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Early Triassic (Induan) Radiolaria and carbon-isotope ratios of a deep-sea sequence from Waiheke Island, North Island, New Zealand

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Abstract

This study examines a Triassic deep-sea sequence consisting of rhythmically bedded radiolarian cherts and shales and its implications for early Induan radiolarian fossils. The sequence, obtained from the Waipapa terrane, Waiheke Island, New Zealand, is composed of six lithologic Units (A–F) and, based on conodont biostratigraphy, spans at least the interval from the lowest Induan to the Anisian. Unit A (the basal unit) consists of black chert and shale beds containing fine pyrite minerals; this corresponds to the oceanic anoxic event described at Arrow Rocks further north in New Zealand. The $\delta^{13}C_{org}$ values of Unit A show a pronounced negative shift between the pale-green chert and black shale/chert, which may represent the negative excursion across the Permian–Triassic boundary that has been documented worldwide. The black cherts, which give minimum C-isotopic ratios (around −30‰), are early Induan, and contain a rich radiolarian fauna characterized by *Entactinosphaera*? *crassispinosa* Sashida and Tonishi, *E.*? *spoerlii* Takemura and Aono, *Bistarkum martiali* Feng, *Entactinia* cf. *itsukaichiensis* Sashida and Tonishi, *Ellipsocopicyntra*? sp., and rare Nassellaria. A new Induan nassellarian species, *Tripedocorbis*? *blackae* n. sp., from the black chert bed, is described herein. Its presence indicates that Triassic-type Nassellaria had already appeared in the early Induan in the pelagic realms of southern hemisphere Panthalassa.

Keywords: Induan; Early Triassic; Radiolaria; Conodont; C-isotope; New species

1. Introduction

The Early Triassic radiolarian record is generally lacking globally, particularly for the Induan for which there are only a few radiolarian localities documented. These include the Dienerian to early Smithian limestone beds of the Karalaya Zone in NW Turkey (Kozur et al., 1996), the Induan to Olenekian chert beds of the Oruatemanu Formation of Arrow Rocks, New Zealand (Kamata et al., 2007; Takemura et al., 2007), and the Early Triassic limestone of Thailand (Sashida et al., 1998, 2000).

The timing of the first appearance of Mesozoic-type Nassellaria displaying a conical shell and the characteristic cephalis structure is still unclear. One of the oldest known Mesozoic nassellarian species is *Tripedocassis oruatemanuensis*, which was described from chert samples of the Oruatemanu Formation of Arrow Rocks, in the Waipapa terrane, New Zealand (Kamata et al., 2007). The earliest appearance of this species is considered to be in the middle Dienerian (late Induan). We describe here a new species of Mesozoic-type Nassellaria asso-

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ciated with some other characteristic taxa from the Griesbachian (early Induan) cherts in a chert-shale sequence spanning the Early Triassic to Middle Triassic on Waiheke Island near Auckland City, New Zealand. This sequence is part of the Mesozoic Waipapa terrane accretionary complex (Spörli et al., 2007). Examination of $\delta^{13}C_{org}$ values in the Induan chert and underlying shale beds and comparison with previously reported data from Permian–Triassic (P–T) boundary sections elsewhere in the world indicate a high probability of the P–T boundary being present in this section.

2. Geological setting

The basement rocks of the Waiheke Island–Kawakawa Bay area belong to the Waipapa composite terrane of New Zealand (Spörli and Aita, 1988; Adams and Maas, 2004), which is composed mainly of two lithofacies tectonically repeated at relatively regular intervals: (1) basaltic rocks (spillite) associated with chert-mudstone (argillite) sequences and (2) clastic rocks ('greywackes') consisting of sandstone and siltstones (Schofield, 1974). The basaltic rocks show pillow and occasionally brecciated structures and have been determined to be of tholeiitic affinity based on their geochemical compositions (Jennings, 1991). Assuming that the lithofacies were stratigraphically intercalated, Schofield (1974, 1979) named the basalt/chert-mudstone units in this area the Waikorariki Formation, Rocky Bay Formation, and Kiripaka Formation, in ascending order. The sequence studied is part of the highest unit (Kiripaka Formation) and is located at Island Bay in the northwest of Waiheke Island, near Auckland City. Subsequently, the work of Prin (1984), Spörli and Aita (1988), and Spörli et al. (1989) showed that the basalt/chert-mudstone (oceanic) units are all older than the surrounding (terrigenous) 'greywackes' and that their base marks the location of major thrusts in an accretionary prism, which caused the major structural repetitions. Thus, the chert sequences of the Waikorariki and Rocky Bay Formations always contain Late Triassic to Early Jurassic radiolarian fossils. In addition, as would be expected with the geometry of an accretionary prism, the western part of the Kiripaka Formation, which is structurally located in the uppermost part of these basement rocks, is even older, containing Early? and Middle Triassic radiolarians (Prin, 1984; Spörli and Aita, 1988; Spörli et al., 1989, 2007). From the siltstones in the terrigenous units encompassing the Waikorariki Formation and the Rocky Bay Formation, Late Jurassic bivalves and radiolarian fossils have been reported (e.g., Schofield, 1974; Spörli and Aita, 1988; Aita and Spörli, 1992). Again, the terrigenous units adjacent to the Kiripaka Formation are older, containing Late Triassic (Carnian/Norian) radiolarian fossils (Hori et al., 2003b). This large gap in age may not only be due to the regular upward increase in age due to normal age gradients on the incoming oceanic floor but could also mark age discontinuities due to incorporation of different plate segments separated by oceanic transforms, as suggested by Spörli et al. (2007).

3. Materials and methods

3.1. The Waiheke (WHK1) section

All samples studied were collected from sedimentary rocks in a well-exposed coastal section (WHK1) in Island Bay, northwestern Waiheke Island, North Island, New Zealand (Fig. 1). The section is associated with basaltic rocks, shale and bedded chert sequences (Fig. 2). The underlying basaltic rocks consist of massive porphyritic lavas, pillow lavas and breccias, and are considered to be tholeiitic metabasalts (Jennings, 1991). Shear zones at low angles to the layering tectonically repeat the basaltic rocks, forming at least two thrust sheets. The bedded chert sequence is folded and cut by many small faults as shown in Fig. 2.

3.1.1. Lithology

The WHK1 section overlies basaltic rocks of more than 60 m in thickness. The top part of the basaltic succession is composed of brick red volcanic breccia (4–5 m thick), green pillow lava (4–5 m thick) and volcanic shale (Fig. 3).

The WHK1 sedimentary sequence is approximately 10 m thick in total and consists of, in ascending order, the following six litho-units (Fig. 4): Unit A – black and yellowish-black chert with black shale, and pale green tuffaceous shale or chert at base; Unit B – greenish to yellowish gray chert; Unit C – well-bedded brick-red chert; Unit D – well-laminated purple and green shale to muddy dark red chert/shale; Unit E – bedded red chert; and Unit F – yellowish gray (partly red) chert. The black shale of Unit A occasionally contains thin pyrite layers and gradually changes upward into the chert-dominated sequence. Most black and gray cherts of Unit A contain fine pyrite crystals.

