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U–Pb age of the *Sphenoceramus schmidti* Zone (middle Campanian, Cretaceous) in Hokkaido, northern Japan

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Abstract Radiometric age dating of zircons ($^{238}U/^{206}Pb$ ratios, using the LA-ICP-MS method) obtained from a tuff sample just below the *Sphenoceramus schmidti*-bearing beds of the Yezo Group in the Nakagawa area, Hokkaido, northern Japan, yielded an age of 80.2 ± 0.8 Ma, 95% conf., which suggests an early middle Campanian (Late Cretaceous) age. This result indicates that the age of the *S. schmidti* Zone is the same in both southwestern and northern Japan. Thus, *Sphenoceramus schmidti* should be regarded as an ideal zonal-index fossil for the lower middle Campanian of the Northwest Pacific region.

Key words: Campanian, Cretaceous, *Sphenoceramus schmidti*, U–Pb age, zircon

Introduction

The inoceramid bivalve *Sphenoceramus schmidti* (Michael, 1899) occurs abundantly in the Upper Cretaceous of southwestern Japan (Noda *et al.*, 1996; Misaki and Maeda, 2009). Because its characteristic shell sculpture, e.g. divergent ribs, is easy to recognize, it has been regarded as an ideal zonal-index fossil (Toshimitsu *et al.*, 1995). Kodama (1990) correlated the *S. schmidti* Zone in the Izumi Group with the uppermost part of polarity chron C33r, and Tsutsumi *et al.* (2014) reported an age of 79.7 ± 0.7 Ma (95% conf.) for a tuff in beds containing *S. schmidti* in the Himenoura Group. In consideration of this evidence, Shigeta *et al.* (2016) correlated the *S. schmidti* Zone with the lower middle Campanian based on the three-subdivision scheme for the Campanian.

Sphenoceramus schmidti is also common in the Upper Cretaceous of the Yezo Group in Hokkaido, northern Japan (Nagao and Matsumoto, 1940) and Sakhalin, Far Eastern Russia (Zonova *et al.*, 1993). Kodama *et al.* (2000) recognized 13 magnetozones in the Upper Cretaceous in the Naiba area, southern Sakhalin, and concluded that the *S. schmidti*-bearing beds correspond to the bottom of polarity chron C32r (= middle upper Campanian). In contrast, Tamaki *et al.* (2008) correlated the *S. schmidti*-bearing beds in the Urakawa area, Hokkaido with the upper part of polarity chron C33r and lower part of C33n (= lower middle Campanian). Thus, the magnetostratigraphic correlation of the *S. schmidti* Zone in the Yezo Group is still a matter of debate and the radiometric age of the zone had never been determined until now.

In this paper, we calibrate the international correlation of the *Sphenoceramus schmidti* Zone with the zircon-based geochronology of the Yezo Group in the Nakagawa area, Hokkaido, and establish a more precise global correlation of the zone.

Notes on stratigraphy

Even though the Yezo Group in the Nakagawa area is complexly folded and faulted, a continuous Upper Cretaceous succession is well exposed along the Abeshinai River and its tributaries (e.g. Matsumoto, 1942; Takahashi *et al.*, 2003). Within the group, the Osoushinai Formation yields numerous relatively well-preserved Campanian megafossils from various horizons.

The 600-m thick Osoushinai Formation consists mainly of dark gray to gray siltstone, sandy siltstone and muddy sandstone, intercalated with 1–100 cm thick white, vitric tuff beds (Takahashi *et al.*, 2003; Fig. 1). The lower and middle parts contain the inoceramid *Sphenoceramus naumanni* (Yokoyama, 1890) and ammonoids *Yokoyamaoceras ishikawai* (Jimbo, 1894), *Gaudryceras tenuiliratum* Yabe, 1903 and *Polyptychoceras pseudogaultinum*

