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[Note]
Normalized cluster analysis method for radiolarian abundance data

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Introduction

Paleoceanographic studies of radiolarians are generally explained using results of cluster analysis. When applying cluster analysis to the total number of specimens of each species per sample weight, we find that the clusters are divided by the high and low values of a species per sample weight, but not according to the similarity in their fluctuation pattern. We propose that cluster analysis for paleoceanographic studies use normalized data converted from original occurrence data.

Results

We conducted cluster analysis dealing with raw numerical abundance data (number of specimens gram^{-1}) using the Windows software "Let's Stat! Pro" ver. 040917 (http://homepage3.nifty.com/QZM01222/. Japanese only) (Table 1). The cluster analysis uses Ward's method. This analysis was applied to unpublished radiolarian data from the lower Cretaceous at DSDP site 463. The dendrogram generated shows five clusters: groups 1-SG, 2-SG, 3-SG, 4-SG, and 5-SG (Fig. 1 upper). These groups were divided according to numerical abundance (Fig. 1 lower). Similar fluctuation intervals or distinct peaks are shown in dark gray, and clearly different fluctuation patterns are displayed in light gray. For example, group 2-SG consists of 18 low-abundance species, with 10 to 20 n/g. This group also includes species with apparently different patterns, such as *Platycryphalus* aff. *hirsuta* (Squinabol) of Foreman and *Hemicryptocapsa* sp. A. These species show different peaks in the lower middle part of the interval examined. Accordingly, using raw numerical abundance data is not suitable for grouping species with similar fluctuation patterns.

For grouping species with similar fluctuation patterns, we normalized these data using the following equation:

$$N_i = A_i/S$$

where N_i is the normalized data in a horizon, A_i is the numerical abundance in a horizon, and S is the sum of the numerical abundance for the species during the interval examined (Table 2).

The dendrogram generated by the cluster analysis can be divided into six clusters: 1-ND, 2-ND, 3-ND, 4-ND, 5-ND, and 6-ND (Fig. 2 upper). The four major clusters containing multiple species show similar fluctuation patterns in each group regardless of the numerical differences (Fig. 2 lower). Similar fluctuation intervals or distinct peaks are displayed in dark gray. All of the species in the 5-ND group, for instance, have a common peak at 624.75 mbsf.

Concluding remarks

Using cluster analysis for numerical abundance data requires special care. The numerical abundance of radiolarians is variable, and a cluster analysis of the data tends to divide groups based on high and low values. Therefore, it is necessary to convert the original occurrence data in order to group species fluctuating in a similar manner.

