970) reported a single specimen of the Griesbachian ammonoid *Glyptophiceras* cf. *gracile* Spath, 1930 from a floated siltstone block, but it was later reassigned to the late Smithian taxon *G. aequicostatus* (Diener, 1913) by Nakazawa *et al*. (1994). Shallow marine deposits of the Hiraiso Formation gradually transition into deeper water facies of the overlying Osawa Formation.

An ammonoid referable to *Tirolites* cf. *ussuriensis* was obtained from the lower part of the Hiraiso Formation at its type locality on the rocky coast between the Maekawara and Akaushi ports, Motoyoshi Town, Kesennuma City, Miyagi Prefecture (Figure 1).

Paleontological description

Systematic descriptions basically follow the classification established by Shevyrev (1986) and in part by Tozer (1981, 1994). Morphological terms are those used in Arkell (1957).

Institution abbreviations.—CGM = Central Scientific Research Geological Prospecting Museum (TsNIGR Museum), St. Petersburg; DVGI = Far Eastern Geological Institute, Vladivostok; NMNS = National Museum of Nature and Science, Tsukuba.

Order Ceratitida Hyatt, 1884
Superfamily Dinaritoidea Mojsisovics, 1882
Family Tirolitidae Mojsisovics, 1882
Genus ***Tirolites*** Mojsisovics, 1879

Type species.—*Tirolites idrianus* Hauer, 1865.

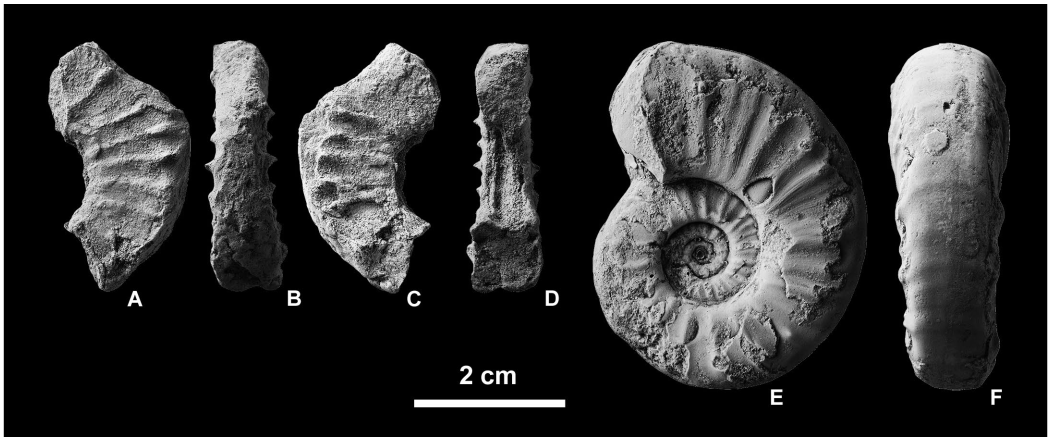

Figure 2. *Tirolites* from South Kitakami and South Primorye. **A–D,** *Tirolites* cf. *ussuriensis* Zharnikova in Buryi and Zharnikova (1981), NMNS PM35069, from the Hiraiso Formation on the rocky coast between the Maekawara and Akaushi ports, Motoyoshi Town, Kesennuma City, in the South Kitakami Belt, Northeast Japan; A, right lateral view; B, ventral view; C. left lateral view; D, dorsal view; **E, F,** *Tirolites ussuriensis*, plaster cast of the holotype (CGM 14/10195), from the *Tirolites-Amphistephanites* Zone (lower Spathian) in the Tchernyshev Bay area, Russky Island, South Primorye, Russia, NMNS PM35070; E, right lateral view; F, ventral view.

Tirolites cf. ***ussuriensis*** Zharnikova in Buryi and Zharnikova, 1981

Figure 2A–D

cf. *Tirolites ussuriensis* Zharnikova in Buryi and Zharnikova, 1981, p. 65, pl. 7, fig. 3; Zakharov and Rybalka, 1987, p. 42, pl. 4, fig. 5.