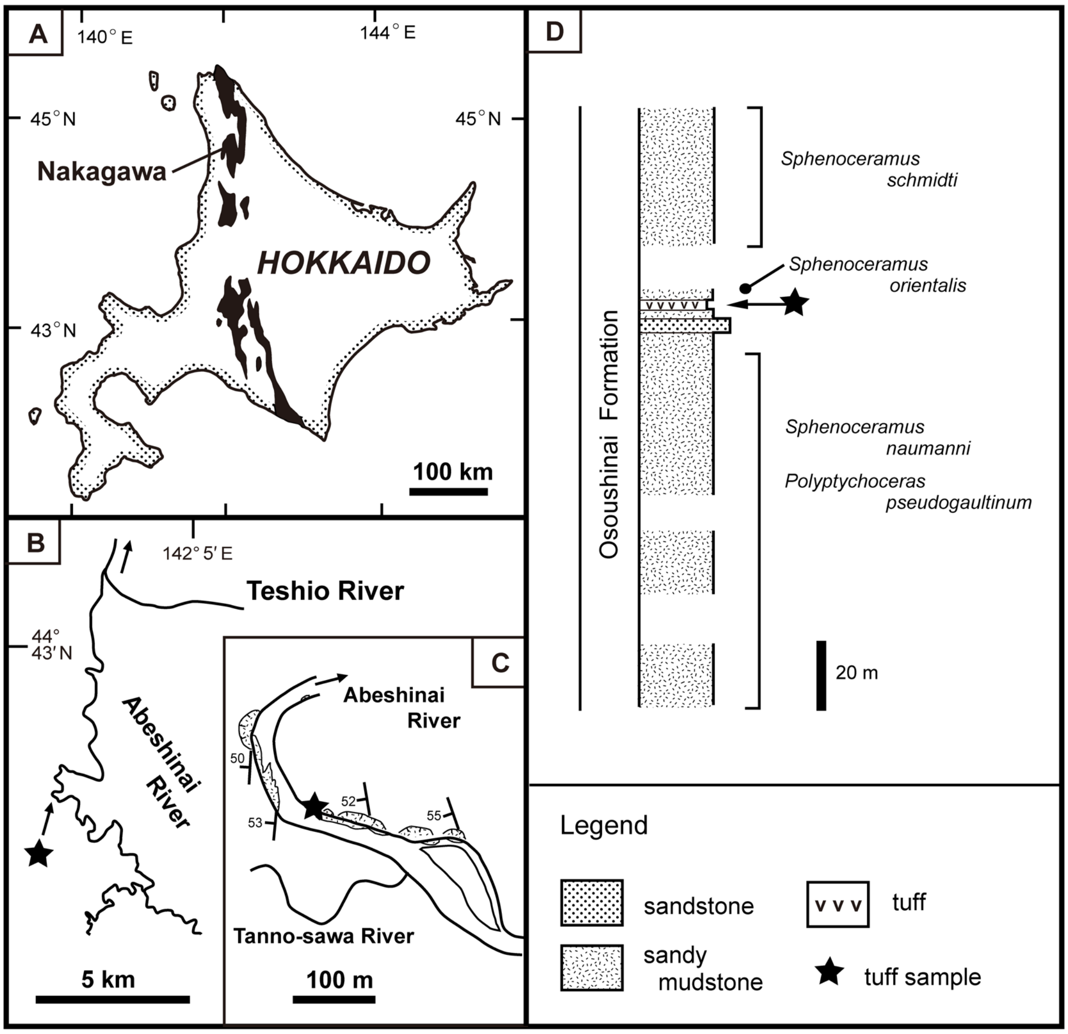

Fig. 1. Index map showing distribution of the Yezo Group (black areas) in Hokkaido (A), locality (B, C) and stratigraphic horizon (D) of the tuff bed that provided the U–Pb zircon age in the Nakagawa area, Hokkaido, northern Japan.