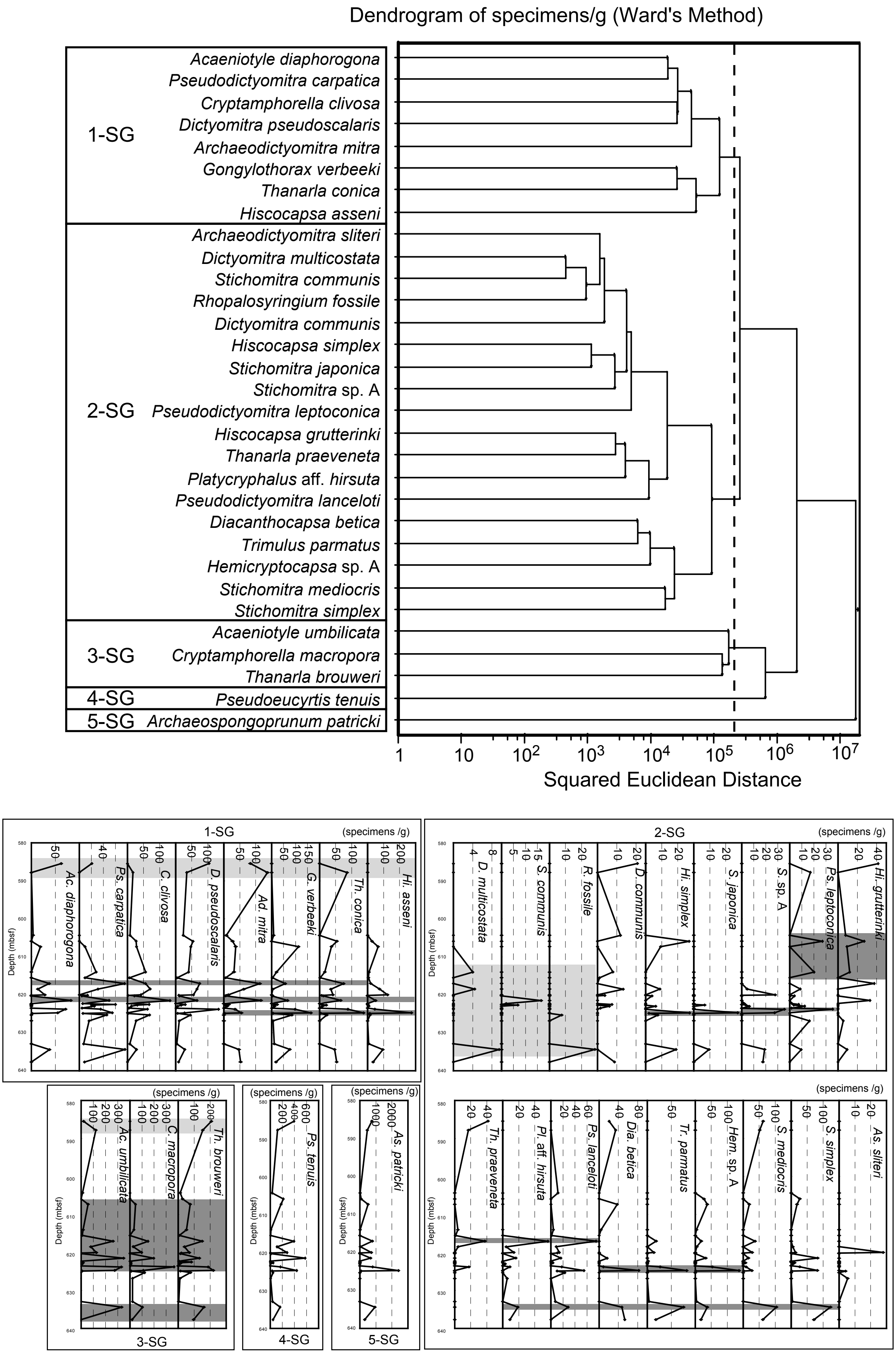

Fig. 1. Dendrogram of the cluster analysis based on the original occurrence data (upper) and the numerical abundance plot for each cluster (lower). Dark gray indicates similar fluctuation intervals or distinct peaks. Light gray indicates clearly different fluctuation patterns.

