The Triassic-Jurassic transition at Kunga Island, Queen Charlotte Islands, British Columbia, Canada

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1. Introduction

Several stratigraphic sections in the Queen Charlotte Islands of British Columbia, Canada contain exceptionally well-preserved radiolarian faunas that cross the Triassic-Jurassic boundary (TJB). In particular, a section at Kunga Island shows a dramatic turnover of radiolarians that could be used to define and constrain the TJB to within one metre, a precision that is greater than any other fossil group. The Kunga section was originally proposed as a GSSP candidate for the base of the Jurassic by Carter & Tipper (1999) and again by Haggart *et al*. (2002). These proposals are updated here. We propose that, if radiolarian sequences are selected as the primary standard (*sensu* Callomon, 1984) for defining the TJB, then the section at Kunga Island should be selected as GSSP.

If radiolarian sequences are not selected as the primary standard, then we propose that they should be considered as a secondary standard and that the Kunga Island section be designated as a parastratotype in order to better characterize the Triassic-Jurassic transition. In some circles, parastratotypes are also known as auxiliary reference sections. In addition to radiolarians, the Kunga Island sequence permits the calibration of time scales based on ammonites, radiometric ages and, indirectly, with the carbon isotope curve. The aim of designating any stratotype is, of course, to provide the international community with the widest spectrum of stratigraphic information that helps both to define the boundary and to characterize it as thoroughly as possible. This maximizes the potential for regional and global correlation. No single section is perfect in this regard and, consequently, the International Stratigraphic Guide of the IUGS Commission on Stratigraphy (Salvador, 1994) has recognized the benefit of designating a parastratotype. The holostratotype is the GSSP and, of course, always has precedence in defining the boundary. The parastratotype provides critical information not present in the holostratotype. The designation of parastratotypes is a well-established procedure and there are several examples in stratigraphic studies of the Jurassic. These include the definition of the Bajocian, where the Murtinheira section at Cabo Mondego, Portugal, is the GSSP and the Bearreraig Bay section on the Isle of Skye, Scotland, is designated an auxiliary stratotype (Pavia & Enay, 1997) and the establishment of the Lower Jurassic ammonite zonation of North America (Smith *et al*., 1988; Jakobs *et al*., 1994; Taylor *et al*., 2001; Longridge *et al*., 2006a).

Below, we summarize the details of the Kunga Island section as currently understood.

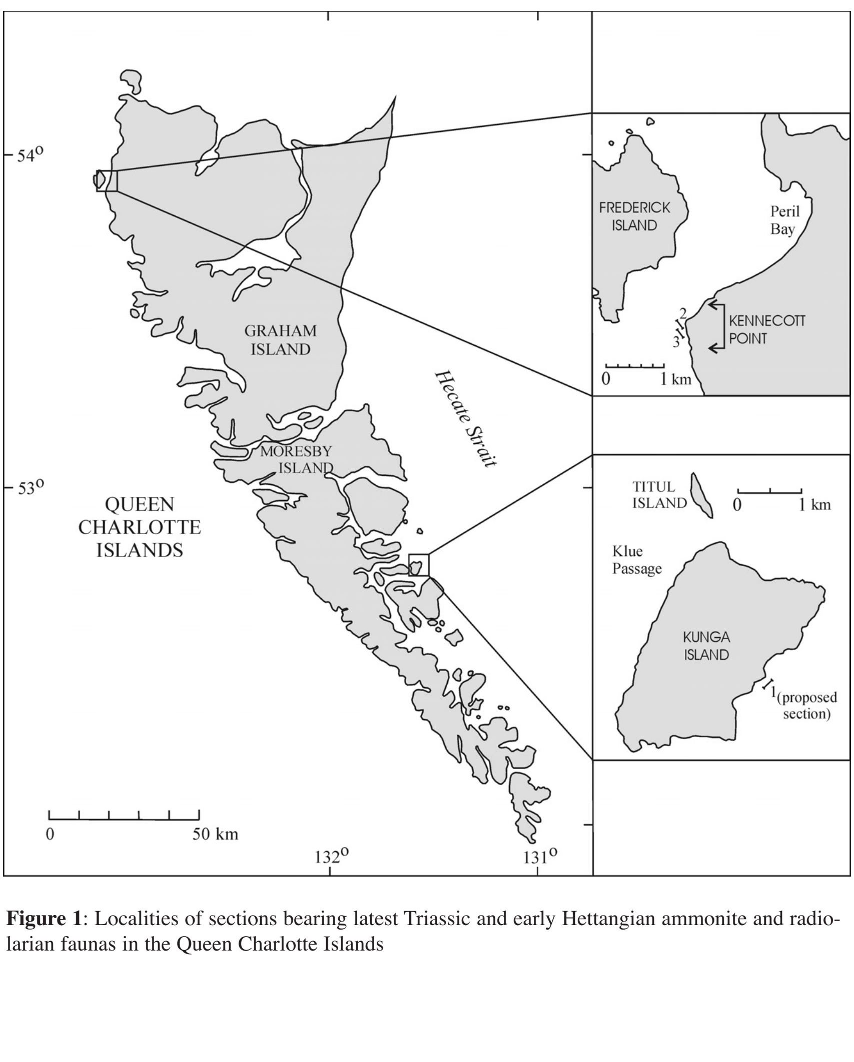


Figure 1: Localities of sections bearing latest Triassic and early Hettangian ammonite and radiolarian faunas in the Queen Charlotte Islands

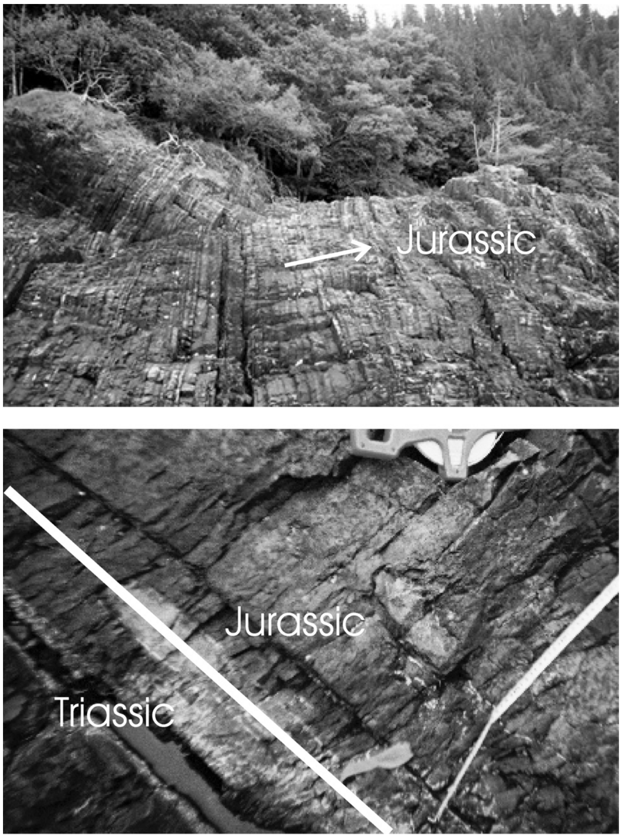


Figure 2: Proposed stratotype section on Kunga Island. View to NE. Adopted from Smith (1998, p.188, fig.4.32). Photo E. Carter. Inserted arrow indicates the boundary level, but not exactly the stratotype point

