Supplementary material
Plants in movement – Floristic and climatic characterization of the New Jersey hinterland during the Palaeogene-Neogene transition in relation to major glaciation events

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Supplement S1-S4

1. Supplement S1 Site M0027: selection, age model and core sediment description

During IODP Expedition 313 to the New Jersey Shallow Shelf (NJJS) three boreholes (M0027A, M0028A, M0029A) were recovered of which only the most inner neritic Site M0027 contained Oligocene sequences; at Site M0028 and M0029 Oligocene sequences were below the total penetration depth (Browning et al., 2013; Miller et al., 2013a).

Deposition of the analysed core sediments occurred from the middle Oligocene to the early Miocene. The sediments comprise four sequences. The age model is based on calcareous nannofossils, dinoflagellate cysts, planktic diatoms, Sr isotopes, and sequence stratigraphy (Browning et al., 2013; Miller et al., 2013a). The sampled part of the Oligocene is not well resolved in the seismic profile (Browning et al., 2013; Miller et al., 2013a, 2013b), either because of the minimal lithological expression or the increasing burial depth; however, Oligocene sequences were identified via core and log inspections (Browning et al., 2013; Miller et al., 2013a, 2013b). Sequence O3 (617 to 538.68 mbsf) is the oldest analysed sequence and was deposited between ~29.3 to ~28.2 Ma. The age uncertainty for this sequence lies between ~0.5 and ~1 Ma. Sequence O3 contains two very poorly resolved intrasequences, which are tied to facies changes (Miller et al., 2013a): The onset of Sequence o.1 at 596.3 mbsf is dated to ~29.0 Ma and the base of Sequence o.5 at 563.0 mbsf is dated to ~28.6 Ma. Sequence O6 (538.68 to 509 or 515 mbsf) reflects the uppermost part of the Oligocene and the transition to the early Miocene (Chattian/Aquitanian) and is not visible seismically (Browning et al., 2013 Miller et al., 2013a, 2013b). A coring gap between 509 and 515 mbsf impedes giving a precise upper sequence boundary of O3 and the basal sequence boundary of the early Miocene Sequence m6 respectively (Miller et al., 2013a). Miller et al. (2013a) set a synthetic sequence boundary at 510 mbsf. The estimated age of sequence O6 is best dated to ~23.5 to ~23.0 Ma and has a potential age error of ~0.25 and ~0.5 Ma. The early Miocene Sequence m6 (509 or 515 to 494.87 mbsf) covers an age interval of ~20.9 to ~20.7 Ma (Aquitanian). Sequence m5.8 (494.87 to 361.28) is dated to ~20.1 to ~19.2 Ma (late Aquitanian/early Burdigalian). Ages of the analysed Miocene sequences m6 and m5.8 have a potential error of ~0.5 to ~1 Ma.