3.1.2. Paleomagnetic data

As described by Kodama et al. (2007), 70 samples were collected for paleomagnetic study from the WHK1 section. Only tuffaceous and black chert beds of Unit A were successfully demagnetized. These results indicate a paleolatitude of ∼34°S for deposition of the WHK1 chert (Kodama et al., 2007). This is the first successful determination of a paleolatitude for oceanic sediments of the Waipapa terrane, overcoming the pervasive Cretaceous and later overprints.

3.2. Method for microfossil analysis

Among the microfossils obtained from the WHK1 section, radiolarians were studied at Ehime University, Japan, and conodonts at Miyazaki University, Japan. The extraction and examination methods for radiolarian fossils were described by Hori (1988). The conodonts were mainly observed under binocular microscope. Most specimens were difficult to extract from the chert and shale samples using acid techniques.

The localities that yielded the microfossils reported in this study have been recorded in the New Zealand Fossil Record File system administered jointly by the Geosciences Society of New Zealand and GNS Science. The New Zealand Fossil Record File (FRF) number of the entire WHK1 section is R10/f177 (R10 is

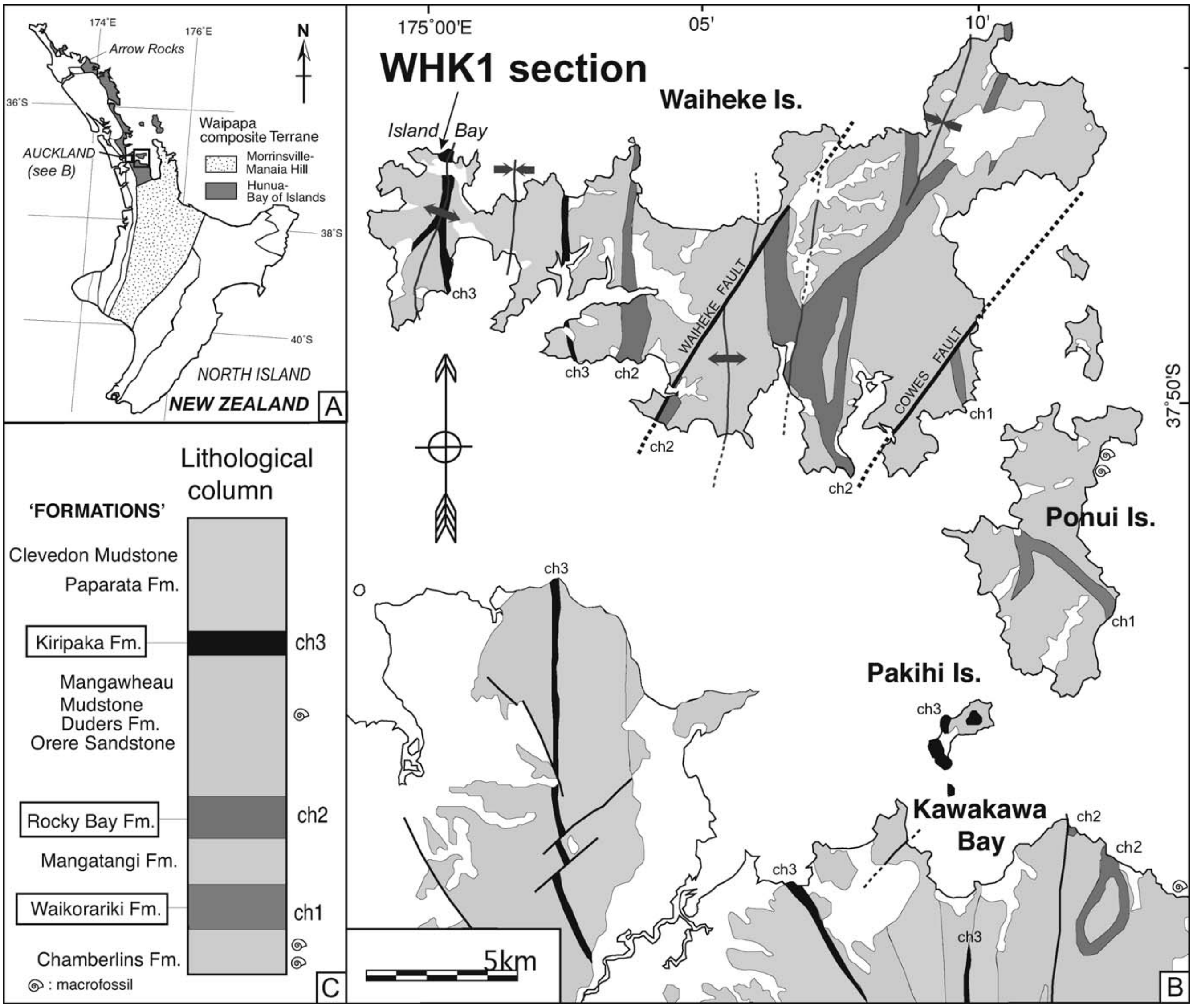

Fig. 1. Location of the WHK1 section studied on Waiheke Island, Auckland, New Zealand. (A) Map of the North Island, New Zealand with subdivision of the Waipapa terrane, after Black (1994) and Begg and Johnston (2000) and location of Arrow Rocks. (B) Geological map of Waiheke Island and adjacent areas. Dark grays and blacks show oceanic units, light grays indicate terrigenous lithologies of the Waipapa terrane. (C) Stacking of lithological units in the region. See text for discussion of significance of this column. Geology in B and C simplified after Schofield (1979). Ch (ch1, ch2 and ch3): chert-bearing sequences. Fossil characters: macrofossil-bearing horizon.

the New Zealand topographic map sheet number). Fossil-bearing horizons within the section are identified by the f177 number of the WHK1 section plus a suffix denoting the height of the sample horizon above the base of the section in meters (e.g., R10/f177/0.7 or R10/f177/0.8).

3.3. Method for carbon isotopic analysis

We examined organic carbon isotopic ratios of chert and shale bulk samples from 10 horizons within the lower part of Unit A to identify a possible record of the P–T boundary in the WHK1 section. After selection and washing with Ellix® water, all samples were ground into fine powder (less than 1 μm), using an agate mill. The powdered samples were decarbonated with 10% HCl in a clean draft chamber at Ehime University, Japan. Organic carbon isotopic compositions and carbon content were measured using an elemental analyzer (FlashEA 1112) coupled with a Thermo-Finnigan Delta plus Advantage isotope ratio mass spectrometer at the Center for Advanced Marine Core Research, Kochi University, Japan. Isotopic measurements were repeated three or four times for each horizon to check the reproducibility of results. The carbon contents were calculated using standard sulfanilamide, and the precision of the organic carbon ratio ($\delta^{13}C_{org}$) determinations was better than 0.1%. The system for analysis of organic carbon ratios was calibrated using histidine and alanine obtained from Sugito Ltd. Lab. All isotopic results are reported in conventional delta (δ) notation, defined as per mill (‰) deviation from the Pee Dee belemnite (PDB) standard value.