2. Location and access

The proposed section is located in the supratidal region on the southeast shore of Kunga Island (NTS 103 B/13, Zone 9; 52˚45.573', 131˚33.638') (Figure 1, section 1, Figure 2). Kunga Island is a small island on the southeastern edge of the Queen Charlotte Islands (QCI), British Columbia (Figure 1) and is part of Gwaii Haanas National Park Reserve. Although this means a permit is necessary prior to collecting, it also provides protection and conservation of the site (Haggart, in press). Access to Kunga Island involves flying into Sandspit, on Moresby Island, QCI, approximately 55km from the Kunga Island site. The section is then accessed by vehicle over about 60km of logging road and then by boat.

3. Paleogeographical context

Kunga Island is part of the Wrangellia terrane, considered to be allochthonous to North America. During Triassic/Jurassic time, Wrangellia was more southerly and further outboard of its current position, relative to the craton, but it was eventually accreted to North America at some time during the Middle Jurassic (van der Heyden, 1992; Thompson *et al*., 1991; Haggart *et al*., 1995), Cretaceous (Monger, 1998) or Paleogene (Ward *et al*., 1997). The constraints on its location at the end of the Triassic and beginning of the Jurassic are reasonably well documented. Permian coral, brachiopod, and fusulinid faunas (Monger, 1984; Belasky, 1994; Belasky *et al*., 2002), Sinemurian and Pliensbachian bivalve faunas (Aberhan, 1999 and references therein), and Pliensbachian ammonite faunas (Smith & Tipper, 1986; Smith *et al*., 2001; Smith, 2006) tie the terrane to the Northern Hemisphere and the eastern Pacific. The distribution of the ammonites *Sunrisites* and *Badouxia* are additional evidence that Wrangellia was located in the eastern Pacific during the Hettangian (Taylor *et al*., 1984; Smith, 2006; Longridge *et al*., in press).

4. Tectonic history and structural setting

The Kunga Island section was deposited in the Mesozoic Hecate Basin (Haggart, 1993). The basin was affected by southwest directed folding and contractional faulting in the Middle Jurassic, block faulting in the Late Jurassic, northeast-directed folding in the Late Cretaceous, and extensional block faulting and reverse faulting in the Paleogene (Thompson *et al*., 1991). Despite this regional deformation, the section at Kunga Island is, for the most part, structurally intact.

5. Lithostratigraphy and depositional paleoenvironment

The Kunga Island section is part of the Sandilands

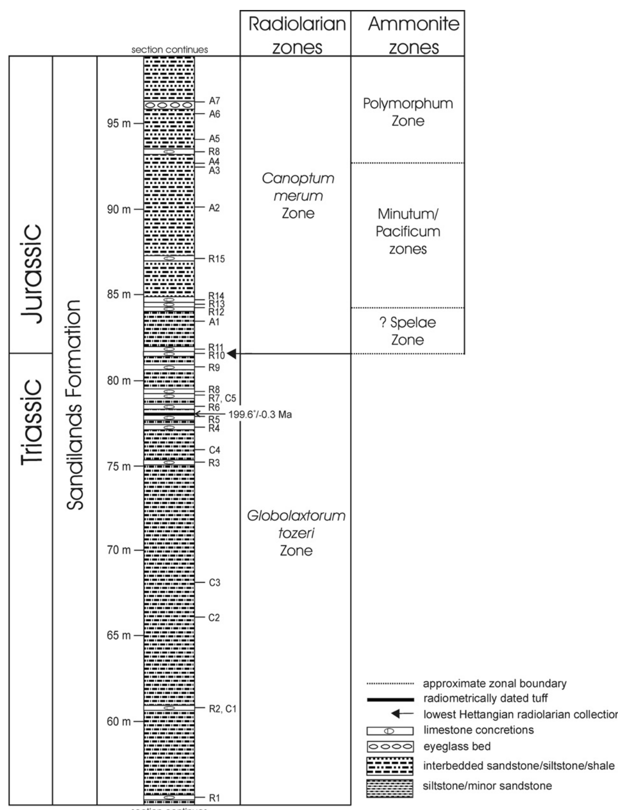


Figure 3: Proposed Kunga Island section showing upper Rhaetian and lower Hettangian radiolarian, upper Rhaetian conodont, and lower Hettangian ammonite localities. R = radiolarians, C = conodonts, A = ammonites. Modified after Haggart *et al*. (2002) and Longridge *et al*. (2007)