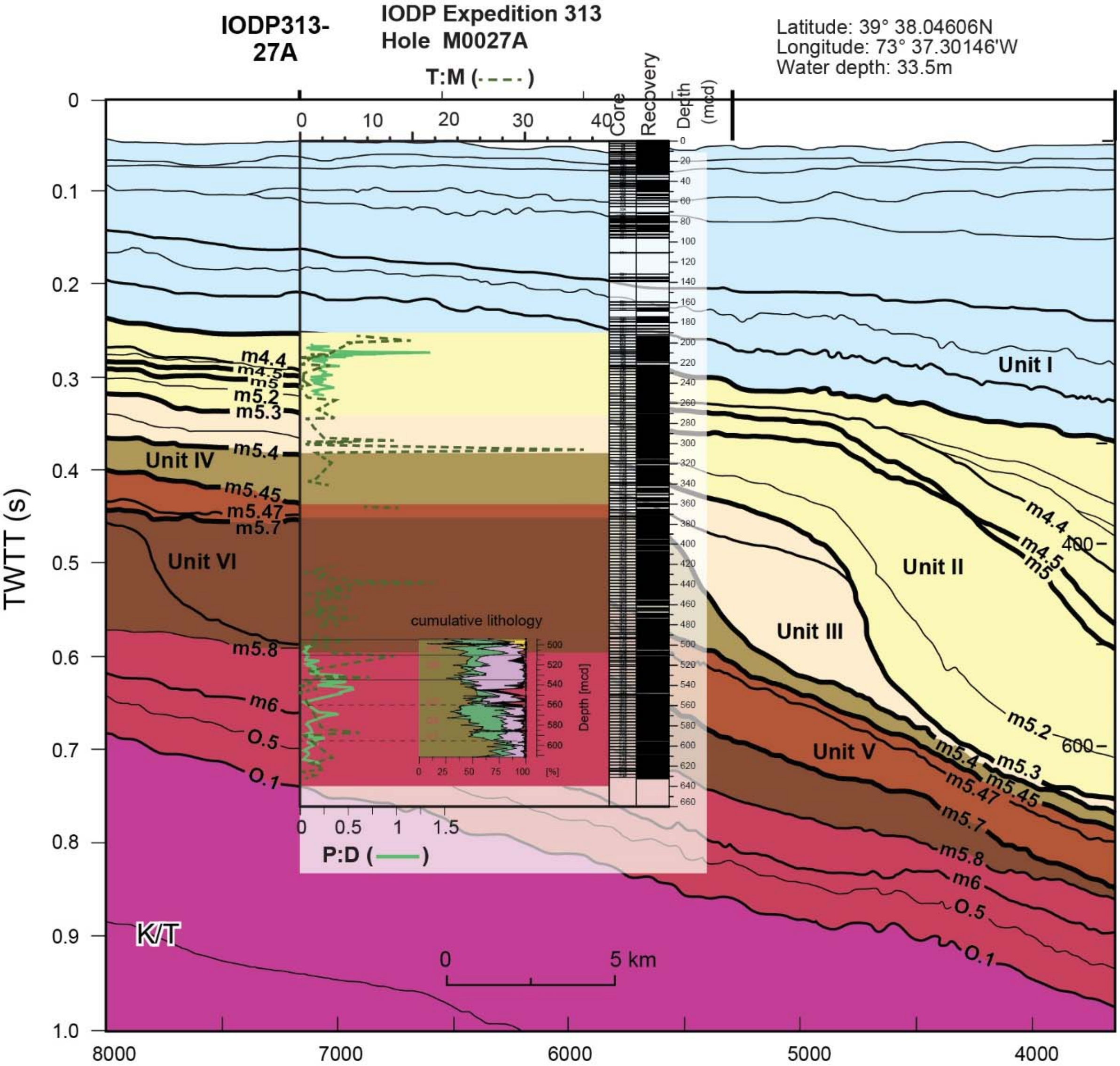

Figure S1. Seismic profile through Site M0027 including T:M (terrestrial versus marine palynomorphs after McCarthy et al., 2013), P:D (pollen versus dinoflagellate cyst; this study: Oligocene to Early Miocene; late Mid-Miocene after Prader et al., 2017) and cumulative lithology after Miller et al. (2013a). Rapid aggradation (vertical accumulation of sediment at times of sea level rise and high sedimentation rate) and progradation (displacement of coastline and clinoform) across the New Jersey margin is evident in the interpreted seismic record, particularly in the thick Unit VI/ sequence m5.8. The P:D ratio reflects shifts in shoreline distance and major peaks in T:M record pulses of downslope mass wasting associated with glacioeustatic lowstands (Mudie and McCarthy, 1998). Mcd: meters composite depth corresponds with mbsf (meter below seafloor), K/T: Cretaceous-Tertiary boundary. Cumulative lithology: brown= clay and silt; green= glauconite; violet= fine quartz sand; yellow= medium and coarser quartz sand; black= carbonate; white= mica and other.