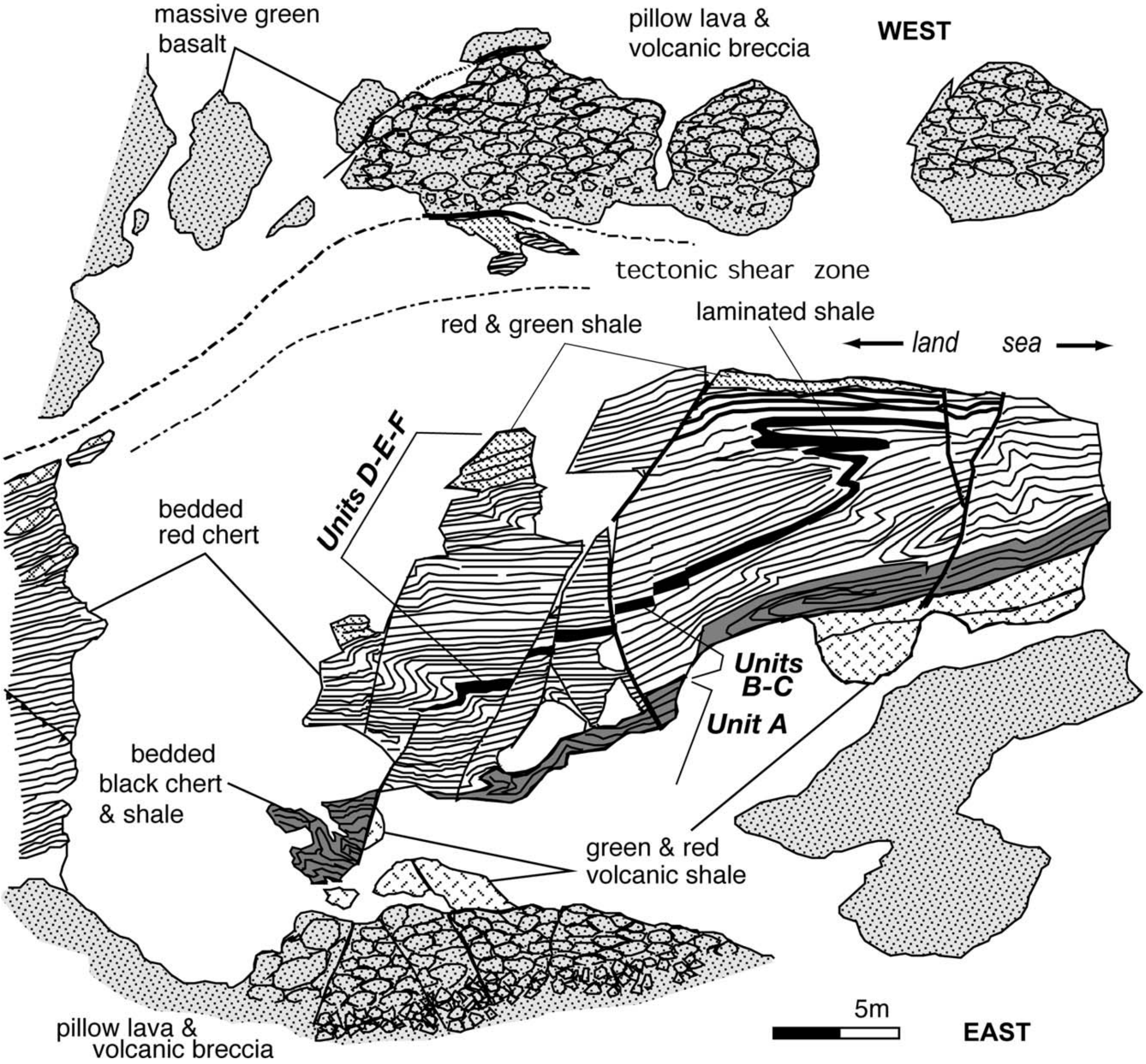

Fig. 2. Outcrop sketch map of the WHK1 section studied at Island Bay, northwestern of Waiheke Island. Stratigraphic younging is to the West. Gray dotted areas consist of basaltic rocks. Locations of the Units A–F logs of the WHK1 section are shown.

4. Results

4.1. Conodont biostratigraphy

The depositional age of the WHK1 section is well constrained by conodonts (e.g., Yamakita et al., 2008). The preliminary results obtained from these samples have established stratigraphic ranges of at least 13 conodont species from 11 horizons (Fig. 4). *Hindeodus* sp. and *Neogondolella carinata* (Clark) were obtained from the lower part of Unit A. The upper part of Unit A contains *Sweetospathodus* cf. *kummeli* (Sweet). *Neostrachanognathus* aff. *tahoensis* Koike, *Neospathodus abruptus* Orchard and *Neogondolella jubata* Sweet occur in Unit B, and *Neospathodus broctus* Orchard, *Ns. triangularis* (Bender), and *Ns. symmetricus* Orchard are found in Unit C. The basal part of Unit E yields *Chiosella* cf. *timorensis* (Nogami), *Neospathodus clinatus* (Orchard), *Neospathodus symmetricus*, *Neogondolella jubata* and *Neogondolella regale* Mocher. From the top part of this section (upper part of Units E and F), specimens of *Neogondolella* cf. *bulgarica* (Budurov and Stefanov) were recovered. On the basis of this conodont biostratigraphy, Unit A is correlated with the Induan (Lower Triassic), although we have not recognized diagnostic species of the lowermost Induan such as *Hindeodus parvus* (Kozur and Pjatakova). Units B–F correspond to the interval from the upper Olenekian to Anisian. The conodont biostratigraphy (e.g., Yamakita et al., 2008) suggests that there is a high possibility that the middle part of Lower Triassic (upper Dienerian to Smithian) is missing in this section. The rep-

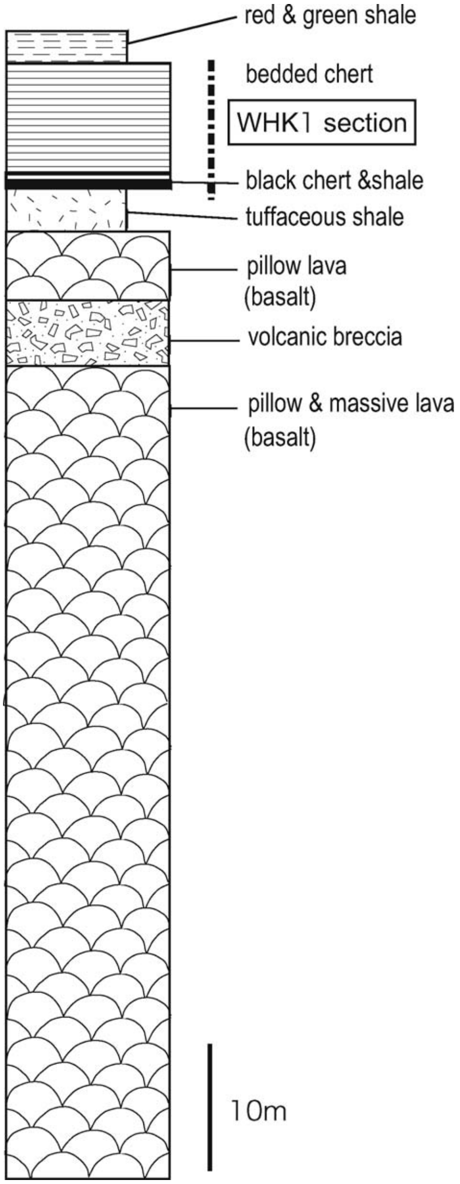

Fig. 3. Simplified stratigraphic column of the chert-basalt sequence at Island Bay, with the position of the WHK1 section of thin-bedded chert studied.

resentative conodont fossils obtained from the WHK1 section are shown in Fig. 5.