Radiolarian species	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16
Betraccium inornatum Blome	X															
Betraccium sp. C sensu Carter 1993	X															
Canoptum sp. A sensu Carter 1993	X															
Plafkerium fidicularium Carter	X															
Plafkerium sp. A sensu Carter 1993	X															
Praecitriduma apexensis Carter	X															
Nabolella aff. *desrochersi* (Carter)	X															
Entactinosphaera? *amphilapes* Carter	X	X														
Nabolella causia (Carter)	X	X														
Nabolella aff. *causia* (Carter)	X	X														
Nabolella desrochersi (Carter)	X	X														
Betraccium aff. *inornatum* Blome	X	X														
Ferresium sp. C sensu Carter 1993	X	X														
Plafkerium sp. B sensu Carter 1993	<	X														
Citriduma sp. C sensu Carter 1993	X	X	X													
Triassocrucella aff. *triassicum* Kozur & Mostler	<			X												
Globolaxtorum cristatum Carter	X	X				X										
Amuria sp. A sensu (Carter 1993)	<	X					X									
Haeckelicyrtium karcharos Carter	<	X					X									
Citriduma asteroides Carter	X	X	X		X			X								
Plafkerium keloense Carter	X	X				X	X	X								
Spumellaria gen. et sp. indet. C sensu Carter 1993	<								X							
Veghicyclia austriaca Kozur & Mostler	X	X					X		X							
Amuria sp. B sensu (Carter 1993)	X	X					X	X	X							
Betraccium kennecottense Carter	X	X			X	X	X	X	X							
Betraccium nodulum Carter	X	X			X	X	X	X	X							
Betraccium sp. E sensu Carter 1993	X	X	X		X		X	X	X							
Bipedis acrostylus Bragin	<	X					X		X							
Bistarkum cylindratum Carter	X	X	X	X	X	X	X	X	X							
Canoptum aff. *dixoni* Pessagno & Whalen	X	X				X	X	X	X							
Canoptum triassicum Yao	X	X		X		X	X	X	X							
Canoptum aff. *unicum* Pessagno & Whalen	<		X	X		X	X	X	X							
Canoptum sp. B sensu Carter 1993	X	X			X	X	X	X	X							
Cantalum gratum Carter	X	X	X		X		X	X	X							
Cantalum sp. A sensu Carter 1993	<						X	X	X							
Canutus? *beehivensis* Carter	X	X	X			X	X	X	X							
Crucella? sp. A sensu Carter 1993	X	X	X		X	X	X	X	X							
Deflandrecyrtium nobense Carter	X	X		X	X	X	X	X	X							
Deflandrecyrtium ithacanthum (Sugiyama)	<						X	X	X							
Entactinosphaera? aff. *simoni* Kozur & Mostler	X	X				X	X	X	X							
Entactinosphaera? *spinulata* Carter	<	X	X		X		X	X	X							
Eucyrtid gen. et sp. indet sensu Carter 1993	<	X	X	X	X		X	X	X							
Ferresium teekwoonense Carter	X	X	X			X	X	X	X							
Fontinella clara Carter	X	X			X		X	X	X							
Fontinella louisensis Carter	X	X							X							
Globolaxtorum tozeri Carter	X	X	X	X	X	X	X	X	X							
Haliomma swellensis Carter	X	X				X	X	X	X							
Icrioma? sp. A sensu Carter 1993	X	X	X			X	X	X	X							

Figure 4: Latest Rhaetian and early Hettangian radiolarians from the proposed section at Kunga Island, Queen Charlotte Islands. < indicates range extends lower, > indicates range extends higher

Formation of the Kunga Group. The Sandilands Formation is several hundred metres thick and ranges in age from early Rhaetian to mostly the latest Sinemurian, although its upper contact is diachronous and locally

Radiolarian species	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16
Pseudoheliodiscus aff. *sandspitensis* (Blome)	<				X		X	X	X							
Laxtorum capitaneum Carter	X	X	X			X	X	X	X							
Laxtorum perfectum Carter	X	X		X		X	X	X	X							
Laxtorum porterheadense Carter	X	X	X			X	X	X	X							
Liassosaturnalis aff. *parvis* Kozur & Mostler	X	X					X	X	X							
Livarella densiporata Kozur & Mostler	X	X		X			X		X							
Loupanus thompsoni Carter	X	X	X		X	X	X	X	X							
Orbiculiformella multibrachiata (Carter)	X	X			X	X	X	X	X							
Pantanellium newkluense Carter	X		X		X		X	X	X							
Paronaella beatricia Carter	<		X	X	X	X	X	X	X							
Paratriassoastrum crassum Carter	X	X			X		X	X	X							
Paratriassoastrum omegaense Carter	<	X	X	X	X	X	X	X	X							
Paratriassoastrum sp. A sensu Carter 1993	X	X	X		X	X	X	X	X							
Paratriassoastrum sp. B sensu Carter 1993	<		X	X	X	X	X	X	X							
Pentactinocarpus cf. *sevaticus* Kozur & Mostler	<	X				X	X	X	X							
Octostella dihexacanthus (Carter)	X	X				X	X	X	X							
Plafkerium gadoense Carter	X	X	X			X	X	X	X							
Praecitriduma canthofistula Carter	<							X	X							
Pseudacanthocircus trogeri Kozur & Mostler	X	X	X	X	X	X	X	X	X							
Serilla conclusum (Carter)	X	X				X	X	X	X							
Serilla ellisensis (Carter)	X	X				X	X	X	X							
Serilla stalkungiensis (Carter)	X	X				X		X	X							
Serilla tangilensis (Carter)	X	X				X			X							
Serilla tledoensis (Carter)	X	X				X	X	X	X							
Serilla sp. A sensu (Carter 1993)	X	X				X	X	X	X							
Nabolella sp. C sensu (Carter 1993)	X	X		X					X							
Spumellaria gen. et sp. indet. E sensu Carter 1993	<	X				X	X	X	X							
Spumellaria gen. et sp. indet. D sensu Carter 1993	X	X	X		X	X	X	X	X							
Livarella valida Yoshida	<			X			X	X	X	X						
Livarella spp.	X	X	X	X	X	X	X	X	X	X	X					
Eptingium onesimos Carter	<	X	X		X	X	X	X	X		X					
Kungalaria newcombi Dumitrica & Carter	X	X				X	X	X	X		X					
Paratriassoastrum spp.	X	X	X	X	X	X	X	X	X	X	X					
Pseudohagiastrum spp.	X	X	X	X	X	X	X	X	X	X	X					
Deflandrecyrtium sp. B sensu Carter 1993	<						X		X			X				
Fontinella habros Carter	X	X	X		X		X	X	X			X				
Fontinella inflata Carter	X	X				X	X	X	X			X				
Pseudoheliodiscus sp. B sensu (Carter 1993)	<						X		X			X				
Spumellaria gen. et sp. indet. B sensu Carter 1993	X	X		X	X	X	X	X	X			X				
Mesosaturnalis acuminatus Carter				X	X	X	X	X	X			X				
Pseudohagiastrum giganteum Carter & Hori					X		X	X	X							
Serilla sp. B sensu (Carter & Guex 1999)						X	X	X	X							
Globolaxtorum sp. A sensu Carter 1993							X	X	X	X						
Stauracanthocircus transitus Kozur & Mostler							X		X			X				>
Spumellaria indet X (Carter in Longridge et al. 2007)							X	X	X	X		X	X	X		>
Tipperella kennecottensis Carter									X	X	X	X	X	X	X	X
Indet. spherical forms										X	X	X	X	X	X	X
Udalia primaeva Whalen & Carter										?	X	X	X	X	X	X