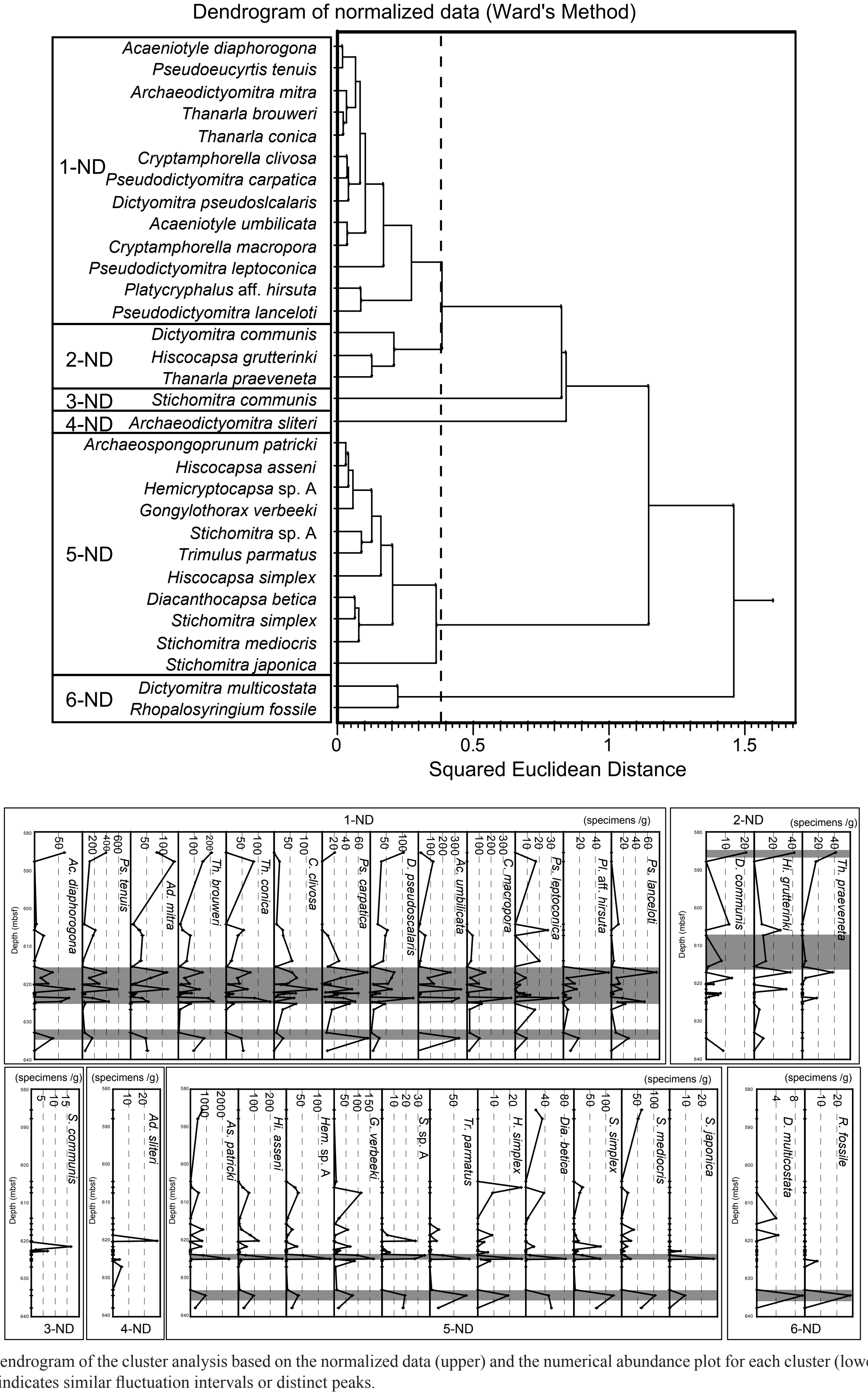

Fig. 2. Dendrogram of the cluster analysis based on the normalized data (upper) and the numerical abundance plot for each cluster (lower). Dark gray indicates similar fluctuation intervals or distinct peaks.