(Yokoyama, 1890) (Fig. 1D). Characterizing the upper part are gigantic specimens of the inoceramid *S. schmidti*, which occur abundantly in calcareous concretions as well as in the host rock (Matsuda and Ubukata, 1999; Takahashi *et al.*, 2003), together with the ammonoids *Urakawites* Matsumoto, 1955, *Teshioites* Matsumoto, 1955 and *Canadoceras* Spath, 1922 (Matsumoto, 1954, 1955).

Material and methods

Material: Radiometric age analysis was conducted on zircons extracted from a tuff sample taken from a 100-cm thick white, vitric tuff bed positioned immediately below the *Sphenoceramus orientalis*-bearing beds, which occur about 18 m below the *S. schmidti*-bearing beds in an exposure of the Osoushinai Formation along the Abeshinai River (44°40′23.90″N, 142°1′15.55″E; Fig. 1).

Methods: The zircon grains were extracted by standard techniques: crushing, heavy liquid separation and handpicking. Then, the zircon grains were mounted in an epoxy disc with the FC1 zircon standard (^{206}Pb/^{238}U = 0.1859; Paces and Miller, 1993), and the SRM610 glass standard and polished until the center of each grain was exposed. The backscattered electron and cathodoluminescence images of the zircon grains were used for selection of the sites for analysis. U–Pb dating of the sample was carried out using the LA-ICP-MS method, which consists of a NWR213, a 213 nm wave length Nd-YAG laser ablation system (Electro Scientific Industries) and an Agilent 7700x quadrupole ICP-MS (Agilent Technologies), installed at the National Museum of Nature and Science at Tsukuba, Japan. The experimental conditions and procedures for the measure-

Table 1. LA-ICP-MS analyzed data and calculated ages of the tuff sample from the upper part of the Osoushinai Formation. Errors are 1 sigma. Pb_c and Pb* indicate the common and radiogenic portions, respectively.