4.2. Radiolarian fauna

Radiolarian fossils have been extracted and identified from two horizons (R10/f177/0.7 and R10/f177/0.8) within the black chert succession in Unit A. We also recognized many radiolarian fossils with robust and thick-walled and/or spherical tests in thin sections in other parts of the section, but have not yet had any success in extracting them. The radiolarian fauna obtained from the black chert is rich in spherical forms but Nassellaria are very rare (Fig. 6) and not identifiable. However, we could recognize the following taxa: *Entactinosphaera*? *crassispinosa* Sashida and Tonishi, 1985, *E.*? *spoerlii* Takemura and Aono in Takemura and Aono, 2007, *E.* cf. *chiakensis* Sashida and Igo, 1992, *Bistarkum martiali* Feng in Feng et al., 2006, *Entactinia* cf. *itsukaichiensis* Sashida and Tonishi, 1985 and *Ellipsocopicyntra*? sp. In addition, rare Nassellaria have been recovered and one new species, *Tripedocorbis*? *blackae* n. sp. (Fig. 7), is described herein. This new species is similar to *Tripedocassis oruatemanuensis* documented from Arrow Rocks, Waipapa terrane, but differs from the latter species by having some distinctive features (see Section 7 for details).

The radiolarian fauna obtained from the base of Unit A appears to be a mixture of Late Permian and Early Triassic (Induan) radiolarians. Spherical radiolarian taxa are similar to those of the Late Permian from Japan (Sashida and Tonishi, 1985), South China (Feng et al., 2006) and Tibet (Li and Bian, 1993) and also to those from Arrow Rocks, New Zealand (Takemura et al., 2007). Among them we could recognize numerous specimens of the genera *Entactinia* and *Entactinosphaera*? in the two horizons studied. However, the Late Permian species *Entactinosphaera*? *crassispinosa* was recorded only in the lower horizon (R10/f177/0.7), whereas the Early Triassic (Induan) species *E.*? *spoerlii*, described from the Arrow Rocks of New Zealand, was recovered in the upper horizon (R10/f177/0.8). Some other unnamed Spumellaria are also common in the Olenekian (late Early Triassic) radiolarian fauna of the Karoro Formation, South Island, New Zealand, as documented by Hori et al. (2003a).

We have not yet recognized any species of the genera *Albaillella* and *Follicucullus*, nor have we found any of Latentifistulidae. These are considered to be Permian taxa which survived the P–T boundary extinction event as they have been documented from the Induan strata of Arrow Rocks (Takemura et al., 2007). Most of the obtained radiolarians such as gen. et sp. indet. A and gen. et sp. indet. B are shown in Fig. 7.

4.3. C-isotope excursion

Tuffaceous pale green cherts at the base of Unit A contain 0.02% to 0.03% total organic carbon (TOC), and black chert (H09+04(WA-2)) shows the highest TOC value of 0.87% (Table 1). Black cherts in Unit A above this horizon have relatively high TOC contents (0.14–0.29%) compared with those of the basal chert. The black shale adjoining the black chert of the lower Unit A shows high TOC values of 6.9–8.5% (Table 1).

The $\delta^{13}C_{org}$ values of the basal tuffaceous chert rapidly decrease from −25.9‰ to −27.4‰ upward and reach a minimum of −31.1‰ in the black chert and associated black shale. Above these, the $\delta^{13}C_{org}$ values vary by ∼1‰ around a −30‰ level (Fig. 8). We carefully checked the reproducibility of the isotopic values in the samples from the black chert, which showed the minimum $\delta^{13}C_{org}$ value, and from the top tuffaceous pale green chert. Values obtained from rock samples collected at different times at the same stratigraphic level show good reproducibility of values with 1‰ or less fluctuation (asterisks in Table 1). Therefore, the negative shift detected in the $\delta^{13}C_{org}$ values of Unit A is reliable.

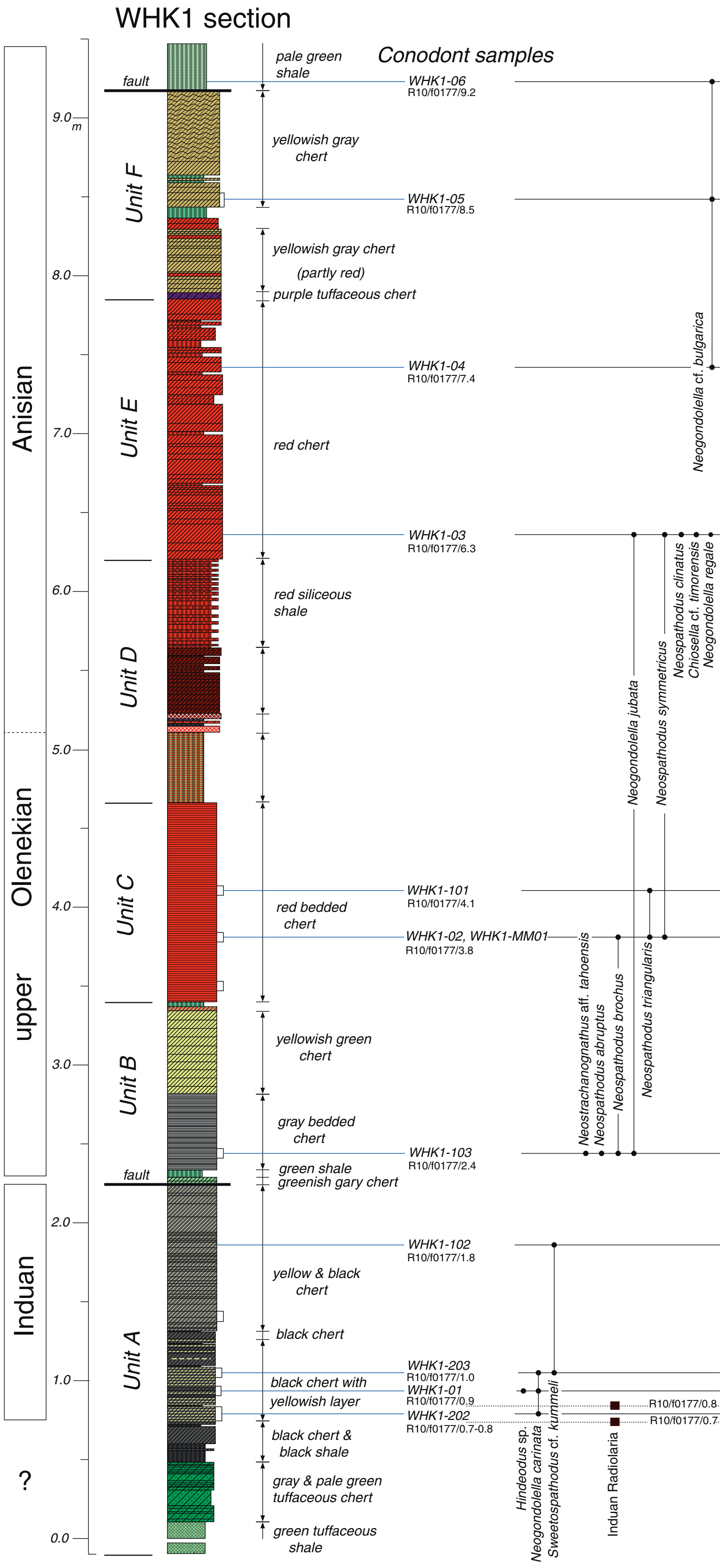

Fig. 4. Stratigraphic column of the WHK1 section, with stratigraphic distribution of conodont species and radiolarian horizons documented in this study. Units A–F are described in the text.