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2. Supplement S2 Sample processing and analysing

2.1.1 Site M0027: selection, age model and core sediment description

The first part of the sample processing was performed at Brock University (St. Catharines, Canada) following a modified protocol after Bates et al. (1978). For all samples ~5cm³ sediment were disaggregated in 0.02 % sodium hexamethaphosphate, treated with 25 % hydrochloridic acid and subsequently with 48 % hydrofluoric acid (HF) and sieved through a 10 µm Nixon mesh. The processed material was mounted in glycerine jelly. The second part of the sample processing was done at the laboratory of the University of Hamburg using the remainder of the first processing step following a modified protocol from Zetter and Ferguson (2001). Due to the moderate preservation, acetolyzation was performed without chlorination. In several samples, palynomorph preservation was limited so that further chemical treatment (acetolyzation) was completely omitted. In these cases, counting and identification of terrestrial palynomorphs were done using the material solely treated with HF. Around 300-400 terrestrial palynomorphs were identified and counted using the acetolyzed material/HF-treated samples for percentage calculation. For the percentage calculations, bisaccate pollen grains are excluded from the reference sum, based upon the fact that these grains tend to be overrepresented in marine records (Mudie and McCarthy, 1994).

Additionally 300 marine/terrestrial palynomorphs were counted separately using the non-acetolyzed material because gonyaulacoid (autotrophic) dinoflagellate cyst (dinocysts) and most of the thin-walled protoperidinoid dinocysts (heterotroph) are sensitive to acetolysis (Mudie and McCarthy 2006). The pollen versus dinoflagellate cyst ratio (P:D) acts as an indicator for transport mechanisms and sea level fluctuations (Mudie and McCarthy, 1994; McCarthy et al., 2013).

In sum, 57 samples were analysed spanning the time interval of the middle late Oligocene (Sequence O3 and Sequence O6) to the early Miocene (Sequence O6, Sequence m6 and Sequence m5.8). Sequence O3 includes 26 samples, 19 samples were counted for Sequence O6, 10 for Sequence m6 and Sequence m5.8 includes only 1 sample Pollen grain identification and counting were done using a Zeiss Axioscope A1 at 630x magnification.

Additional, for an accurate identification, some pollen grains were analyzed via SEM using the single grain technique (Hesse et al., 2009).

The diagnosis of pollen grain ornamentation of different infrageneric groups of Quercus follows the description of Grímsson et al. (2015) and Bouchal et al. (2014).

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3. Supplement S3 Pollen grain identification and climate reconstruction

In this study, pollen grains identified at family level only were generally excluded from the palaeoclimate reconstruction after Greenwood et al. (2005) and Prebble et al. (2017). Different representatives of a family can have totally different growing preferences and would generate climatic overlaps of huge range. The Juglandaceae subfamily Engelhardioideae, whose members have a very similar pollen grain ornamentation were as well excluded. Similarly, several genera such as *Alnus* or *Betula* were excluded in a second step since they flourish under heterogenous macroclimatic conditions nowadays.

In the case of the Castanoideae (Fagaceae subfamily), which often are distinguishable via scanning electron microscope (Bouchal et al., 2014), we have generated a climatic envelop of the entire subfamily. The pollen ornamentation of the genera *Morella* and *Myrica* (Myricaceae) are identical (Grímsson et al., 2016) and several former *Myrica* spp. are now included into the genus *Morella* (Herbert, 2005). The climatic profile used for our study is based on *Morella* spp. with exclusion of the boreal genus *Myrica gale* (compare Thomson et al., 2000a, 2000b, 2006).

The genus *Craigia* (Tiloideae, Malvaceae), which was widespread during the Cenozoic in the Northern Hemisphere (Bůzek, et al., 1989) but is today restricted to China and Vietnam (eFloras, 2008), has *Tilia*-like pollen grains (Kvaček et al., 2002). However, we used the climatic profile for *Tilia* in this case because the shape of the apertures and the tectum of the analysed pollen grains of Site M0027 referred more to *Tilia* (Plate I, O-P; Plate S4-ii, I).