Table 1. Original abundance data for radiolarians

Sample (Site, core-section, top-depth(cm))	Depth (mbsf)	*Acaeniotyle diaphorogona*	*Acaeniotyle umbilicata*	*Archaeodictyomitra mitra*	*Archaeodictyomitra sliteri*	*Archaeospongoprunum patricki*	*Cryptamphorella clivosa*	*Cryptamphorella macropora*	*Diacanthocapsa betica*	*Dictyomitra communis*	*Dictyomitra multicostata*	*Dictyomitra pseudoscalaris*	*Gongylothorax verbeeki*	*Hemicryptocapsa* sp. A
463, 67-1, 46-51	585.46	62.2568	20.7523	83.0091	0	747.082	0	0	20.7523	20.7523	0	103.761	0	0
463, 67-2, 130-132	587.8	0	120.043	137.192	0	463.023	17.149	0	34.298	0	0	34.298	0	0
463, 69-1, 34-39	604.34	3.95648	11.8694	7.91296	0	11.8694	7.91296	0	0	11.8694	0	23.7389	7.91296	0
463, 69-2, 40-42	605.9	54.2143	0	27.1072	0	81.3215	27.1072	0	0	0	0	54.2143	0	27.1072
463, 69-3, 33-36	607.33	18.4544	55.3633	36.9089	0	507.497	27.6817	46.1361	36.9089	0	0	46.1361	110.727	36.9089
463, 70-1, 52-56	614.02	0	16.0643	32.1285	0	8.03213	56.2249	32.1285	4.01606	8.03213	4.01606	40.1606	20.0803	4.01606
463, 70-2, 52-56	615.52	0	8.24317	5.15198	0	7.21278	6.18238	0	0	1.0304	0	4.12159	3.09119	0
463, 70-3, 54-58	617.04	37.4707	262.295	112.412	0	786.885	56.2061	149.883	0	0	0	74.9415	56.2061	18.7354
463, 70-4, 50-53	618.5	13.289	79.7342	62.0155	0	35.4374	70.8749	26.5781	0	13.289	4.42968	66.4452	4.42968	4.42968
463, 70-5, 51-53	620.01	27.7778	125	13.8889	27.7778	722.222	41.6667	97.2222	0	0	0	55.5556	0	0
463, 70-5, 65-66	620.15	0	1.92215	7.68861	0	5.76646	1.92215	0.96108	0.96108	3.84431	0	9.61076	2.88323	0
463, 70-5, 80-82	620.3	0	1.99302	5.97907	0	0	21.9233	0	0	0	0	11.9581	3.98605	0
463, 70-6, 50-52	621.5	82.602	346.928	115.643	0	677.336	132.163	198.245	16.5204	0	0	66.0816	66.0816	33.0408
463, 70-6, 130-132	622.3	0	0	0	0	7.54006	0	0	0	0	0	0	0	0
463, 70-7, 5-7	622.55	7.49766	0	14.9953	0	14.9953	67.4789	7.49766	0	7.49766	0	29.9906	22.493	0
463, 70-7, 21-23	622.71	0	17.014	6.80561	0	0	30.6253	6.80561	0	0	0	17.014	10.2084	0
463, 70-cc, 21-23	623.01	0	6.2281	9.34216	0	6.2281	12.4562	9.34216	0	6.2281	0	6.2281	12.4562	0
463, 71-1, 52-54	623.52	0	0	1.57109	0	1.57109	4.71328	3.14218	0	1.57109	0	1.57109	1.57109	0
463, 71-1, 80-83	623.8	71.1506	329.072	35.5753	0	800.445	62.2568	364.647	8.89383	0	0	133.407	97.8321	53.363
463, 71-2, 25-27	624.75	54.2833	271.416	54.2833	0	2388.46	0	108.567	81.4249	0	0	27.1416	162.85	135.708
463, 71-2, 40-42	624.9	2.02634	10.1317	2.02634	4.05268	85.1064	2.02634	12.1581	2.02634	0	0	6.07903	6.07903	2.02634
463, 71-2, 82-85	625.32	0	0	0	7.63359	0	68.7023	122.137	0	0	0	45.8015	83.9695	0
463, 71-3, 85-89	626.85	0	0	0	5.43478	0	27.1739	21.7391	0	0	0	10.8696	5.43478	0
463, 72-1, 41-44	632.91	0	0	0	0	7.18778	7.18778	21.5633	0	0	0	3.59389	10.7817	3.59389
463, 72-2, 40-43	634.4	37.9372	331.95	47.4215	0	948.429	28.4529	104.327	47.4215	0	9.48429	28.4529	75.8743	37.9372
463, 72-4, 69-71	637.69	0	0	53.0094	0	309.221	0	17.6698	53.0094	8.8349	0	8.8349	17.6698	17.6698