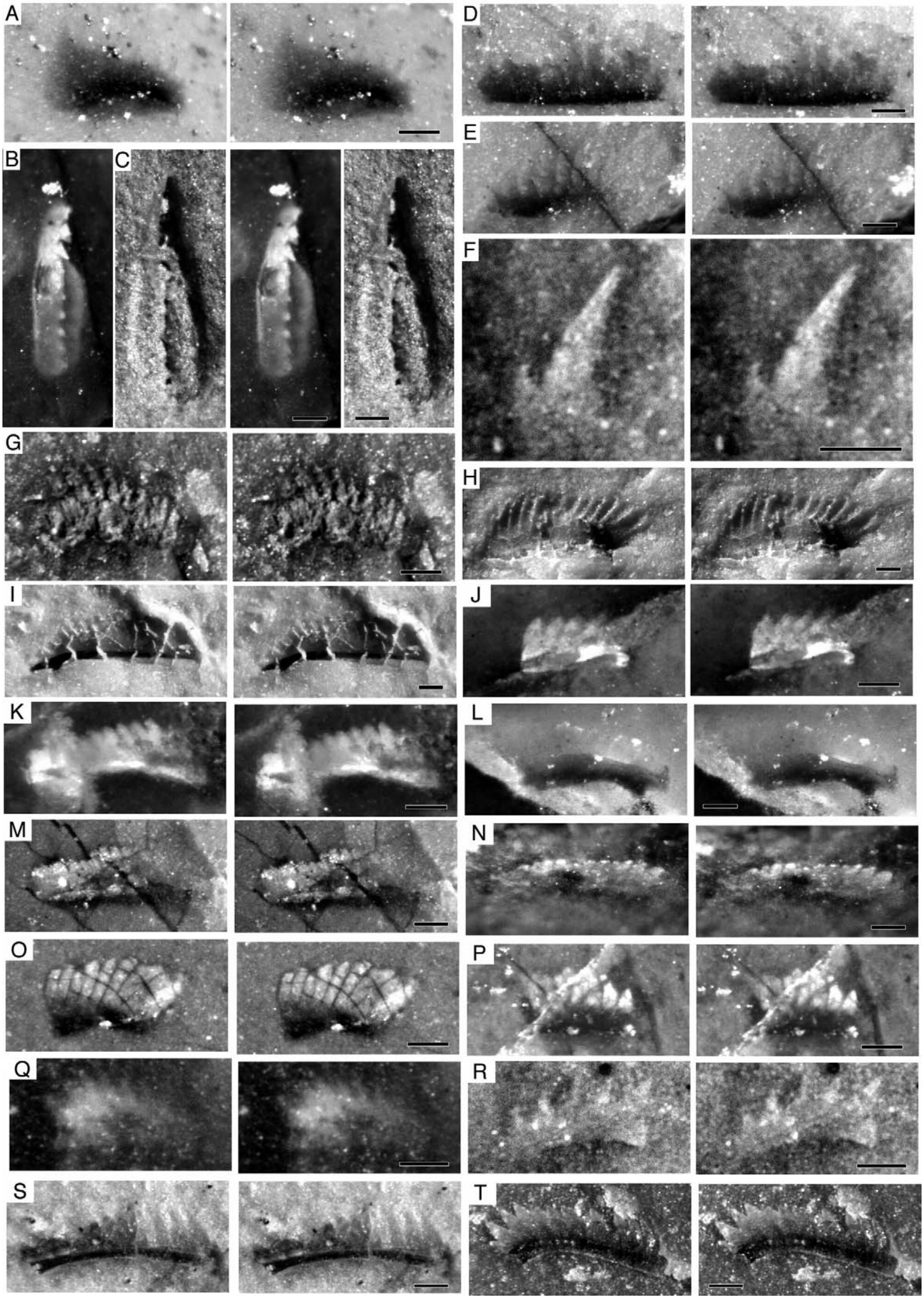

Fig. 5. Conodonts from WHK1 section. All photographs are in stereographic pairs. (A) *Hindeodus* sp. Lateral view, WHK1-01, R10/f177/0/9. (B) *Neogondolella carinata* (Clark). Oral view, WHK1-202, R10/f177/0.7-0.8. (C) *Neogondolella carinata* (Clark). Oral view, WHK1-203, R10/f177/1.0. (D and E) *Sweetognathodus* cf. *kummeli* (Sweet). Lateral view, WHK1-102, R10/f177/1.8. (F) *Neostrachanognathus* aff. *tahoensis* Koike. Lateral view, WHK1-103, R10/f177/2.4. (G) *Neospathodus abruptus* Orchard. Lateral view, WHK1-103, R10/f177/2.4. (H) *Neospathodus brochus* Orchard. Lateral view, WHK1-103, R10/f177/2.4. (I) *Neogondolella jubata* Sweet. Lateral view, WHK1-103, R10/f177/2.4. (J) *Neospathodus triangularis* (Bender). Lateral view, WHK1-02, R10/f177/3.8. (K and L) *Neogondolella jubata* Sweet. Lateral view, WHK1-03, R10/f177/6.3. (M) *Neogondolella regale* Mosher. Lateral view, WHK1-03, R10/f177/6.3. (N) *Chiosella* cf. *timorensis* (Nogami).

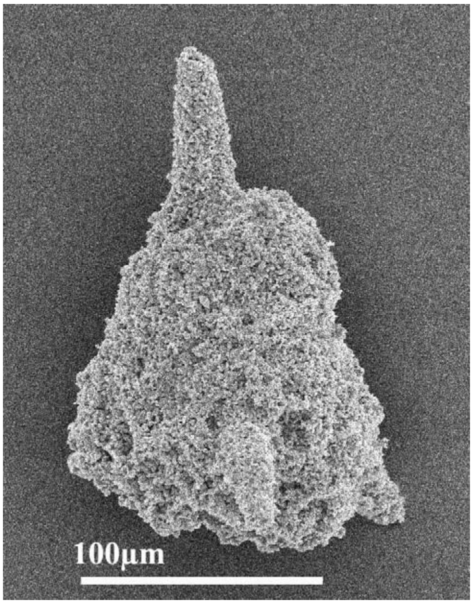

Fig. 6. Induan Nassellaria, *Tripedocorbis*? *blackae* n. sp., from the WHK1 section. ESEU Coll. MR0010, RH837, 6.7 m in WHK1-202, R10/f177/0.7. Scale bar is 100 μm.

5. Discussion

5.1. Radiolarian faunal turnover across the P–T boundary

The large taxonomic gap recognized between the Permian and Triassic Radiolaria (e.g., De Wever et al., 2001) is considered to represent the Permian–Triassic (P–T) boundary mass extinction event. However, the mode and magnitude of radiolarian faunal turnover crossing the P–T boundary are still uncertain because very few uppermost Permian and lowermost Triassic sections with radiolarian fossils are known worldwide. Many questions regarding radiolarian evolution across the P–T boundary remain. For example, when did Mesozoic (Triassic)-type Nassellaria appear? How many radiolarian taxa became extinct and how many survived the P–T boundary event? Did the extinction event occur uniformly on a global scale, or did any radiolarian refugia exist during the P–T boundary crisis?

