Supporting Information

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Table S1. List of ancestor/descendant relationships where the range overlap falls within our proposed estimate of total error

Ancestor	Descendant	Ancestor LAD	Descendant FAD	Range overlap	Potential speciation mechanism
Paleogene					
Hedbergella holmdelensis	*Globanomalina archeocompressa**	64.9	64.95	0.05	One potential anagenetic event
Hedbergella monmouthensis	*Praemurica taurica**	64.85	64.9	0.05	
H. monmouthensis	*Eoglobigerina eobulloides**	64.85	64.97	0.12	Two cladogenetic events and one potential anagenetic event[†]
H. monmouthensis	*Parasubbotina aff_pseudobulloides**	64.85	65	0.15	
Parasubbotina aff_pseudobulloides	*Parasubbotina pseudobulloides**	64.8	64.9	0.1	One potential anagenetic event
Praemurica taurica	*Praemurica psuedoinconstans*	63.8	64.8	1.0	One potential anagenetic event
Eoglobigerina eobulloides	*Subbotina trivialis*	63.6	64.92	1.32	One cladogenetic event[‡] (*E. eobulloides–S. trivialis*)
E. eobulloides	*Eoglobigerina edita*	63.6	64.9	1.3	(1) and one potential anagenetic event (*E. eobulloides–E. edita*)
Globanomalina archeocompressa	*Globanomalina planocompressa*	62.8	64.9	2.1	One cladogenetic event, one potential anagenetic event[†]
G. archeocompressa	*Globanomalina compressa**	62.8	62.9	0.1	
Globanomalina planocompressa	*Globanomalina imitata**	62	62.05	0.05	One potential anagenetic event
Praemurica pseudoinconstans	*Praemurica inconstans*	61.15	62.8	1.65	One potential anagenetic event
Eoglobigerina edita	*Eoglobigerina spiralis**	61.15	61.2	0.05	One potential anagenetic event
Subbotina trivialis	*Subbotina triangularis**	61	61.1	0.1	One cladogenetic event and one potential anagenetic[†]
S. trivialis	*Subbotina cancellata**	61	61.2	0.2	
Praemurica inconstans	*Praemurica uncinata**	60.9	61.2	0.3	One potential anagenetic event
Praemurica uncinata	*Praemurica lozanoi**	60.7	60.75	0.05	Two cladogenetic events[†]
P. uncinata	*Igorina pusilla**	60.7	60.95	0.25	(*P. uncinata–P. lozano*i;
P. uncinata	*Morozovella praeangulata**	60.7	61.15	0.45	*P. uncinata–P. pusilla*) and one putative angenetic event[§] (*P. uncinata–M. praeangulata*) (2)
Globanomalina compressa	*Globanomalina ehrenbergi**	60.7	61.1	0.4	One potential anagenetic event
Morozovella praeangulata	*Acarinina strabocella**	60	60.8	0.8	One cladogenetic event[†] (*M. praeangulata–A. strabocella*)
M. praeangulata	*Morozovella angulata*	60	60.95	0.95	and one putative anagenetic event[§] (*M. praeangulata–M. angulata*) (2)
Igorina pusilla	*Igorina tadjikistanensis**	59.5	60	0.5	One cladogenetic event and one potential anagenetic event[†]
I. pusilla	*Igorina albeari**	59.5	60.05	0.55	
Globanomalina ehrenbergi	*Globanomalina pseudomenardii**	59.38	59.4	0.02	One cladogenetic event and one potential anagenetic event[†]
G. ehrenbergi	*Globanomalina chapmani**	59.38	59.45	0.07	

Table S1. Cont.