Labels	$^{206}Pb_c$ (1) (%)	U (ppm)	Th (ppm)	Th/U	$^{238}U/^{206}Pb^*$ (1)	$^{207}Pb^*/^{206}Pb^*$ (1)	$^{238}U/^{206}Pb^*$ age (1) (Ma)	$^{238}U/^{206}Pb^*$ age (2) (Ma)
Abe_01	1.64	183	72	0.40	76.30 ± 2.50	0.0505 ± 0.0138	83.9 ± 2.7	83.7 ± 2.7
Abe_02	0.54	406	126	0.32	81.01 ± 1.81	0.0418 ± 0.0064	79.1 ± 1.8	79.6 ± 1.7
Abe_03	0.48	209	111	0.55	80.38 ± 2.41	0.0474 ± 0.0116	79.7 ± 2.4	79.8 ± 2.3
Abe_04	0.11	207	84	0.41	84.89 ± 2.47	0.0497 ± 0.0115	75.5 ± 2.2	75.3 ± 2.2
Abe_05	0.68	290	186	0.66	81.98 ± 2.55	0.0455 ± 0.0102	78.2 ± 2.4	78.4 ± 2.4
Abe_06	0.77	173	74	0.44	80.42 ± 2.47	0.0430 ± 0.0135	79.7 ± 2.4	80.1 ± 2.5
Abe_07	0.29	492	254	0.53	79.85 ± 1.77	0.0479 ± 0.0070	80.2 ± 1.8	80.2 ± 1.7
Abe_08	0.77	117	66	0.58	78.96 ± 3.48	0.0469 ± 0.0216	81.1 ± 3.6	81.2 ± 3.3
Abe_09	2.01	170	111	0.67	86.84 ± 3.05	0.0477 ± 0.0172	73.8 ± 2.6	73.8 ± 2.4
Abe_10	0.94	490	262	0.55	78.26 ± 1.68	0.0425 ± 0.0084	81.8 ± 1.8	82.4 ± 1.7
Abe_11	0.13	353	209	0.61	77.93 ± 1.87	0.0535 ± 0.0090	82.2 ± 2.0	81.6 ± 1.9
Abe_12	0.81	172	95	0.57	80.24 ± 2.64	0.0474 ± 0.0125	79.8 ± 2.6	79.9 ± 2.6
Abe_13	2.64	137	77	0.58	79.78 ± 3.36	0.0378 ± 0.0215	80.3 ± 3.4	81.3 ± 3.2
Abe_14	0.79	196	94	0.49	82.22 ± 2.77	0.0437 ± 0.0132	77.9 ± 2.6	78.3 ± 2.6
Abe_15	0.73	364	147	0.42	79.86 ± 1.92	0.0442 ± 0.0077	80.2 ± 1.9	80.6 ± 1.9
Abe_16	0.17	474	158	0.34	73.89 ± 1.55	0.0410 ± 0.0060	86.7 ± 1.8	86.7 ± 1.7
Abe_17	0.13	503	455	0.93	81.53 ± 1.73	0.0520 ± 0.0095	78.6 ± 1.7	78.1 ± 1.5
Abe_18	1.89	171	102	0.61	80.39 ± 2.85	0.0525 ± 0.0176	79.7 ± 2.8	79.1 ± 2.6
Abe_19	0.23	312	157	0.52	79.30 ± 2.42	0.0488 ± 0.0098	80.8 ± 2.5	80.6 ± 2.4
Abe_20	1.02	375	299	0.82	79.10 ± 2.20	0.0381 ± 0.0115	81.0 ± 2.2	81.7 ± 2.0
Abe_21	0.01	139	69	0.51	78.72 ± 3.43	0.0431 ± 0.0218	81.4 ± 3.5	81.3 ± 3.1
Abe_22	0.00	258	118	0.47	78.71 ± 2.09	0.0507 ± 0.0061	81.4 ± 2.1	80.9 ± 2.2
Abe_23	0.60	663	269	0.42	80.39 ± 1.58	0.0499 ± 0.0060	79.7 ± 1.6	79.3 ± 1.5
Abe_24	0.00	117	62	0.54	77.36 ± 3.24	0.0540 ± 0.0109	82.8 ± 3.5	82.0 ± 3.6
Abe_25	0.25	190	138	0.75	87.08 ± 3.21	0.0505 ± 0.0177	73.6 ± 2.7	73.2 ± 2.4
Abe_26	1.08	99	50	0.52	76.07 ± 3.76	0.0623 ± 0.0325	84.2 ± 4.1	82.5 ± 4.1
Abe_27	1.09	137	76	0.57	79.24 ± 3.51	0.0573 ± 0.0213	80.8 ± 3.6	79.8 ± 3.4
Abe_28	2.14	335	174	0.53	78.39 ± 1.95	0.0255 ± 0.0093	81.7 ± 2.0	83.4 ± 1.9
Abe_29	1.60	226	125	0.57	82.76 ± 2.43	0.0378 ± 0.0117	77.4 ± 2.3	78.3 ± 2.2
Abe_30	0.00	99	52	0.54	73.16 ± 3.02	0.0500 ± 0.0126	87.5 ± 3.6	87.2 ± 3.8
Abe_31	2.62	100	50	0.52	83.43 ± 4.85	0.0441 ± 0.0358	76.8 ± 4.4	77.1 ± 3.7
Abe_32	0.33	139	74	0.55	79.67 ± 3.32	0.0504 ± 0.0188	80.4 ± 3.3	80.0 ± 3.1