Our WHK1 section provides an answer to one of these questions. On the basis of our data, Triassic-type Nassellaria probably first appeared in the early Induan (Griesbachian) around the Southern Hemisphere latitude of about 34°. However, the internal structure of *Tripedocorbis*? *blackae* n. sp. described herein should be further investigated to confirm this suggestion. In contrast, Triassic Nassellaria have been documented from middle Induan (Dienerian), and Permian survival fauna, such as species of *Albaillella*, *Follicucullus* and Latentifistulidae, have been recognized in the lower Induan (Griesbachian) of the Oruatemanu Formation at Arrow Rocks (Takemura et al., 2007). To date, no specimens of these genera have been recovered from the WHK1 section, although some Permian type radiolarians, such as *Entactinosphaera*? *crassispinosa*, *Bistarkum martiali* and *Entactinia* cf. *itsukaichiensis* have been observed. However, as discussed by Sashida and Igo (1992) and Feng et al. (2006), *Bistarkum martiali* is a disaster taxon and *Entactinia* spp. definitely survived into the Early Triassic interval. Only *Entactinosphaera*? *crassispinosa* is known as a Late Permian species, but given the occurrences of *Entactinosphaera*? *spoerlii* at Arrow Rocks, this radiolarian group must also be regarded as a long-range taxon persisting through the Late Permian to Early Triassic interval.

The difference in the radiolarian assemblage between Arrow Rocks and the Waiheke Island, both within the same Waipapa terrane, can be explained in at least two ways. Some plausible causes of this discrepancy include: (1) the survival taxa are also present in the WHK1 section but we have not yet found them, or (2) Arrow Rocks represents a refugium where Permian-type radiolarians survived, and such refugia were restricted geographically in the Triassic world. With respect to the latter suggestion, there is certain evidence to support environmental differences between the Arrow Rocks and Waiheke sections. First, in contrast to Waiheke, the Arrow Rocks strata were formed near large seamounts (Sakakibara and Black, 2007). In this northern region there appears to be a larger volume of basaltic rocks than at Waiheke, not only at Arrow Rocks, but also nearby in the Mahinepua Peninsula, and Stephenson and Cone islands (Aita and Spörli, 2007). In addition, the basaltic rocks are associated with fossiliferous limestones (e.g., Campbell, 2007), which are not present in the southern area. Second, geochemical analysis of Arrow Rocks basalts suggested they are oceanic island tholeiite or large igneous provinces (Sakakibara and Black, 2007). Although tholeiitic basalts also occur in Waiheke Island, their chemical compositions are different from those at Arrow Rocks (Jennings, 1991; Black, 1994; Sakakibara, personal communication). Third, the sedimentation rate in the P–T boundary sequence from Arrow Rocks is two or three times greater than that of the WHK1 section (Yamakita et al., 2008), which indicates high production of biogenic silica. The strata of the WHK1 section therefore probably formed under lower productivity and deeper water conditions within the pelagic Southern Hemisphere Panthalassa compared to the strata at Arrow Rocks.

Arrow Rocks presently lies about 290 km NNW of Waiheke Island. However, the relative position of the two sites in the Early Triassic time is uncertain because there is no location data for Arrow Rocks from paleomagnetic studies. Further paleomagnetic work is needed to accurately determine the depositional site of the Arrow Rocks sequence; however, previous attempts have not been successful (Kodama et al., 2007).

Lateral view, WHK1-03, R10/f177/6.3. (O) *Neospathodus symmetricus* Orchard. Lateral view, WHK1-03, R10/f177/6.3. (P) *Neospathodus clinatus* Orchard. Lateral view, WHK1-03, R10/f177/6.3. (Q) *Neogondolella* cf. *bulgarica* (Budurov and Stefanov). Lateral view, WHK1-04, R10/f177/7.4. (R–T). *Neogondolella* cf. *bulgarica* (Budurov and Stefanov). Lateral view, WHK1-06, R10/f177/9.2. Scale bars are 100 μm.

Table 1
TOC (wt%) and δ^{13}C (vs. PDB, ‰) values of bulk organic carbon in chert and shale samples from Unit A of the WHK1 section. δ^{13}C shows average values.

Sample	Lithology	*H* (cm)	$\delta^{13}C_{org\ (vs.\ PDB,\ ‰)}$	Max–Min	TOC (wt%)
H09+7(0)	Black/yellow ch	90	−30.2	2.0	0.24
H09+7(2)	Black/yellow ch	86	−30.2	1.3	0.29
H09+7(1)	Black chert	82	−29.9	4.1	0.29
H09+06	Black chert	80	−30.5	2.0	0.14
H09+05	Black shale	69	−31.1	0.7	8.48
H09+04(WA-2)	Black chert	66	−31.1[a]	0.9	0.87
H09+03	Black shale	62	−30.0	0.8	6.92
H09+02(WA-1)	Tuffaceous ch	28	−27.4[a]	0.8	0.03
H09+01	Tuffaceous ch	24	−25.8	0.5	0.02
H09−01	Tuffaceous sh	0	−25.9	0.5	0.02

[a] Values reproduced with 1‰ or less fluctuation from two separate sample collections.