Sample (Site, core-section, top-depth(cm))	*Hiscocapsa asseni*	*Hiscocapsa grutterinki*	*Hiscocapsa simplex*	*Platycryphalus* aff. *hirsuta*	*Pseudodictyomitra carpatica*	*Pseudodictyomitra lanceloti*	*Pseudodictyomitra leptoconica*	*Pseudoeucyrtis tenuis*	*Rhopalosyringium fossile*	*Stichomitra communis*	*Stichomitra japonica*	*Stichomitra mediocris*	*Stichomitra simplex*	*Stichomitra* sp. A	*Thanarla broweri*	*Thanarla conica*	*Thanarla praeveneta*	*Trimulus parmatus*
463, 67-1, 46-51	0	41.5045	0	0	20.7523	0	0	394.293	0	0	0	62.2568	0	0	207.523	0	41.5045	0
463, 67-2, 130-132	0	0	0	0	17.149	0	17.149	120.043	0	0	0	51.4469	0	0	154.341	85.7449	17.149	0
463, 69-1, 34-39	0	7.91296	0	0	3.95648	11.8694	0	31.6518	0	0	0	0	0	0	11.8694	0	0	0
463, 69-2, 40-42	27.1072	27.1072	27.1072	0	0	0	27.1072	216.857	0	0	0	0	27.1072	0	27.1072	54.2143	0	0
463, 69-3, 33-36	64.5905	9.22722	9.22722	0	9.22722	0	0	175.317	0	0	0	18.4544	18.4544	0	73.8178	36.9089	0	0
463, 70-1, 52-56	8.03213	12.0482	0	0	28.1124	4.01606	20.0803	12.0482	0	0	0	0	0	0	52.2088	16.0643	4.01606	0
463, 70-2, 52-56	5.15198	0	0	0	9.27357	1.0304	0	6.18238	0	0	0	0	0	0	7.21278	2.06079	1.0304	0
463, 70-3, 54-58	18.7354	37.4707	0	56.2061	74.9415	74.9415	0	393.443	0	0	0	37.4707	0	0	149.883	74.9415	37.4707	18.7354
463, 70-4, 50-53	75.3045	0	8.85936	4.42968	31.0078	8.85936	8.85936	110.742	0	0	0	0	4.42968	4.42968	39.8671	35.4374	4.42968	0
463, 70-5, 51-53	125	0	0	13.8889	0	13.8889	0	277.778	0	0	0	27.7778	27.7778	13.8889	69.4444	41.6667	0	13.8889
463, 70-5, 65-66	0	0	0	0	13.4551	10.5718	0.96108	0	0	0	0	0	0	0	19.2215	6.72753	0	0
463, 70-5, 80-82	0	0	3.98605	0	3.98605	0	3.98605	13.9512	0	0	0	0	1.99302	0	13.9512	11.9581	0	0
463, 70-6, 50-52	49.5612	33.0408	0	16.5204	49.5612	16.5204	0	578.214	0	16.5204	0	16.5204	82.602	0	132.163	66.0816	0	0
463, 70-6, 130-132	0	0	0	0	5.65504	0	1.88501	0	0	1.88501	0	0	0	1.88501	5.65504	0	0	1.88501
463, 70-7, 5-7	0	0	0	0	59.9813	0	7.49766	0	0	0	0	0	0	0	82.4742	7.49766	0	0
463, 70-7, 21-23	3.40281	0	0	0	20.4168	3.40281	3.40281	47.6393	0	6.80561	6.80561	6.80561	10.2084	3.40281	20.4168	20.4168	0	0
463, 70-cc, 21-23	6.2281	0	6.2281	3.11405	24.9124	0	12.4562	3.11405	0	0	0	0	6.2281	6.2281	9.34216	9.34216	0	0
463, 71-1, 52-54	0	0	0	0	4.71328	0	1.57109	0	0	0	0	0	0	0	0	0	0	0
463, 71-1, 80-83	44.4691	0	0	8.89383	35.5753	17.7877	35.5753	168.983	0	0	0	8.89383	26.6815	35.5753	186.77	88.9383	17.7877	26.6815
463, 71-2, 25-27	271.416	0	27.1416	0	54.2833	54.2833	0	434.266	0	0	27.1416	27.1416	81.4249	27.1416	217.133	135.708	0	81.4249
463, 71-2, 40-42	14.1844	0	2.02634	0	6.07903	10.1317	0	32.4215	0	0	0	2.02634	2.02634	0	14.1844	4.05268	0	2.02634
463, 71-2, 82-85	15.2672	0	7.63359	0	45.8015	22.9008	0	45.8015	7.63359	0	0	0	0	0	76.3359	22.9008	0	0
463, 71-3, 85-89	0	5.43478	0	5.43478	16.3043	0	16.3043	5.43478	0	0	0	0	0	0	10.8696	0	0	0
463, 72-1, 41-44	7.18778	0	0	0	7.18778	7.18778	0	35.9389	0	0	0	0	3.59389	0	3.59389	0	0	3.59389
463, 72-2, 40-43	94.8429	9.48429	18.9686	18.9686	75.8743	28.4529	9.48429	161.233	28.4529	0	9.48429	104.327	123.296	18.9686	161.233	47.4215	0	75.8743
463, 72-4, 69-71	35.3396	0	0	8.8349	8.8349	0	0	44.1745	0	0	0	61.8443	70.6792	17.6698	97.1839	53.0094	0	17.6698