Figure 4 cont'd

ranges in age from earliest Pliensbachian (Tipper & Carter, 1990; Tipper *et al*., 1991, 1994; Smith & Tipper, 1996) to Toarcian (Haggart, 2004). The Rhaetian and very basal Hettangian part of the Formation at Kunga Island are remarkably consistent, well-indurated silicified siltstone with minor, fine- to medium-grained sandstone, and thin tuff interbeds (Figure 3). Common micrite concretions frequently yield abundant radiolarians and con-

Radiolarian species	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16
Udalia spp.										X	X	X	X	X	X	X
Tozerium nascens Whalen & Carter										?		X	X	X	X	X
Gen. et sp. indet. A sensu Whalen & Carter 1998										?		X	X	X	X	X
Charlottea spp.											?	X	X	X	X	>
Droltus hecatensis Pessagno & Whalen											X	X	?	X		X
Thurstonia spp.											?	X	X	X	X	X
Atalanta epaphrodita Cordey & Carter												X				>
Archaeocenosphaera laseekensis Pessagno & Yang												X	X	X	X	>
Bipedis elizabethae Whalen & Carter												X		X		>
Laxtorum sp. B sensu Whalen & Carter 1998												X		X		>
Pantanellium tanuense Pessagno & Blome												X	X	X	X	X
Parahsuum spp.												X	X	X		X
Paronaella ravenensis Whalen & Carter												X	X	X		X
Praehexsaturnalis tetraradiatus Kozur & Mostler												X		X		>
Relanus reefensis Pessagno & Whalen												X	X	X	X	X
Spumellaria indet B sensu Carter 1994												X	X	X	X	X
Canoptum merum Pessagno & Whalen												?		X		>
Amuria impensa Whalen & Carter														X	X	>

Figure 4 cont'd

Conodont species	C1	C2	C3	C4	C5	C6
Undifferentiated *Epigondolella*	X					
Epigondolella sp.		X				
Ramiform elements		X		X		X
Epigondolella ex. gr. *bidentata*			X			
Parvigondolella sp.			X			
Neogondolella sp.						X

Figure 5: Latest Rhaetian conodonts from the proposed section at Kunga Island, Queen Charlotte Islands

Ammonite species	A1	A2	A3	A4	A5	A6	A7
Choristoceras aff. *minutus*		X	X				
Odoghertyceras cf. *deweveri*							
Neophyllites (?) sp.							
Psiloceratid indet.	X						
Psiloceras ex. gr. *tilmanni*					X		X
Psiloceras cf. *marcouxi*							
Psiloceras cf. *planocostatum*		X					
Psiloceras cf. *polymorphum*						X	X
Nevadaphyllites (?) sp.							
Transipsiloceras cf. *transiens*				X			

Figure 6: Early Hettangian ammonites from the proposed section at Kunga Island, Queen Charlotte Islands

odonts. Despite intensive search, no macrofossils have been found in the Rhaetian part of the Kunga Island sequence, which was probably deposited in deep water. Above this stratigraphic level, the section becomes much more clastic-dominated and limestone disappears (Figure 3). About 15m higher, limestone concretions reappear and yield middle Hettangian radiolarians (Carter *et al*., 1998). Beds in the section are near vertical, but otherwise the section displays minimal structural disruption (Carter ,1993; Carter *et al*., 1998). Permanent markers identifying beds in the section were installed by the Geological Survey of Canada. These markers begin at the latest Triassic radiometrically dated tuff bed (0.0m) and range well into the Hettangian (TJB is at 3.6m).

Cameron & Tipper (1985) suggested that much of the Sandilands Formation was deposited in a relatively deep back-arc basin, somewhat distant from a source of fine volcanic detritus which is present in distal turbidites and less common air-fall tuffs (Pálfy *et al*., 1990; Tipper & Guex, 1994). However, the precise paleogeographic setting of the Late Triassic-Early Jurassic strata of the Wrangellia terrane is poorly constrained at present, and more recent work suggests that the Rhaetian/Hettangian parts of the Sandilands Formation were deposited in an outer shelf to upper slope setting (Haggart *et al*., 2001, 2002). The lack of significant turbidites within the Kunga Island section supports the interpretation of deposition in a shallower water environment. Importantly, the presence of abundant radiolarians suggests direct access to the open ocean.

6. Paleontology

The QCI contain two localities with uninterrupted succession of Rhaetian to Hettangian strata: Kennecott Point and Kunga Island (Figure 1). The radiolarians are abundant and well preserved at both localities and clearly represent the most important faunal successions of Rhaetian-Hettangian radiolarians known today. The Rhaetian part of the sequence is dated by closely associated conodonts at both localities (Tipper & Carter, 1990; Orchard, 1991; Carter, 1993; Tipper *et al*., 1994) and rare ammonoids at Kennecott Point (Tipper & Carter, 1990; Tipper *et al*., 1994; Ward *et al*., 2004), while lower Hettangian ammonites date the succession at both localities (Tipper & Guex, 1994; Tipper *et al*., 1994; Carter *et al*., 1998; Longridge *et al*., 2007). Radiolarians are the most abundant group throughout the Rhaetian and provide the most complete and continuous record of faunal change across the TJB. Many closely spaced collections at each locality document the dynamics of faunal change and closely constrain the position of the TJB. The dramatic turnover of radiolarian species (Carter, 1994, 1998; Carter *et al*., 1998) is characterized by a significant extinction of Rhaetian taxa that are replaced by a low diversity Hettangian fauna composed of very simple forms.