(1) Common Pb corrected by assuming $^{206}Pb/^{238}U$–$^{208}Pb/^{232}Th$ age-concordance
(2) Common Pb corrected by assuming $^{206}Pb/^{238}U$–$^{207}Pb/^{235}U$ age-concordance

ments were based on the methods described in Tsutsumi *et al.* (2012). The spot size of the laser was 25 μm. Corrections for common Pb was made on the basis of the measured $^{207}Pb/^{206}Pb$ ratio (^{207}Pb correction) or $^{208}Pb/^{206}Pb$ and Th/U ratios (^{208}Pb correction) (e.g. Williams, 1998) as well as the model for common Pb compositions proposed by Stacey and Kramers (1975). In this paper, we adopt the ^{207}Pb correction for age discussion because it is more effective in calculating the Phanerozoic ^{238}U–$^{206}Pb^*$ age than the ^{208}Pb correction (e.g. Williams, 1998). The pooled ages presented in this study were calculated using Isoplot/Ex software (Ludwig, 2003). The uncertainties in the mean ^{238}U–$^{206}Pb^*$ ages represent 95% confidence intervals (95% conf.). $^{206}Pb^*$ indicates radiometric ^{206}Pb.

Results

Analyzed data from zircons; common ^{206}Pb, U, and Th concentrations, Th/U, $^{238}U/^{206}Pb^*$, and $^{207}Pb^*/^{206}Pb^*$ ratios, and radiometric $^{238}U/^{206}Pb^*$ ages are listed in Table 1. All errors state 1 sigma level. All zircons in the samples show rhythmic oscillatory and/or sector zoning on cathodoluminescence images, which is commonly observed in igneous zircons (e.g. Corfu *et al.*, 2003), and their higher Th/U ratios (>0.1) also support their igneous origin (Williams and Claesson, 1987; Schiøtte *et al.*, 1988; Kinny *et al.*, 1990; Hoskin and Black, 2000). Figure 2 shows a Tera-Wasserberg concordia diagram and an age distribution plot for all analyzed spots of the sample. All zircon U–Pb ages cluster in the range 73–87 Ma. The weighted mean age, after the rejection of three data points, yield 80.2 ± 0.8 Ma (MSWD = 0.8; 95% conf.), which is thought to