Table 2. Normalized abundance data for radiolarians

Sample (Site, core-section, top-depth(cm))	Depth (mbsf)	*Acaeniotyle diaphorogona*	*Acaeniotyle umbilicata*	*Archaeodictyomitra mitra*	*Archaeodictyomitra sliteri*	*Archaeospongoprunum patricki*	*Cryptamphorella clivosa*	*Cryptamphorella macropora*	*Diacanthocapsa betica*	*Dictyomitra communis*	*Dictyomitra multicostata*	*Dictyomitra pseudoscalaris*	*Gongylothorax verbeeki*	*Hemicryptocapsa* sp. A	*Hiscocapsa asseni*	*Hiscocapsa grutterinki*	*Hiscocapsa simplex*	*Platycryphalus* aff. *hirsuta*	*Pseudodictyomitra carpatica*	*Pseudodictyomitra lanceloti*	*Pseudodictyomitra leptoconica*	*Pseudoeucyrtis tenuis*	*Rhopalosyringium fossile*	*Stichomitra communis*	*Stichomitra japonica*	*Stichomitra mediocris*	*Stichomitra simplex*	*Stichomitra* sp. A	*Thanarla broweri*	*Thanarla conica*	*Thanarla praeveneta*	*Trimulus parmatus*
463, 67-1, 46-51	585.46	0.13164	0.010	0.09519	0	0.08664	0	0	0.06777	0.25018	0	0.11402	0	0	0	0.22652	0	0	0.0331	0	0	0.11914	0	0	0	0.1465	0	0	0.11255	0	0.33637	0
463, 67-2, 130-132	587.8	0	0.060	0.15732	0	0.0537	0.02204	0	0.112	0	0	0.03769	0	0	0	0	0	0	0.02735	0	0.10311	0.03627	0	0	0	0.12106	0	0	0.08371	0.10443	0.13898	0
463, 69-1, 34-39	604.34	0.00837	0.006	0.00907	0	0.00138	0.01017	0	0	0.14309	0	0.02609	0.01011	0	0	0.04319	0	0	0.00631	0.04152	0	0.00956	0	0	0	0	0	0	0.00644	0	0	0
463, 69-2, 40-42	605.9	0.11464	0	0.03108	0	0.00943	0.03484	0	0	0	0	0.05958	0	0.07238	0.03131	0.14794	0.24382	0	0	0	0.16298	0.06553	0	0	0	0	0.05572	0	0.0147	0.06603	0	0
463, 69-3, 33-36	607.33	0.03902	0.027	0.04232	0	0.05885	0.03558	0.03416	0.12053	0	0	0.0507	0.14148	0.09855	0.0746	0.05036	0.08299	0	0.01472	0	0	0.05297	0	0	0	0.04343	0.03793	0	0.04004	0.04495	0	0
463, 70-1, 52-56	614.02	0	0.008	0.03684	0	0.00093	0.07226	0.02379	0.01311	0.09683	0.22399	0.04413	0.02566	0.01072	0.00928	0.06575	0	0	0.04483	0.01405	0.12073	0.00364	0	0	0	0	0	0	0.02832	0.01956	0.03255	0
463, 70-2, 52-56	615.52	0	0.004	0.00591	0	0.00084	0.00795	0	0	0.01242	0	0.00453	0.00395	0	0.00595	0	0	0	0.01479	0.0036	0	0.00187	0	0	0	0	0	0	0.00391	0.00251	0.00835	0
463, 70-3, 54-58	617.04	0.07923	0.130	0.1289	0	0.09126	0.07224	0.11096	0	0	0	0.08235	0.07182	0.05002	0.02164	0.2045	0	0.4124	0.11952	0.26218	0	0.11888	0	0	0	0.08817	0	0	0.08129	0.09127	0.30368	0.07749
463, 70-4, 50-53	618.5	0.0281	0.040	0.07111	0	0.00411	0.09109	0.01968	0	0.16021	0.24705	0.07302	0.00566	0.01183	0.08697	0	0.07969	0.0325	0.04945	0.03099	0.05327	0.03346	0	0	0	0	0.00911	0.03429	0.02162	0.04316	0.0359	0
463, 70-5, 51-53	620.01	0.05874	0.062	0.01593	0.61867	0.08376	0.05355	0.07198	0	0	0	0.06105	0	0	0.14437	0	0	0.10191	0	0.04859	0	0.08393	0	0	0	0.06536	0.0571	0.10751	0.03766	0.05075	0	0.05744