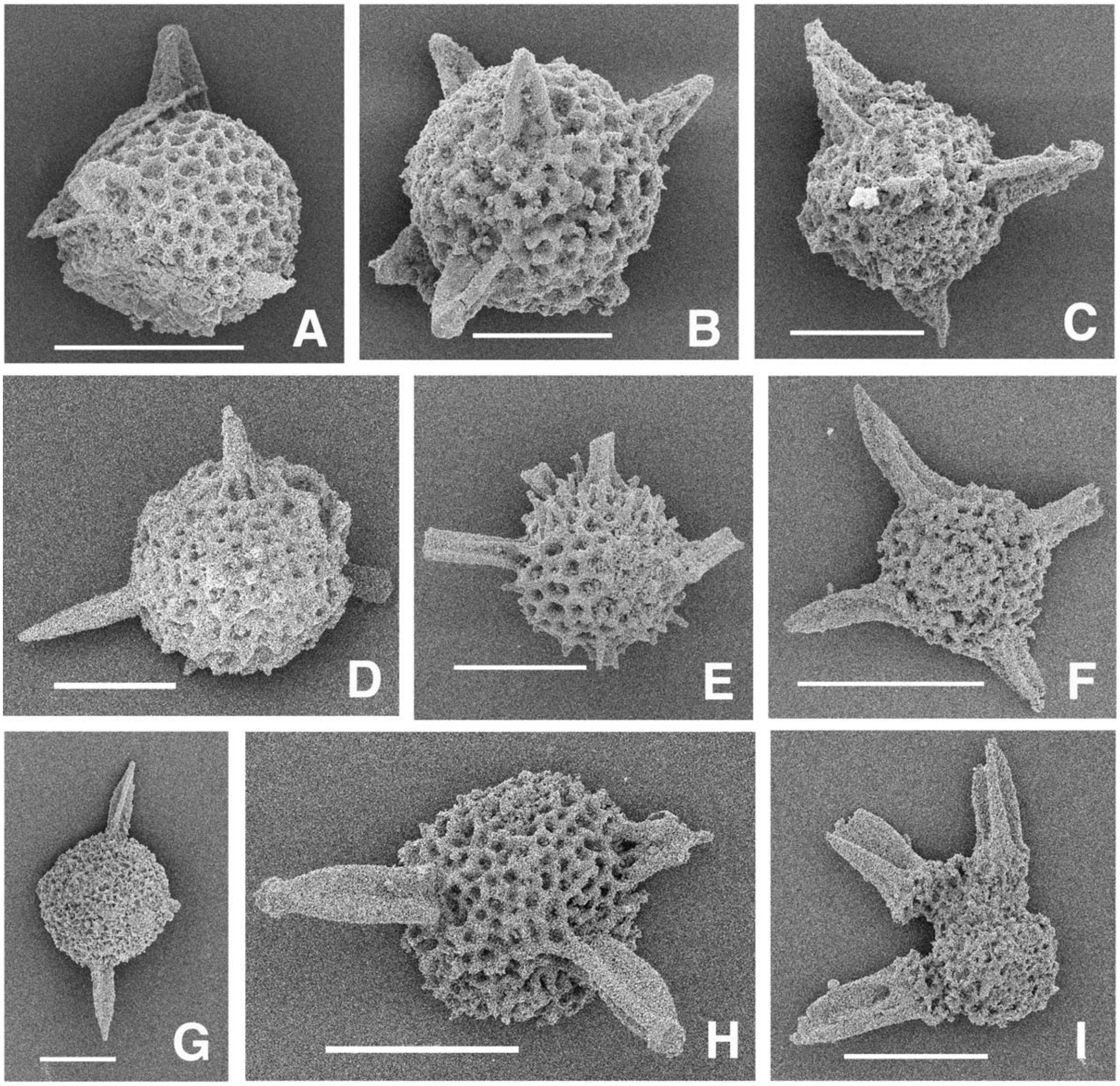

Fig. 7. Radiolaria from the lower part of Unit A in the WHK1 section. (A) *Entactinosphaera*? cf. *crassispinosa* Sashida and Tonishi, WHK1-202base, R10/f177/0.7. (B) *Entactinosphaera*? *spoerlii* Takemura and Aono, WHK1-202top, R10/f177/0.8. (C) *Entactinosphaera*? sp., WHK1-202top, R10/f177/0.8. (D) *Entactinosphaera* cf. *chiakensis* Sashida and Igo, WHK1-202base, R10/f177/0.7. (E) *Entactinia* cf. *itsukaichiensis* Sashida and Tonishi, WHK1-202base, R10/f177/0.7. (F) *Bistarkum martiali* Feng, WHK1-202base, R10/f177/0.7. (G) *Ellipsocopicyntra*? sp., WHK1-202top, R10/f177/0.8. (H) Gen. et sp. indet. A, WHK1-202base, R10/f177/0.7. (I) Gen. et sp. indet. B, WHK1-202base, R10/f177/0.7. Scale bars are 100 μm.

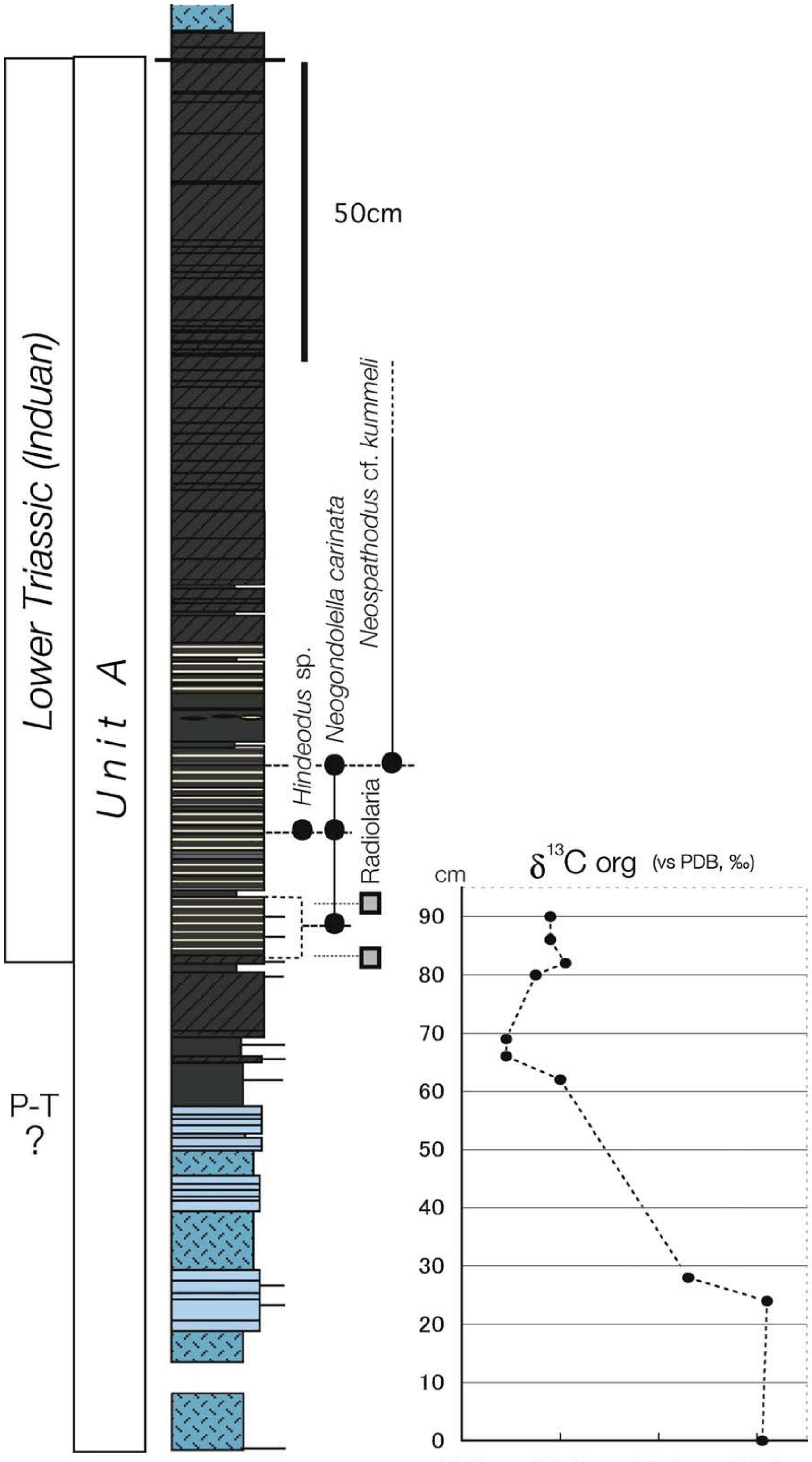

Fig. 8. Left: lithological column of Unit A in the WHK1 section, with horizons of conodont and radiolarian fossils examined. Right: profile of organic carbon of δ^{13}C (vs. PDB, ‰) for the lower part of Unit A.