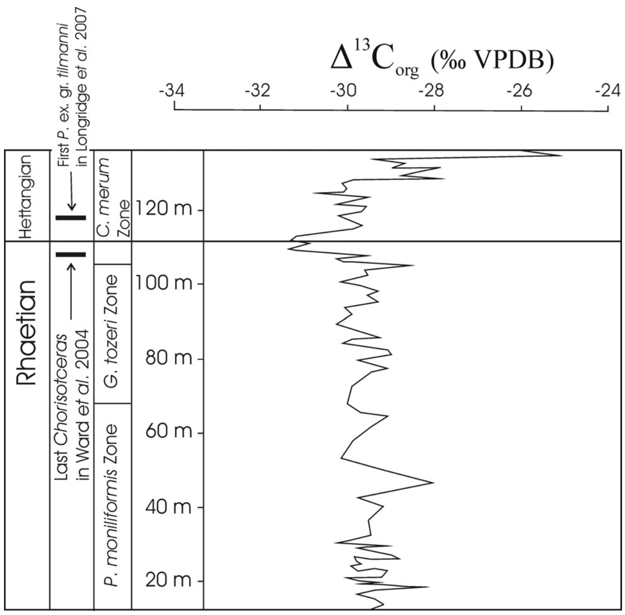


Figure 7: $\delta^{13}C_{org}$ record for Rhaetian to Lower Hettangian strata at Kennecott Point, Queen Charlotte Islands, British Columbia. Modified from Williford *et al*. (2007)

Since the 1970s, Mesozoic radiolarians have been dated by associated ammonoids, conodonts and/or other fossil groups, and vast numbers of radiolarian species have been described. Many were integrated into local and regional zonal schemes that have been increasingly refined over the years. However, subsequent testing over wider areas using the Unitary Associations (UA) method (Guex, 1991) has now reached a level of accuracy that allows radiolarians to stand alone as primary indicators for dating rock. This capability is particularly important in areas where radiolarians are the only fossils available for age dating (*e.g*. chert sequences in oceanic terranes), or where the completeness of the faunal succession is such that the accuracy achieved by radiolarians is superior to that of other fossil groups.

Very few radiolarians of Rhaetian and Hettangian age were known prior to Geological Survey of Canada-sponsored discoveries at Kennecott Point and the southeast side of Kunga Island (1986-1990). Preliminary results clearly indicated that a well-preserved succession of Rhaetian and Hettangian radiolarians was present at both localities (Carter *et al*., 1989; Carter, 1990; Tipper & Carter, 1990). Further collecting at Kunga Island in 1997-98 and 2000 increased the sampling density across this critical interval and provided more precise data on the range of key taxa. In 1993, Carter described the Rhaetian faunas and established two radiolarian zones: the *Proparvicingula moniliformis* Zone and the overlying *Globolaxtorum tozeri* Zone using the Unitary Associations method of Guex (1977, 1991). This work was based on the documentation of over 140 short-ranging Rhaetian species, most of which were new (Carter, 1993). A number of species have been described since that time (Yeh & Cheng, 1996; Sugiyama, 1997; Dumitrica & Carter, 1999; Tekin, 1999, 2002a; Carter & Hori, 2005; Longridge *et al*., 2007); others have been recognized informally, and the ranges of still others, originating in the Carnian and Norian, have been extended to the Rhaetian.

7. Biostratigraphy – radiolarians, conodonts, ammonites

On the southeast side of Kunga Island there is a continuous sequence from the Rhaetian (Carter, 1993, fig.9) to the middle Hettangian (Carter *et al*., 1998). Over 130m of Rhaetian strata are present in two sections (sections 3 and 5 of Carter, 1993; Figure 1, section 1). These strata overlie up to 100m of partly-disrupted, dark grey, calcite-veined, argillaceous strata with rare *Monotis* in the 30-50m interval. Above the section proposed herein (Figure 3), ~45m of strata contains middle Hettangian ammonites. The two Rhaetian sections have been correlated using radiolarians. Despite intensive search, no macrofossils have been found in Rhaetian beds at Kunga Island, but conodonts are common and radiolarians abundant.

The Triassic-Jurassic transitional interval as discussed herein includes radiolarians from the *Globolaxtorum tozeri* Zone (upper Rhaetian) and the *Canoptum merum* Zone (lower Hettangian) (Figure 4), upper Rhaetian conodonts (Carter, 1993; Figure 5) and ammonites that are possibly from the *Spelae* Zone and definitely from the *Minutum* to *Polymorphum* Zones (lower Hettangian) (Longridge *et al*., 2007, fig.6) (Figure 3).

In total, radiolarians occur in 16 discrete horizons, collected over a stratigraphic interval of 37.45m, the majority of which are concentrated in about 10m of strata spanning the boundary (Figure 3). Diagnostic TJB radiolarians are shown on Plate 1. Rhaetian radiolarian collections begin 56m above the base of the formation and are present up to 80.75m, an interval of 24.75m. Five conodont horizons occur in the top 20.8m of upper Triassic strata, with the highest conodont occurrence at 79.1m (Figure 3). Prior to collecting in 2000, the first typical Hettangian radiolarians were believed to begin at 84.5m (Carter, 1998; Carter *et al*., 1998). However, since the finding of transitional faunas (mostly Jurassic) at 81.55m and 81.8m in 2000, this level has been lowered to 81.55m (Carter & Hori, 2005). This level is <1.0m above the final occurrence of Rhaetian radiolarians, 2.45m above the last conodonts and 3.6m above a tuff layer within the Triassic-Jurassic transition yielding a U-Pb zircon age of 199.6± 0.3Ma (Pálfy *et al*., 2000). Seven ammonite horizons occur within 14.8m of early Hettangian strata, with the first ammonite at 83.45m, 1.9m above the first Jurassic radiolarians (Figure 3).

8. Radiolarian biology and extinction

Basal Hettangian radiolarian faunas of the *Canoptum merum* Zone can be recognized by the common occurrence of *Tipperella kennecottensis*, together with other simple spherical forms with rod-like spines, the incoming of *Canoptum merum*, *Droltus hecatensis*, *Tozerium nascens*, *Udalia primaeva* and, a little higher, by the first appearance of the distinctive species *Pantanellium tanuense* (Plate 1). A complete discussion of the lower Hettangian faunas is found in Longridge *et al*. (2007).

Radiolarian faunas from the upper Rhaetian *Globolaxtorum tozeri* zone, up to the extinction event at the end of the Triassic, are rich and diverse, composed largely of genera originating in the late Carnian and Norian, and some in the Rhaetian. They differ from radiolarians of the underlying *Betraccium deweveri* Zone (upper Norian *Monotis* equivalent) by lacking the widely distributed nominal taxon, and many species of *Ferresium* and *Laxtorum* described by Blome (1984). Spumellarians outnumber nassellarians by a ratio of about 2:1. Radiation began early in the Rhaetian at Kunga Island and continued to topmost beds (Carter, 1993), a phenomenon that contrasts sharply with the diminishing diversity of other faunas at this time. The radiolarian fauna includes over 170 short-ranging species: 154 species were described or informally designated by Carter (1993), a few others have been recognized subsequently (Dumitrica & Carter, 1999; Carter & Hori, 2005), and many others are still undescribed. Some are widely distributed, *e.g*. *Globolaxtorum tozeri*, and have proven to be extremely useful for age dating (Yeh & Cheng, 1996; Sugiyama, 1997; Tekin, 1999; Amodeo, 1999; Bertinelli *et al*., 2004; Yeh & Yang, 2006; Orchard *et al*., 2007, in press). The most abundant and characteristic genera of the *G. tozeri* Zone are *Betraccium* Pessagno & Blome (but not *B. deweveri*), ?*Canutus* Pessagno & Whalen, *Citriduma* De Wever, *Deflandrecyrtium* Kozur & Mostler, *Fontinella* Carter, *Globolaxtorum* Carter, *Kungalaria* Dumitrica & Carter, *Laxtorum* Blome, *Livarella* Kozur & Mostler, *Loupanus* Carter, *Nabolella* Petrushevskaya, *Plafkerium* Pessagno and *Serilla* (= *Risella*) Carter (Carter, in press).