463, 70-5, 65-66	620.15	0	0.001	0.00882	0	0.00067	0.00247	0.00071	0.00314	0.04635	0	0.01056	0.00368	0	0	0	0	0	0.02146	0.03698	0.00578	0	0	0	0	0	0	0	0.01042	0.00819	0	0
463, 70-5, 80-82	620.3	0	0.001	0.00686	0	0	0.02818	0	0	0	0	0.01314	0.00509	0	0	0	0.03585	0	0.00636	0	0.02397	0.00422	0	0	0	0	0.0041	0	0.00757	0.01456	0	0
463, 70-6, 50-52	621.5	0.17466	0.172	0.13261	0	0.07855	0.16986	0.14677	0.05395	0	0	0.07262	0.08444	0.08822	0.05724	0.18032	0	0.12121	0.07904	0.05779	0	0.17471	0	0.65528	0	0.03887	0.16979	0	0.07168	0.08048	0	0
463, 70-6, 130-132	622.3	0	0	0	0	0.00087	0	0	0	0	0	0	0	0	0	0	0	0	0.00902	0	0.01133	0	0	0.07477	0	0	0	0.01459	0.00307	0	0	0.0078
463, 70-7, 5-7	622.55	0.01585	0	0.0172	0	0.00174	0.08672	0.00555	0	0.09039	0	0.03296	0.02874	0	0	0	0	0	0.09566	0	0.04508	0	0	0	0	0	0	0	0.04473	0.00913	0	0
463, 70-7, 21-23	622.71	0	0.008	0.0078	0	0	0.03936	0.00504	0	0	0	0.0187	0.01304	0	0.00393	0	0	0	0.03256	0.0119	0.02046	0.01439	0	0.26995	0.1567	0.01601	0.02098	0.02634	0.01107	0.02487	0	0
463, 70-cc, 21-23	623.01	0	0.003	0.01071	0	7.E-04	0.01601	0.00692	0	0.07508	0	0.00684	0.01592	0	0.00719	0	0.05602	0.02285	0.03973	0	0.07489	0.00094	0	0	0	0	0.0128	0.04821	0.00507	0.01138	0	0
463, 71-1, 52-54	623.52	0	0.00	0.0018	0	2.E-04	0.00606	0.00233	0	0.01894	0	0.00173	0.00201	0	0	0	0	0	0.00752	0	0.00945	0	0	0	0	0	0	0	0	0	0	0
463, 71-1, 80-83	623.8	0.15045	0.163	0.04079	0	0.09283	0.08001	0.26996	0.02904	0	0	0.1466	0.12501	0.14248	0.05136	0	0	0.06526	0.05674	0.06223	0.2139	0.05106	0	0	0	0.02093	0.05484	0.27537	0.1013	0.10832	0.14416	0.11035
463, 71-2, 25-27	624.75	0.11478	0.135	0.06225	0	0.27699	0	0.08038	0.26589	0	0	0.02983	0.20808	0.36234	0.31348	0	0.24413	0	0.08657	0.1899	0	0.13122	0	0	0.62493	0.06387	0.16737	0.21009	0.11776	0.16528	0	0.33677
463, 71-2, 40-42	624.9	0.00428	0.005	0.00232	0.09026	0.00987	0.0026	0.009	0.00662	0	0	0.00668	0.00777	0.00541	0.01638	0	0.01823	0	0.00969	0.03544	0	0.0098	0	0	0	0.00477	0.00417	0	0.00769	0.00494	0	0.00838
463, 71-2, 82-85	625.32	0	0	0	0.17002	0	0.0883	0.09042	0	0	0	0.05033	0.10729	0	0.01763	0	0.06866	0	0.07304	0.08012	0	0.01384	0.21154	0	0	0	0	0	0.0414	0.02789	0	0
463, 71-3, 85-89	626.85	0	0	0	0.12105	0	0.03492	0.01609	0	0	0	0.01194	0.00694	0	0	0.02966	0	0.03988	0.026	0	0.09803	0.00164	0	0	0	0	0	0	0.0059	0	0	0
463, 72-1, 41-44	632.91	0	0	0	0	0.00083	0.00924	0.01596	0	0	0	0.00395	0.01378	0.0096	0.0083	0	0	0	0.01146	0.02515	0	0.01086	0	0	0	0	0.00739	0	0.00195	0	0	0.01486
463, 72-2, 40-43	634.4	0.08022	0.165	0.05438	0	0.10999	0.03657	0.07724	0.15485	0	0.52896	0.03127	0.09695	0.10129	0.10954	0.05176	0.17061	0.13918	0.121	0.09954	0.05702	0.04872	0.78846	0	0.21837	0.2455	0.25343	0.14683	0.08745	0.05775	0	0.31382
463, 72-4, 69-71	637.69	0	0	0.06079	0	0.03586	0	0.01308	0.1731	0.10651	0	0.00971	0.02258	0.04718	0.04082	0	0	0.06482	0.01409	0	0	0.01335	0	0	0	0.14553	0.14528	0.13677	0.05271	0.06456	0	0.07308