Material examined.—One specimen, a body chamber fragment, NMNS PM35069, extracted from massive sandstone in the lower part of the Hiraiso Formation exposed along the rocky coast between the Maekawara and Akaushi ports, Motoyoshi Town, Kesennuma City, Miyagi Prefecture (38°47′48.8″N, 141°32′38″E; Figure 1). The horizon is equivalent to the lower part of section 8 of Kashiyama and Oji (2004, fig. 4).

Description.—Fairly evolute, fairly compressed shell with rectangular whorl section, broadly rounded venter, rounded ventral shoulders, and flat, subparallel flanks. Umbilicus moderately wide with moderately high, subvertical wall and rounded shoulders. Ornamentation consists of spiny tubercles on ventrolateral shoulders as well as strong, slightly sinuous, prorsiradiate ribs.

Remarks.—Although the described specimen is fragmental and the whorl section is slightly deformed laterally, its distinctive ornamentation enables us to identify it with reasonable confidence as *Tirolites ussuriensis* (Figure 2E, F).

Occurrence.—*Tirolites ussuriensis* is known from the upper part of the lower Spathian *Tirolites-Amphistephanus* Zone on Russky Island, South Primorye (Buryi and Zharnikova, 1981; Zakharov and Rybalka, 1987).

Discussion

Age of the Hiraiso Formation

Bando (1970) originally considered the age of the Hiraiso Formation to be Griesbachian (early Induan) based on a single ammonoid identified as *Glyptophiceras* cf. *gracile* from a floated block of siltstone, which possibly came from the Osawa Formation (Ehiro, 2002). Later, Nakazawa *et al*. (1994) attributed the specimen to *G. aequicostatus* and assigned it a late Smithian age. However, our examination of the specimen indicates that it is not *G. aequicostatus*, and instead should be assigned to the early Spathian ammonoid *Neocolumbites* Zakharov, 1968, judging from the much finer ribs on its body chamber and a suture line whose first lateral saddle is higher than the second saddle. *Glyptophiceras* is characterized by ribs that vary from low, dense, and sinuous to very strong, distant and concave throughout ontogeny and its suture line exhibits a first lateral saddle that is lower than the second saddle.

Since *Tirolites* is one of the most important age-diagnostic genera for the early Spathian (e.g. Jenks *et al*., 2015), its occurrence in the lower part of the Hiraiso Formation clearly constrains the age of this particular horizon. In South Primorye, two ammonoid zones comprise the lower Spathian, the *Tirolites*-*Amphistephanites* and *Neocolumbites insignis* zones in ascending order (Zakharov, 1997; Jenks *et al*., 2015; Figure 3). *Tirolites ussuriensis* occurs in the upper part of the *Tirolites*-*Amphistephanites* Zone (= *T. ussuriensis* beds). The *Neocolumbites insignis* Zone is characterized by the occurrences of *Neocolum-*

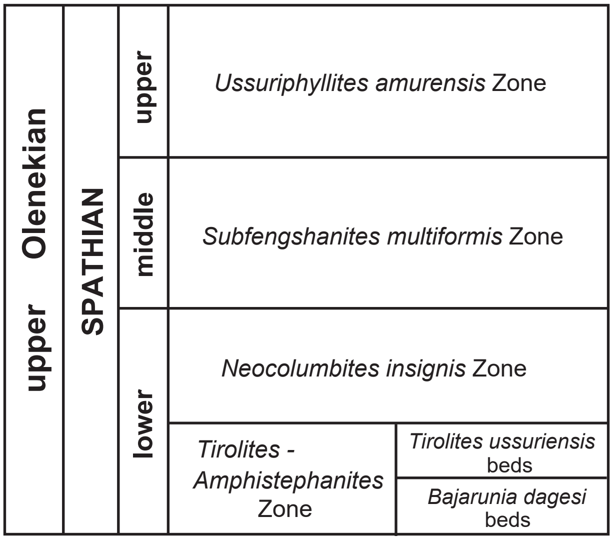

Figure 3. Spathian (upper Olenekian, Lower Triassic) ammonoid zones in South Primorye (based on Zakharov, 1997; Zakharov and Mousavi Abnavi, 2013; Jenks *et al*., 2015; Shigeta and Kumagae, 2016).