Twisted spines are characteristic of many Upper Triassic species, to the degree that poorly preserved samples can even be dated approximately by the presence of strongly twisted spines. This distinctive feature is prevalent amongst both spumellarians and nassellarians of Rhaetian age, and is particularly useful when differentiating late Rhaetian (with twisted spines) and early Hettangian faunas (with straight, rod-like spines).

Carter (1990) distinguished several broad taxonomic groups amongst the Rhaetian fauna: (1) conservative forms such as canoptids and pantanellids; (2) architecturally complex forms such as the hat-shaped nassellarians *Deflandrecyrtium*, *Haeckelicyrtium, Nabolella* and *Citriduma*; (3) rapidly-radiating forms of the *Laxtorum-Globolaxtorum* lineage and the *Ferresium-Risella* lineage (Carter & Guex, 1999); and (4) ancestral Jurassic forms such as *Crucella*, *Bistarkum*, *Bipedis*, *Canutus*, *Droltus etc*. Continuing studies indicate these assemblages are still valid, and suggest that each of these groups tends to react in a similar way approaching the TJB, *i.e*. most architecturally complex and rapidly-evolving forms disappear at the end of the Triassic, while the conservative and ancestral Jurassic forms survive.

Radiolarians underwent major faunal change at the end of the Triassic: five families disappeared including the Hexaporobracchiidae, Hindeosphaeridae, Nabolellidae, Pentactinocarpidae (De Wever *et al*., 2001, p.389) and the Deflandrecyrtiidae. Many Triassic genera became extinct or nearly so (Longridge *et al*., 2007, p.152), but the most noticeable effect was upon species. Ninety-five species are recorded in the *Globolaxtorum tozeri* Zone alone (Figure 4). A few range upward from the *Betraccium deweveri* Zone or below, over 60 species arose in the *Proparvicingula moniliformis* Zone, and 12 species originated within the *G. tozeri* Zone. With the exception of over 20 species that disappeared in lower beds of the *G. tozeri* Zone, the remainder range into the highest beds of the Triassic, and a very few pass into the basal Hettangian (see discussion of 'short-ranging Rhaetian holdovers' in Longridge *et al*., 2007, p.153). The abrupt disappearance of over 55 species takes place above the 80.75m level and is followed <1m above by the appearance of a low diversity transitional fauna comprised of a few Rhaetian species, most notably *Livarella*, many peculiar transitional forms, and a few Hettangian genera. Less than three metres above, at 84.25m, an abundant basal Hettangian fauna is present that is characteristic of the *Canoptum merum* Zone.

9. Worldwide correlation using radiolarians

A similar radiolarian fauna has been recognized in Japan (Hori, 1992) and faunal correlation across the TJB on a global scale has been established (Carter & Hori, 2005). Other faunas of Rhaetian and/or Hettangian/Sinemurian age are recognized in Austria (Gawlik *et al*., 2001), Baja California (Whalen *et al*., 1998), Italy (Bertinelli *et al*., 2004), Nevada (Orchard *et al*., 2007), New Zealand (Spörli & Aita, 1988; Hori *et al*., 1996), Peru (Suzuki *et al*. 2002), Turkey (Tekin, 1999, 2002a, b), the Philippines (Yeh, 1992; Yeh & Cheng, 1996, 1998) and Far East Asia, including Russia (Bragin, 1991), China (Yang & Mizutani, 1991; Yeh & Yang, 2006) and Japan (*e.g*. Yao *et al*., 1980; Kishida & Hisada, 1985; Igo & Nishimura, 1984; Sato *et al*., 1986; Sugiyama, 1997; *etc*.). Studies are ongoing in several of these localities and although the precise boundary interval is missing in all but Japan thus far, published data fully support observations on faunal extinction and recovery around the TJB.

10. Radioisotopic dating

The Kunga Island section has provided a U-Pb date for the TJB of 199.6±0.3Ma from 3.6m below the boundary (Pálfy *et al*., 2000), and work is underway to refine its accuracy and precision. A slight increase in age is expected (Pálfy & Mundil, 2005). There is also considerable potential to obtain more geochronologic data from the upper Rhaetian and lower to middle Hettangian.

11. Magnetostratigraphy and carbon isotope stratigraphy

Magnetostratigraphy was attempted on the Kunga Island section but the samples were remagnetized (Carter & Galbrun, 1990; Galbrun, pers. comm. to Carter, 1990). The section has been affected by low-grade metamorphism and has a conodont alteration index of 4.5-5.0 (Orchard & Forster, 1991). The diagenetic alteration of the section means that it is not possible to obtain a useful carbon curve (Ward *et al*., 2001). However, a section at Kennecott Point in the northwest QCI (Figure 1, section 2) is much less metamorphosed (Orchard & Forster, 1991; Haggart *et al*., 2001, 2002) and has produced a carbon isotope curve showing a distinct and prolonged negative excursion of ~2 per mil spanning the TJB (Figure 7; Ward *et al*., 2001, 2004; Williford *et al*., 2007). This section is readily correlated with the Kunga Island section using radiolarian and ammonite faunas common to both sections.