Ancestor	Descendant	Ancestor LAD	Descendant FAD	Range overlap	Potential speciation mechanism
Acarinina strabocella	*Acarinina nitida**	59.3	59.5	0.2	One putative anagenetic event[§] (3)
Morozovella conicotruncata	*Morozovella velascoensis**	59.3	59.9	0.6	One potential angenetic event
Morozovella angulata	*Morozovella apanthesma**	59.3	60	0.7	One cladogenetic event[‡]
M. angulata	*Morozovella conicotruncata*	59.3	60.8	1.5	(*M. angulata–M. apanthesma*) (4) and one putative anagenetic event[§] (*M. angulata–M. conicotruncata*) (2)
Subbotina cancellata	*Subbotina patagonica**	56.8	57	0.2	One cladogenetic event[‡]
S. cancellata	*Subbotina velascoensis*	56.8	59.2	2.4	(*S. cancellata–S. velascoensis*) (1) and one potential anagenetic event (*S.cancellata–S. patagonica*)
Acarinina mckannai	*Acarinina soldadoensis**	56.3	56.4	0.1	One putative anagenetic event[§] (5)
Acarinina nitida	*Acarinina esnaensis**	56.2	56.3	0.1	One cladogenetic event and one potential
A. nitida	*Acarinina coalingensis**	56.2	56.5	0.3	anagenetic even[†]
Globanomalina imitata	*Globanomalina australiformis**	55.8	55.88	0.08	One cladogenetic event and one potential anagenetic event[†]
G. imitata	*Globanomalina ovalis**	55.8	56.5	0.7	
Subbotina triangularis	*Subbotina roesnaesensis**	55.55	55.6	0.05	One potential anagenetic event
Igorina tadjikistanensis	*Igorina lodoensis**	55.4	55.8	0.4	One cladogenetic event[‡] (6)
Acarinina sibaiyaensis	*Acarinina africana**	55.3	55.4	0.1	One potential anagenetic event
Globanomalina ovalis	*Globanomalina luxorensis**	55.3	55.7	0.4	One potential anagenetic event
Morozovella velascoensis	*Morozovella edgari**	54.45	54.9	0.45	One cladogenetic event[‡] (2, 7)
Morozovella apanthesma	*Morozovella aequa*	54.45	56.5	2.05	One cladogenetic event
M. apanthesma	*Planorotalites pseudoscitula*	54.45	55.9	1.45	(*M. apanthesma–P. pseudoscitula*)[‡] (1) and one potential anagenetic event (*M. apanthesma–M. aequa*)
Subbotina velascoensis	*Subbotina hornibrooki*	54.45	55.6	1.15	One cladogenetic event[‡] (1)
Morozovella velascoensis	*Morozovella allisonensis*	54.45	55.5	1.05	One cladogenetic event[‡] (1)
Globanomalina luxorensis	*Pseudohastigerina wilcoxensis*	54.45	55.3	0.85	One potential anagenetic event
Globanomalina planoconica	*Planoglobanomalina pseudoalgeriana**	50.6	50.8	0.2	One potential anagenetic event
Morozovella lensiformis	*Morozovella aragonensis*	50.6	52.3	1.7	One potential anagenetic event
Acarinina interposita	*Acarinina pentacamerata*	50.4	52.3	1.9	One potential anagenetic event
Acarinina coalingensis	*Acarinina primitiva**	50.1	50.8	0.7	One potential anagenetic event
Acarinina pseudotopilensis	*Acarinina mcgowrani*	47.25	49.25	2.0	One potential anagenetic event
Parasubbotina inaequispira	*Guembelitrioides nuttalli*	45.4	46.4	1.0	One cladogenetic event[‡] (1)
Clavigerinella caucasica	*Hantkenina singanoae**	44.45	44.5	0.05	One cladogenetic event[‡] (8)
Hantkenina singanoae	*Hantkenina mexicana**	44.4	44.41	0.01	One potential anagenetic event
Hantkenina mexicana	*Hantkenina liebusi**	43.8	44.2	0.4	One potential anagenetic event
Igorina broedermanni	*Igorina anapetes*	43.7	45.4	1.7	One putative anagenetic[§] (6)
Subbotina roesnaesensis	*Globigerina officinalis**	43.2	43.5	0.3	One potential anagenetic event
Globoturborotalita bassriverensis	*Globoturborotalita ouachitaensis**	42.4	43.1	0.7	Two cladogenetic events
G. bassriverensis	*Globoturborotalita martini*	42.4	44	1.6	(*G. bassriverensis–G. martini*;
G. bassriverensis	*Turborotalita carcoselleensis*	42.4	44.4	2.0	*G. bassriverensis–Turborotalita carcoselleensis*)[‡] (1) and one potential anagenetic event
Acarinina pseudosubsphaerica	*Acarinina echinata*	42.3	43.2	0.9	One cladogenetic event[‡] (1)

Table S1. Cont.