5.2. Correlation of the C-isotopic profile

The C-isotope excursion at the P–T boundary has been well studied worldwide and its profile curves are very complicated (e.g., see the review of Korte and Kozur, 2010). However, negative δ^{13}C excursions crossing the P–T boundary are clearly detected in most sequences. High-resolution studies have revealed a W-shaped profile of δ^{13}C with two minimum values, the first one occurring at around the P–T boundary (described as Episode I by Xie et al., 2007) and the second within the *Isarcica* conodont zone (early Induan) (Episode II of Xie et al., 2007).

For the WHK1 section in New Zealand, the negative excursion of the curve could be correlated with the W-shaped excursion based on three different interpretations: (1) it is equivalent to Episode I; (2) it is equivalent to Episode II; or (3) it corresponds to a combination of Episodes I and II. Our data are of low resolution because the negative shift is spread over an interval from 30 to 60 cm in our section (Fig. 8). Therefore, interpretation 3 is most likely. This interpretation is supported by the following: the negative shift of $\delta^{13}C_{org}$ in the WHK1 section shows a similar decrease (~5–6‰) to that of the P–T boundary sequence from Arrow Rocks (Hori et al., 2007), to that of much shallower facies from the Maitai terrane, New Zealand, where a 7‰ shift (in mean value) has been documented (Krull et al., 2000), and also to those of several P–T boundary sequences in South China (e.g., Xia et al., 2004; Shen et al., 2006; Xie et al., 2007 for example) and the Tethys (e.g., Baud et al., 1989; Korte and Kozur, 2010 for reviews). The $\delta^{13}C_{org}$ values from the deep-sea sedimentary rocks of the Arrow Rocks change from values of −29‰ to −30‰ in the Upper Permian to −35‰ to −36‰ in the lower Induan part crossing the P–T boundary; the lowest Induan black cherts are characterized by high TOC contents and concentrations of heavy metals, suggesting an oceanic anoxic event, OAEα defined by Hori et al. (2007). Although the absolute $\delta^{13}C_{org}$ value in the WHK1 section is slightly larger, the amplitude of the excursion is the same as that from Arrow Rocks, and organic-rich sedimentary rocks also developed at the stratigraphic level of the $\delta^{13}C_{org}$ minimum. Therefore, the base of Unit A at Waiheke seems to be well correlated with the OAEα horizon at Arrow Rocks.

The $\delta^{13}C_{carb}$ (inorganic isotopic ratio) value at the Meishan GSSP changes by about 4‰ to −1‰ across the P–T boundary (e.g., Xie et al., 2007), which is a similar magnitude (around 5‰) to those excursions recognized in deep-sea sequences from New Zealand (Arrow Rocks and Waiheke). Our conodont data from the WHK1 section indicate that the negative excursion occurred in the pre-carinata zone, which may suggest a comparison with Episode II, but the magnitude of the negative shift (over 5‰) is not comparable with Episode II (less than 3‰). The WHK1 sequence displays an extremely slow sedimentation rate (<0.5 m/m.y.) and may therefore represent a condensed sedimentary record.

Given the above facts and discussion, it can be concluded that the P–T boundary in our Waiheke section is probably located in the interval between 30 and 60 cm in Fig. 8 in the basal Unit A, but the possibility that the sequence does not extend down to the P–T boundary cannot be excluded. For example, there are some Early Induan stratigraphic sections showing a large negative shift of $\delta^{13}C_{org}$ values that do not correspond to the P–T boundary (e.g., Xia et al., 2004). In addition, the stable isotopic ratio of organic carbon varies with different carbon sources. Therefore, a more detailed examination of the WHK1 section is required to determine the presence or absence of the P–T boundary and, if it is present, its accurate stratigraphic position.

6. Summary

We have stratigraphically and geochemically examined a deep-sea sedimentary sequence, the WHK1 section, from Waiheke Island, Waipapa terrane, New Zealand, and have obtained the following results:

(1) The section is composed of six lithologic units, Unit A–F (in ascending order), which, based on conodont biostratigraphy, span an interval from Early Triassic to Middle Triassic (Induan to Anisian) time.
(2) Early Induan radiolarian fauna was described including *Entactinosphaera*? *crassispinosa*, *E.*? *spoerlii*, *E.* cf. *chiakensis*, *Bistarkum martiali*, and *Entactinia* cf. *itsukaichiensis*, and one new species of Induan Nassellaria.
(3) A negative excursion of $\delta^{13}C_{org}$ and high TOC values are recognized within the black shale and chert beds of the WHK1 section, which can be correlated to the OAEα horizon of Arrow Rocks, New Zealand, and suggests the possibility of a P–T boundary record at its base.

Further multidisciplinary studies are required to clarify the development and environmental role of Early Triassic (Induan) radiolarian faunas in the pelagic Southern Hemisphere Panthalassic Ocean.

7. Systematic paleontology

Only one taxon is described herein because we have not yet recovered enough specimens to study the whole fauna. Further systematic descriptions will be provided in a separate paper. Type and illustrated specimens from this study were deposited in the collections of Ehime University, Japan.

Class RADIOLARIA Müller, 1858
Order Nassellaria Ehrenberg, 1876

Family Tripedurnulidae Dumitrica, 1991

Remarks: The family Tripedurnulidae was described by Dumitrica (1991) based on Middle Triassic Nassellaria, consisting of a cephalis and three feet. Dumitrica did not mention or deny the multi-segment shell structure of this family. This new species possibly has two chambers.

Genus *Tripedocorbis* Dumitrica, 1991

Remarks: The recovered specimen is not sufficiently well preserved to see its internal skeleton. It is tentatively assigned to the genus *Tripedocorbis* based on the resemblance between features of its skeletal morphology and those of the species initially described under the genus *Tripedocorbis* Dumitrica, 1991. Such features include surface characters, a well developed conical horn, and three conical feet, of which one, the D foot, is broken off. *Tripedocassis oruatemanuensis* Kamata and this new species are possibly ancestral forms of the family Tripedurnulidae Dumitrica as mentioned by Kamata (2007).

Tripedocorbis? *blackae* n. sp. Hori

(Fig. 6)

Holotype: Fig. 6 (ESEU Coll. MR0010, 6.7 m, RH837); R10/f177/0.7. WHK1 section, Kiripaka Formation, Island Bay, Waiheke Island, New Zealand.

Etymology: In honor of Professor Philippa Black for her valuable contributions to the study of the geology of Waipapa terrane, New Zealand.

Diagnosis: Small conical shell consisting of two segments. Cephalis globose with smooth surface, separated from distal part by well-marked constriction. Apical horn conical, long, dorsally displaced and slightly bladed at base. Feet conical, gradually tapering distally, and extended outside shell on top of porous part.

Dimensions: Shell width of first segment: 43 μm. Shell width of second segment: 60 μm. Length of shell without horn: 43 μm. Length of apical horn: 33 μm. Length of feet: 23–30 μm.

Remarks: The description of the species is only based on the holotype because it differs sufficiently from other Induan species so far described and because this species is very important for the study of radiolarian evolution across the P–T boundary. The species resembles *Tripedocassis oruatemanuensis* Kamata, 2007, described from the upper Induan (Dienerian) of the Oruatemanu Formation from Arrow Rocks, New Zealand, from which it differs in having a well-marked stricture in the shell and a long apical horn.

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