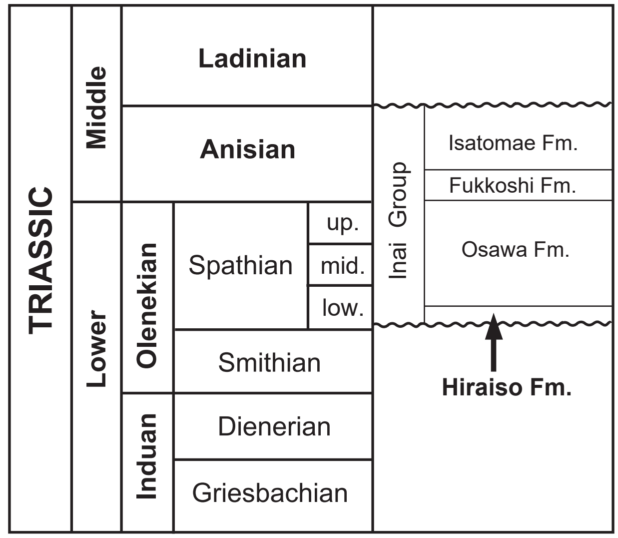

Figure 4. Stratigraphic divisions of the Lower–Middle Triassic Inai Group. The discovery of *Tirolites* cf. *ussuriensis* Zharnikova in Buryi and Zharnikova (1981) indicates that the Hiraiso Formation should be correlated with the lower Spathian.

bites, *Columbites* and *Hellenites* (Zakharov *et al*., 2004a, b). Bando and Shimoyama's (1974) report of *Columbites* from the lower part of the Osawa Formation clearly shows that the underlying Hiraiso Formation should be correlated with the lower Spathian (Figure 4).

Implications for paleobiogeography

The lack of Precambrian zircon in the sandstones of the Lower–Middle Triassic Inai Group suggests that the South Kitakami Terrane was probably located along the active margin of an oceanic island arc rather than along the margin of a large continental block (Okawa *et al*., 2013). The occurrence of the temnospondyl amphibian from the Hiraiso Formation (Nakajima and Schoch, 2011) suggests that the formation was deposited not far from the eastern margin of either the North or South China blocks in the low northern latitudes.

The faunal composition of the Hiraiso Formation, characterized by the dominance of *Eumorphotis iwanowi* (Bittner, 1899) and crinoid ossicles, strongly resembles that of the *Tirolites ussuriensis* beds in South Primorye (Bittner, 1899; Kiparisova, 1938; Zakharov, 1968, 1997; Kashiyama and Oji, 2004; Figure 5). South Primorye was probably located along the eastern continental margin of the Khanka Block, which was part of a continent attached to the Northeast China Block, in the middle northern latitudes (Khanchuk, 2001; Yokoyama *et al*., 2009a, b). This interpretation suggests that the fauna was widely distributed in shallow marine waters in the low to middle northern latitudes on the western side of the Panthalassa during the early Spathian.

Implications for the Early Triassic biotic recovery

Eumorphotis Bittner, 1901, one of the most common bivalve genera of the Lower Triassic in South Primorye (Bittner, 1899; Kiparisova, 1938; Kumagae and Nakazawa, 2009), underwent a drastic enlargement of its shell size at the Smithian-Spathian boundary. Specimens assigned to the genus from pre-Spathian deposits are less than 40 mm in shell height whereas specimens of the Spathian taxon *Eumorphotis iwanowi* are about twice as large (Bittner, 1899; Figure 5). The abundance of crinoid ossicles also changes significantly at the Smithian-Spathian boundary. While they only occur rarely in the Smithian of South Primorye (Oji, 2009), they are quite common in the Spathian shallow marine deposits (Figure 5).