Ancestor	Descendant	Ancestor LAD	Descendant FAD	Range overlap	Potential speciation mechanism
Globigerinatheka curryi	*Globigerinatheka euganea*	41.6	42.8	1.2	One potential anagenetic event
Turborotalia frontosa	*Turborotalia pomeroli*	40.8	43.2	2.4	One potential anagenetic event
Globigerinatheka euganea	*Globigerinatheka luterbacheri**	40.2	40.3	0.1	One cladogenetic event and one potential anagenetic event[†]
G. euganea	*Orbulinoides beckmanni**	40.2	40.5	0.3	
Hantkenina dumblei	*Hantkenina compressa*	39	41.2	2.2	One potential anagenetic event
Acarinina primitiva	*Dentoglobigerina galavisi**	38.8	39	0.2	One potential anagenetic event
Turborotalita carcoselleensis	*Turborotalita praequinqueloba**	35.9	36	0.1	One potential anagenetic event
Turborotalia cocoaensis	*Turborotalia cunialensis**	33.8	34.1	0.3	One potential anagenetic event
Subbotina linaperta	*Subbotina utilizindex*	33.7	35.4	1.7	One potential anagenetic event
Dentoglobigerina sp.	*Dentoglobigerina prasaepis**	32.9	33.3	0.4	One cladogenetic event, one potential anagenetic event[†]
Dentoglobigerina sp.	*Dentoglobigerina tapuriensis**	32.9	33.7	0.8	
Subbotina sp. 1	*Subbotina* sp. 2	32.6	33.8	1.2	One cladogenetic event[‡] (1)
Subbotina eocaena	*Subbotina* sp. 1	32.2	34.1	1.9	One cladogenetic event[‡] (1)
Globoturborotalita martini	*Globoturborotalita labiacrassata**	30.3	30.4	0.1	One cladogenetic event, one potential anagenetic event[†]
G. martini	*Globoturborotalita woodi**	30.3	30.6	0.3	
Turborotalia ampliapertura	*Turborotalia euapertura*	30.3	32.65	2.35	One potential anagenetic event
Dentoglobigerina galavisi	*Dentoglobigerina larmeui**	27.2	27.3	0.1	One potential anagenetic event
Dentoglobigerina sellii	*Dentoglobigerina binaiensis*	24.1	26	1.9	One cladogenetic event[‡] (1)
Protentelloides primitiva	*Protentelloides dalhousiei*	23.8	25.7	1.9	One potential anagenetic event
Paragloborotalia pseudokugleri	*Paragloborotalia kugleri**	23.5	23.8	0.3	One potential anagenetic event
Neogene					
Paragloborotalia kugleri	*Fohsella peripheroronda*	21.5	22	0.5	One cladogenetic event[‡] (1)
Catapsydrax parvulus	*Catapsydrax stainforthi**	16.9	17.1	0.2	One potential anagenetic event
Praeorbulina circularis	*Orbulina suturalis**	14.9	15.1	0.2	One potential anagenetic event
Hirsutella praescitula	*Hirsutella scitula**	14.8	15	0.2	One cladogenetic event, one potential anagenetic event[†]
H. praescitula	*Hirsutella challenger*	14.8	15.15	0.35	
Menardella archeomenardii	*Menardella praemenardii*	14.2	14.6	0.4	One cladogenetic event[‡] (1)
Fohsella peripheroronda	*Fohsella peripheroacuta*	13.8	14.3	0.5	One potential anagenetic event
F. peripheroacuta	*Fohsella praefohsi*	13.4	13.8	0.4	One cladogenetic event[‡] (*F. peripheroacuta–F. lenguaensis*) (1); one potential anagenetic event (*F. peripheroacuta–F. praefohsi*)
F. peripheroacuta	*Fohsella lenguaensis*	13.4	13.7	0.3	
Fohsella praefohsi	*Fohsella fohsi*	13.1	13.4	0.3	One cladogenetic event[‡] (9)
Menardella praemenardii	*Menardella menardii**	12.3	12.31	0.01	One potential anagenetic event
Hirsutella primitiva	*Hirsutella praemargaritae**	5.7	5.9	0.2	One potential anagenetic event
Globorotalia merotumida	*Globorotalia plesiotumida*	5.8	6.4	0.6	One potential anagenetic event
Globoconella conoidea	*Globoconella conomiozea*	5.7	6	0.3	One cladogenetic event[‡] (10)
Globoconella conomiozea	*Globoconella terminalis**	5.5	5.6	0.1	One cladogenetic event[‡] (10)
Globoconella terminalis	*Globoconella pliozea**	5	5.05	0.05	One cladogenetic event[‡] (*G. terminalis–G. pliozea*) (11) and one putative anagenetic event[§] (*G. terminalis–G. sphericomiozea*) (11)
G. terminalis	*Globoconella sphericomiozea*	5	5.4	0.4	

Table S1. Cont.