12. The base of the Jurassic System at Kunga Island

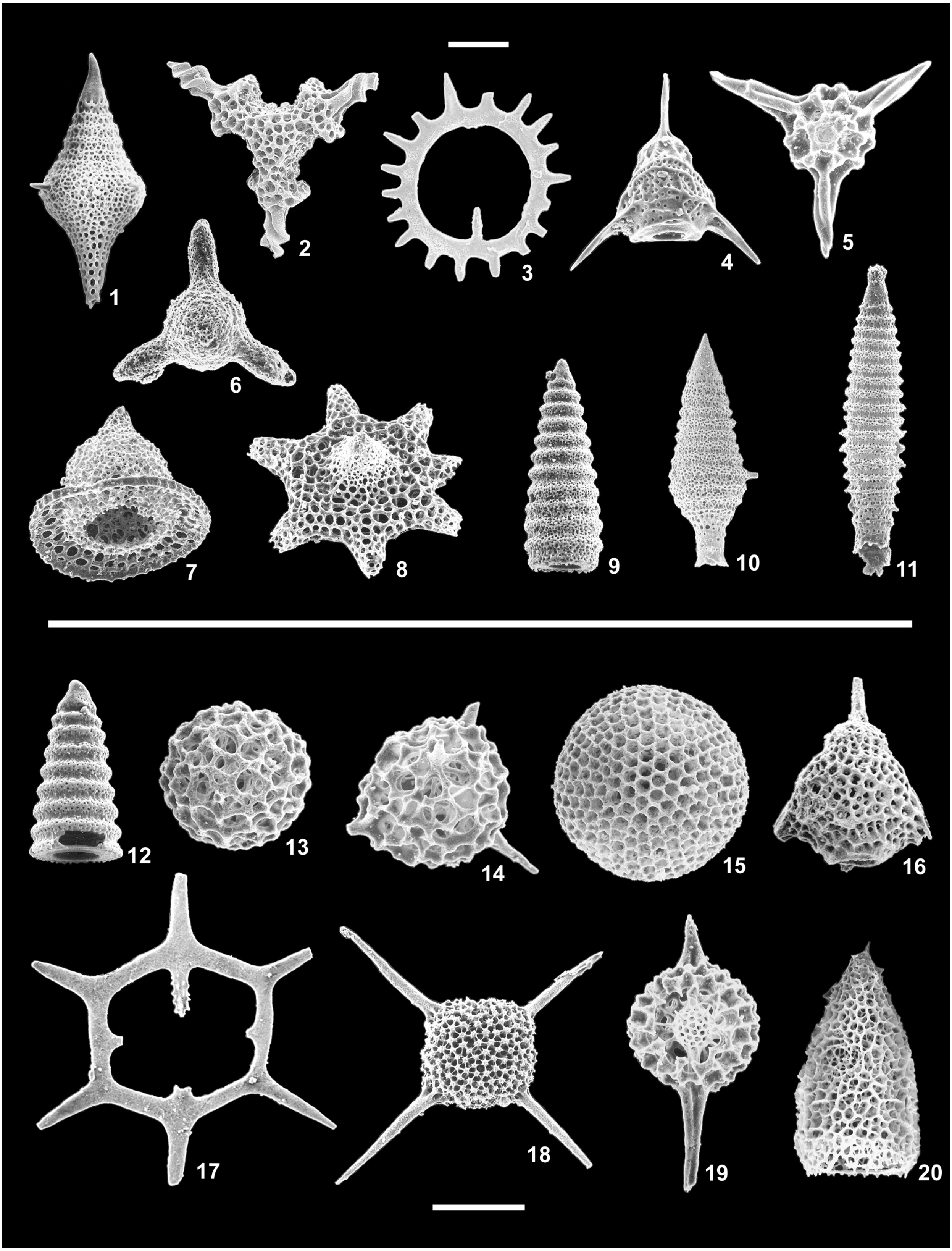
If the TJB is defined using radiolarians as the primary standard, the Kunga Island section is an excellent candidate GSSP for the base of the Jurassic System. The radiolarian fauna that crosses the TJB in the QCI is the most diverse and well documented of this age in the world. The close correlation of the TJB radiolarian faunas with those in the Inuyama area of Japan demonstrates the global distribution of the radiolarians and their utility as index fossils. Radiolarian preservation is excellent and the rapid stratigraphic turnover, continuous deposition and lack of facies changes make the Kunga Island section an exceptional GSSP candidate. The section has already provided a date to constrain the TJB and has significant potential for further refining the geochronologic time scale for the Late Triassic and Hettangian. The ammonoid fauna from the section permits correlation with early Hettangian ammonite sequences elsewhere (Longridge *et al*., 2007). Although ammonites conclusively restricted to the *Spelae* Zone have not been found, *Psiloceras* cf. *planocostatum* and *Choristoceras* aff. *minutum* can be used to correlate the lower part of the Hettangian portion of the section with the *Minutum* and *Pacificum* Zones. *Transipsiloceras* cf. *transiens* and *Psiloceras* cf. *polymorphum* permit correlation of the upper portion of the section with the *Polymorphum* Zone. Correlations are also possible using Triassic and Jurassic ammonite faunas from sections at Kennecott Point (Figure 1, sections 2 and 3; Longridge *et al*., 2007, sections I and II), where there is a well documented carbon isotope curve showing a negative anomaly that can be used for global correlation (Figure 7; Ward *et al*., 2001, 2004; Williford *et al*., 2007).

The exceptional quality and relatively sharp transition of the radiolarian fauna across the TJB as well as the potential for radiometric dating in the Late Triassic and throughout the early and middle Hettangian make the Kunga Island section unique. Thus, we feel that if radiolarians are not used to define the TJB, the Kunga Island section should be designated as a parastratotype section.