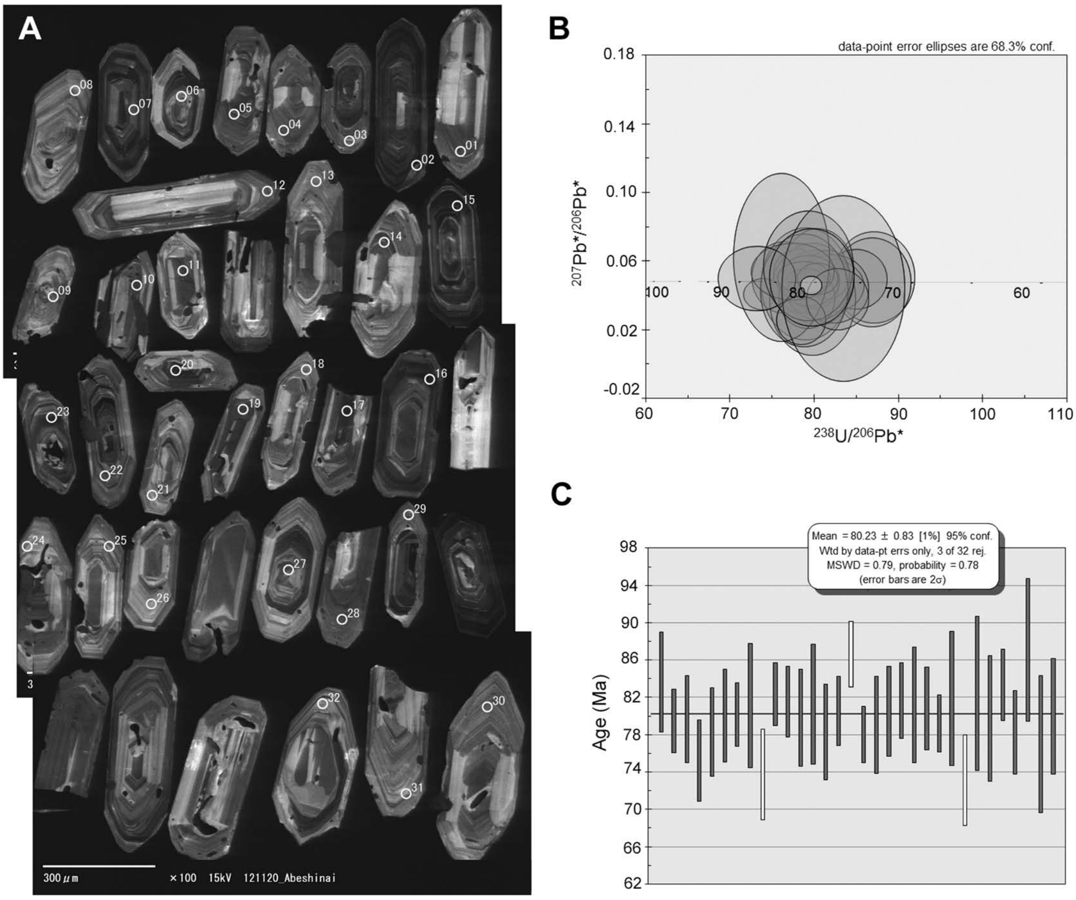

Fig. 2. U–Pb zircon ages of tuff sample collected from the upper part of the Osoushinai Formation. A, cathodoluminescence image (CL) of zircon grains from the sample. Circles on the grains represent spots analyzed by LA-ICP-MS. Spots are 25 μm across. B, Tera-Wasserburg U–Pb concordia diagram of zircons. C, ^{238}U–^{206}Pb age distribution plot of tuff sample. $^{207}Pb^*$ and $^{206}Pb^*$ indicate radiometric ^{207}Pb and ^{206}Pb, respectively.

represent the magmatism/deposition age of the tuff sample.

Discussion

Zircon geochronology in this study reveals that the U–Pb age of the tuff just below the *Sphenoceramus schmidti*-bearing beds is 80.2 ± 0.8 Ma (95% conf.), which infers an early middle Campanian age. This result confirms the validity of the work of Tamaki *et al.* (2008), who correlated the beds in the Urakawa area, Hokkaido with the upper part of polarity chron C33r and lower part of C33n (= lower middle Campanian). In contrast, our result differs from the work of Kodama *et al.* (2000), who correlated the *S. schmidti*-bearing beds in the Naiba area, Sakhalin with the bottom of polarity chron C32r (= middle upper Campanian). We question the accuracy of this magnetostratigraphic correlation primarily because strata just below the *S. schmidti*-bearing beds are not well exposed in the Naiba area (Shigeta *et al.*, 2015, 2016).

The *Sphenoceramus schmidti* Zone in southwestern Japan was shown to be lower middle Campanian by both magnetostratigraphy and zircon geochronology (Kodama, 1990; Tsutsumi *et al.*, 2014), thus suggesting that the age of the zone in southwestern Japan is the same as in Hokkaido. Therefore, *Sphenoceramus schmidti* should be regarded as an ideal zonal-index fossil for the lower middle Campanian of the Northwest Pacific region

Sphenoceramus schmidti also occurs in the Upper Cretaceous of the Pacific coastal region of North America (e.g. Usher, 1952; Matsumoto, 1960; Jones, 1963). Ward *et al.* (1983, 2012) indicated that the *S. schmidti* Zone of the Great Valley Sequence in northern California should be placed near the top of polarity chron C34n (= Santonian) and lowest part of polarity chron C33r (= lowest Campanian), which differs greatly from that of the

Northwest Pacific region. We question the accuracy of this conclusion because the magnetostratigraphy of northern California has only been studied in very short stratigraphic sequences. Further magnetostratigraphic studies of a continuous sequence spanning the Santonian to Maastrichtian as well as radiometric age determinations are needed settle this problem.

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