Ancestor	Descendant	Ancestor LAD	Descendant FAD	Range overlap	Potential speciation mechanism
Globoconella sphericomiozea	*Globoconella puncticulata**	4.5	4.6	0.1	One cladogenetic event‡ (10)
Pulleniatina praespectabilis	*Pulleniatina spectabilis**	4.4	4.6	0.2	One potential anagenetic event
Pulleniatina spectabilis	*Pulleniatina finalis**	4.2	4.25	0.05	One potential anagenetic event
Hirsutella margaritae	*Hirsutella hirsuta**	2.95	3	0.05	One cladogenetic event, one potential
H. margaritae	*Hirsutella theyeri*	2.95	3.5	0.55	anagenetic event†
Globoconella puncticulata	*Globoconella inflata*	2.3	2.6	0.3	One cladogenetic event‡ (10)
Menardella menardii	*Menardella fimbriata**	0	0.2	0.2	One cladogenetic event¶
Beella digitata	*Beella megastoma*	0	0.3	0.3	One cladogenetic event¶

The listed events represent ancestor/descendant transitions where range overlap is within our estimate of total-error margins (2.4 Ma for the Paleogene; 0.6 Ma for the Neogene). Where the range of a morphospecies crosses the Paleogene/Neogene boundary, we apply our Paleogene estimate for total error to the FAD (±1.2 Ma) and our Neogene estimate for the error to the LAD (±0.3 Ma). Events where overlap is equal to or less than dating-error margins (0.8 Ma for the Paleogene; 0.2 Ma for the Neogene) are marked with an *. For each listed event, we assume potential anagenesis, except where available evidence indicates putative anagenesis or cladogenesis. Evidence used includes:

†Two or more descendants originated from a single ancestor, indicating one potential anagenetic event and multiple cladogenetic events.

‡Frequency distributions of ancestor and descendant morphotypes are nonoverlapping in morphospace, or are overlapping in morphospace, but distinguishable, indicating cladogenesis (1, 11, 12). For events where ancestor/descendant overlap falls within dating error, we invoke ‡ only where co-occurring specimens can be demonstrated to constitute two or more populations with distinguishable frequency-distributions in morphospace (e.g. ref. 12). We use ancestor/descendant transitions designated speciation events by Aze et al. (1) to resolve typological error in light of their statement that empty morphospace between populations in multidimensional space is necessary for a speciation event to have occurred.

§Ancestor–descendant pairs cannot be differentiated in morphospace, indicating putative anagenesis.

¶Ancestor and descendant are both extant and therefore contemporaneous, indicating cladogenesis.

1. Aze T, et al. (2011) A phylogeny of Cenozoic macroperforate planktonic foraminifera from fossil data. *Biol Rev Camb Philos Soc* 86(4):900–927.
2. Corfield RM, Granlund AH (1988) Speciation and structural evolution in the Palaeocene *Morozovella* lineage (planktonic foraminiferida). *Journal of Micropalaeontology* 7(1):59–72.
3. Quillévéré F, Debat V, Auffray J-C (2002) Ontogenetic and evolutionary patterns of shape differentiation during the initial diversification of Paleocene acarininids (planktonic foraminifera). *Paleobiology* 28(4):435–448.
4. Norris RD, Nishi H (2001) Evolutionary trends in coiling of tropical Paleogene planktic foraminifera. *Paleobiology* 27(2):327–347.
5. Quillévéré F, Norris RD, Berggren WA, Aubry M-P (2000) 59.2 Ma and 56.5 Ma: Two significant moments in the evolution of acarininids (planktonic foraminifera). *GFF* 122(1):131–132.
6. Soldan DM, Petrizzo MR, Silva IP, Cau A (2011) Phylogenetic relationships and evolutionary history of the Paleogene genus *Igorina* through parsimony analysis. *J Foraminiferal Res* 41(3):260–284.
7. Kelly DC, Bralower TJ, Zachos JC (2001) On the demise of the early Paleogene *Morozovella velascoensis* lineage: Terminal progenesis in the planktonic foraminifera. *Palaios* 16(5): 507–523.
8. Coxall HK, Huber BT, Pearson PN (2003) Origin and morphology of the Eocene planktonic foraminifer *Hantkenina*. *J Foraminiferal Res* 33(3):237–261.
9. Norris RD, Corfield RM, Cartlidge J (1996) What is gradualism? Cryptic speciation in globorotaliid foraminifera. *Paleobiology* 22(3):386–405.
10. Wei K-Y (1987) Multivariate morphometric differentiation of chronospecies in the late Neogene planktonic foraminiferal lineage *Globoconella*. *Mar Micropaleontol* 12:183–202.
11. Wei K-Y, Kennett JP (1988) Phyletic gradualism and punctuated equilibrium in the Late Neogene planktonic foraminiferal clade *Globoconella*. *Paleobiology* 14(4):345–363.
12. Hull PM, Norris RD (2009) Evidence for abrupt speciation in a classic case of gradual evolution. *Proc Natl Acad Sci USA* 106(50):21224–21229.