1. *Globolaxtorum tozeri* Carter. GSC 85927 from GSC loc. C-140489, Kennecott Point; scale bar = 100μm.
2. *Risella* sp. D sensu Carter and Guex 1999. GSC 107645 from R-1, GSC loc. C-173287, Kunga Island; scale bar = 100μm.
3. *Mesosaturnalis acuminatus* Carter. GSC 101908 from R-1, GSC loc. C-173287, Kunga Island; scale bar = 158μm.
4. *Bipedis acrostylus* Bragin. GSC 85921 from GSC loc. C-127798, Louise Island; scale bar = 81μm.
5. *Betraccium kennecottense* Carter. GSC 85911 from GSC loc. C-164674, Kennecott Point; scale bar = 80μm.
6. *Livarella densiporata* Kozur and Mostler. GSC 85912 from GSC loc. C-164674, Kennecott Point; scale bar = 100μm.
7. *Nabolella causia* (Carter). GSC 85929 from GSC loc. C-164674, Kunga Island; scale bar = 100μm.
8. *Citriduma asteroides* Carter. GSC 85930 from GSC loc. C-164674, Kunga Island; scale bar = 100μm.
9. *Canoptum triassicum* Yao. GSC 102083 from GSC loc. C-164693/13, Kunga Island; scale bar = 100μm.
10. *Laxtorum capitaneum* Carter. GSC 107648 from R-8, GSC loc. C-173280, Kunga Island; scale bar = 100um.
11. *Canoptum* sp. aff. *C. unicum* Pessagno and Whalen. GSC 85933 from GSC loc. C-140489, Kennecott Point; scale bar = 100μm.
12. *Canoptum merum* Pessagno and Whalen. GSC 99425 from GSC loc. C-140496, Kennecott Point.
13. Spumellaria indet. B sensu Carter 1994. GSC 99423 from R2, GSC loc. C-173357, Kunga Island.
14. *Tozerium nascens* Whalen and Carter. GSC 99424 from GSC loc. C-173332, Kunga Island.
15. *Archaeocenosphaera laseekensis* Pessagno and Yang. GSC 99426 from R2, GSC loc. C-173357, Kunga Island.
16. *Bipedis elizabethae* Whalen and Carter. GSC 99433 from GSC loc. C-173332, Kunga Island.
17. *Praehexasaturnalis tetraradiatus* Kozur and Mostler. GSC 99439 from GSC loc. C-173332, Kunga Island.
18. *Udalia primaeva* Whalen and Carter. GSC 107742 from GSC loc. C-173332, Kunga Island.
19. *Pantanellium tanuense* Pessagno and Blome. GSC 129052 from R4, GSC loc. 173285, Kunga Island.
20. *Droltus hecatensis* Pessagno and Whalen. GSC 99434 from R2, GSC loc. C-173357, Kunga Island.

Plate 1

Scanning electron micrographs of diagnostic Triassic/Jurassic boundary radiolaria from the Sandilands Formation, Queen Charlotte Islands
Figs 1-11 upper Rhaetian: scale-bar at plate top = µm cited for each illustration
Figs 12-20 lower Hettangian: scale-bar at plate base = 100µm for all specimens illustrated



This will further characterize the interval and increase its correlation potential, improving the probability of it being recognized elsewhere. The ammonite faunas from the Kunga Island section, as well as the negative carbon curve excursion at Kennecott Point, permit correlation with several other TJB GSSP candidates. For example, we have previously published information proposing that the North American Jurassic stratotype proposals be combined such that the Ferguson Hill section in Nevada is the GSSP (Taylor *et al*., 1983; Guex *et al*., 1997, 2006; Lucas *et al*., 2007, this *Newsletter*) and the Kunga Island section is a parastratotype (Longridge *et al*., 2006b, 2007; Lucas *et al*., 2007; this *Newsletter*). The current level of the TJB in the Kunga Island section, as indicated in Figure 3, is based exclusively on the radiolarian faunas. If the Kunga Island section is designated as a parastratotype, rather than a GSSP, the level of the boundary would have to be adjusted to align it with whatever primary standard is used in the GSSP.

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Appendix

Section 1. Kunga Island, southeast side (= section 5 in Carter, 1993; section SKUD in Carter *et al*., 1998; section III (partial) in Longridge *et al*., 2007). NTS 103 B/13, Zone 9; N 52°45.573', W 131°33.638'.

Radiolarian collections: R1-R9 are Rhaetian faunas from the *Globolaxtorum tozeri* Zone (R1 marks the base of zone); collections R10-R16 are lower Hettangian faunas from the *Canoptum merum* Zone.

R16: GSC loc. C-305413; collected 93.45m above base of section.
R15: GSC loc. C-304141; collected 87.15m above base of section.
R14: GSC loc. C-305412; collected 84.74m above base of section.
R13: GSC loc. C-305411; collected 84.45m above base of section.
R12: GSC loc. C-173357, C-303576, C-304137 and C-305409; collected 84.25m above base of section.
R11: GSC loc. C-305406; collected 81.80m above base of section.
R10: GSC loc. C-305405; collected 81.55m above base of section.
R9: GSC loc. C-164696/11, C-173288, C-303575, C-305404; collected 80.75m above base of section.
R8: GSC loc. C-303574, C-305402; collected 79.3m above base of section.
R7: GSC loc. C-173286, C-173287, C-303573; collected 79.1m above base of section.
R6: GSC loc. C-305401; collected 78.45m above base of section.
R5: GSC loc. C-303572; collected 77.85m above base of section.
R4: GSC loc. C-173285; collected 75.9m above base of section.
R3: GSC loc. C-303571; collected 75.2m above base of section.
R2: GSC loc. C-173280; collected 60.75m above base of section.
R1: GSC loc. C-164696/11; collected 56.0m above base of section.

Additional GSC localities for figured radiolarians on Plate 1 include:
Kunga Island, southeast side. GSC loc. 164696/13 (87-CNA-SKUB-13; section 2, Carter, 1993), C-164674 (87-CNA-SKU-SP-1; section 6, Carter, 1993), and C-173332 (89-CNA-SKUE-6; section 2, Carter *et al*., 1998).
Kennecott Point. GSC loc. C-164674 (87- CNA-KPA-12), C-140489 (87- CNA-KPA-17; section 1, Carter, 1993). GSC loc. C-140496 (87- CNA-KPB-1; section 9, Carter *et al*., 1998).
Louise Island. GSC loc. C-127798 (86-CNA-SP-1/1; section 4, Carter, 1993).

Conodont collections: C1-C5 are Rhaetian faunas from the *Globolaxtorum tozeri* radiolarian Zone.
C5: GSC loc. C-303573, C-173287; collected 79.1m above base of section.
C4: GSC loc. C-173284; collected 75.9m above base of section.
C3: GSC loc. C-173282; collected 68.1m above base of section.
C2: GSC loc. C-173281; collected 66.05m above base of section.
C1: GSC loc. C-173280; collected 60.75m above base of section.

Ammonite collections: A1-A7 are early Hettangian faunas; A1 is possibly from the *Spelae* Zone, A2-A3 are from the *Minutum* and *Pacificum* Zones, and A4-A7 are from the *Polymorphum* Zone.
A7: GSC loc. C-159351; collected 96.35m above base of section.
A6: GSC loc. C-175325; collected 95.75m above base of section.
A5: GSC loc. C-210792; collected 94.2m above base of section.
A4: GSC loc. C-175324; collected 92.85m above base of section.
A3: GSC loc. C-175323; collected 92.55m above base of section.
A2: GSC loc. C-175302; collected 90.2m above base of section.
A1: GSC loc. C-175322; collected 83.45m above base of section.