It is well recognized that a drastic change of climate and oceanic environment straddled the Smithian-Spathian boundary. A prominent positive carbon isotope excursion may be associated with global climatic change (Payne *et al*., 2004; Galfetti *et al*., 2007, 2008; Horacek *et al*., 2007; Tong *et al*., 2007; Sun *et al*., 2012; Saito *et al*., 2013; Romano *et al*., 2013). Modeling of ammonoid paleobiogeography suggests that the warm and equable climate during the late Smithian was replaced by latitudinally differentiated conditions in the Spathian (Brayard *et al*., 2006). The reestablishment of a highly diverse plant ecosystem recognized in the Barents Sea, Norway is inter-

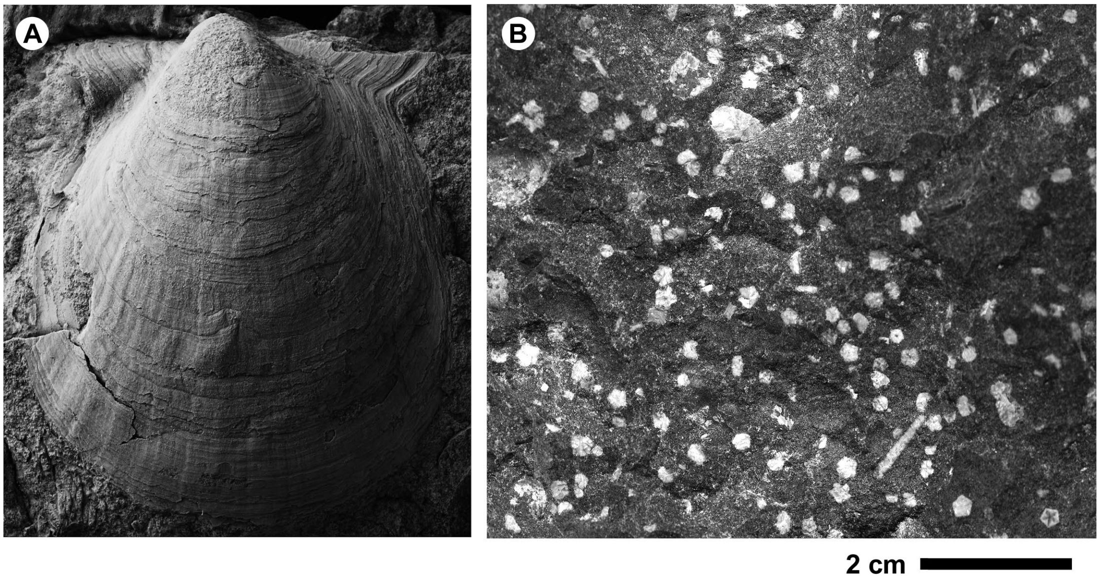

Figure 5. **A,** *Eumorphotis iwanowi* (Bittner, 1899), NMNS PM35071 from the Schmidt Cape section, southeastern Russky Island, South Primorye, Russia (42°57′39.73″N, 131°53′25.70″E); **B,** crinoid ossicle-bearing fine-grained sandstone from the Schmidt Cape section (42°57′39.43″N, 131°53′25.48″E), suggesting that crinoids were common in the shallow marine environment during the early Spathian. Both specimens were collected by Taro Kumagae.

preted as an effect of a major climatic change (Galfetti *et al*., 2007). The offshore mudstone in South Primorye suggests that the oxygen-deficient sea floor was transformed into an aerobic environment inhabitable to benthic organisms at the Smithian-Spathian boundary (Shigeta and Kumagae, 2016). Although it is unclear whether the appearance of large bivalves and flourishing of crinoids in these shallow marine environments was just one in a chain of episodes in the global climate change and/or oceanic environment recovery, the resultant fauna suggests a drastic change in the marine ecosystem at the Smithian-Spathian boundary.

Concluding remarks

The Hiraiso Formation not only documents the nature of a shallow marine environment and its inhabitants during the early Spathian, but it also provides evidence of a drastic change in the marine ecosystem at the Smithian-Spathian boundary. Further paleoecological and paleoenvironmental studies of the Hiraiso Formation may provide an important key for the understanding of global environmental changes and the dynamics of the biotic recovery following the Permian-Triassic mass extinction as well as the Smithian-Spathian boundary extinction event.

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