The generated palaeoclimatic estimates (MAT, CMMT, WMMT, MAP) based on climatic profiles were taken from Thomson et al. (2000a; 2000b; 2006) for North American species and from Fang et al. (2011) for Chinese species. Further estimates are based on data from Natural Resources Canada (NRC) and Global Biodiversity Information Facility (GBIF) using WorldClim.

Table S3 Summary of identified taxa for Site M0027 together with sources of climatic range and assignments to vegetation units, alphabetically ordered.

Taxon	Climate source	NLR used	Vegetation unit
Gymnosperms			
Abies	-		1
Cathaya	a	*C. argyrophylla*	2
Cedrus	b		2
Cupressaceae	-		3
Ephedra	-		7
Larix	-		1
Picea	-		1
Pinus subg. *Pinus*	-		2
Pinus subg. *Strobus*	-		2

Sciadopitys	d	*S. verticillata*	2
Tsuga canadensis	b	*T. canadensis*	4
Tsuga caroliniana	b	*T. caroliniana*	4
Angiosperms			
Acer	b	*Acer* spp. (NA)	4
Alnus	-		5
Anacardiaceae	-		4
Apiaceae	-		6
Artemisia	-		6
Betula	-		5
Carpinus/*Ostrya*	b	*Carpinus* and *Ostrya* spp. (NA)	4
Carya	b	*Carya* spp. (NA)	5
Castaneoideae	b	*Castanea* spp./ *Castanopsis chrysophylla*/ *Lithocarpus densiflorus*	4
Cedrelospermum ?	-		4
Chenopodiaceae/ Amaranthaceae	-		7
Clethra	-		4
Cornus	b	*Cornus* spp. (woody, NA)	4
Corylus	b	*Corylus* spp. (NA)	4
Cyperaceae	-		6
Diospyros	b	*Diospyros* spp. (NA)	4
Elaeagnus	-		4
Engelhardioideae	-		4
Ericaceae	-		4
Eucommia	a	*E. ulmoides*	4
Fabaceae	-		6
Fagus	b	*F. grandifolia*	4
Fraxinus	b	*Fraxinus* spp. (NA)	5
Gordonia	b	*G. lasianthus*	4
Hamamelidaceae	-		4
Humulus	-		5
Ilex	a	*Ilex* spp. (NA)	5
Itea	b	*I. virginica*	5
Juglans	b	*Juglans* spp. (NA)	5
Juglandaceae	-		4

Liliaceae	-		5
Liquidambar	b	*L. styraciflua*	5
Lonicera	-		4
Magnolia	b	*Magnolia* spp. (NA)	4
Myrica/*Morella*	a	*Morella* spp. (NA)	5
Nyssa	b	*Nyssa* spp. (NA)	5
Oleaceae	-		4
Ostrya	b	*Ostrya* spp. (NA)	4
Parthenocissus	c	*Parthenocissus* spp. (NA)	4
Platanus	b	*Platanus* spp. (NA)	4
Poaceae	-		6
Prunus	b	*Prunus* spp. (NA)	4
Pterocarya	a	*Pterocarya* spp. (China)	4
Quercus	b	*Quercus* spp. (NA)	4
Reevesia	a	*Reevesia* spp. (China)	4
Rhamnaceae	-		5
Rosaceae	-		4
Salix	-		5
Sapotaceae	-		5
Symplocos	b	*S. tinctoria*	5
Tilia	b	*Tilia spp.* (NA)	4
Ulmus	b	*Ulmus spp.* (NA)	5
Ulmus/*Zelkova*	b	*Ulmus* spp. (NA)	5
Vitaceae	-		5
Vitis	-		5
Zelkova	a	*Zelkova* spp. (China)	5
Pteridophytes			
Equisetum	-		5
Lycopodium	-		5
Osmunda	c	*Osmunda* s.l. (NA)	5
Polypodiaceae	-		5

[a]: Fang *et al.* (2011), [b] Thomson *et al.* (2000a, 2000b), [c] NRC, [d] GBIF+WorldCLIM

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4. Supplement S4 Light microscopic images Plate S4-i and S4-ii

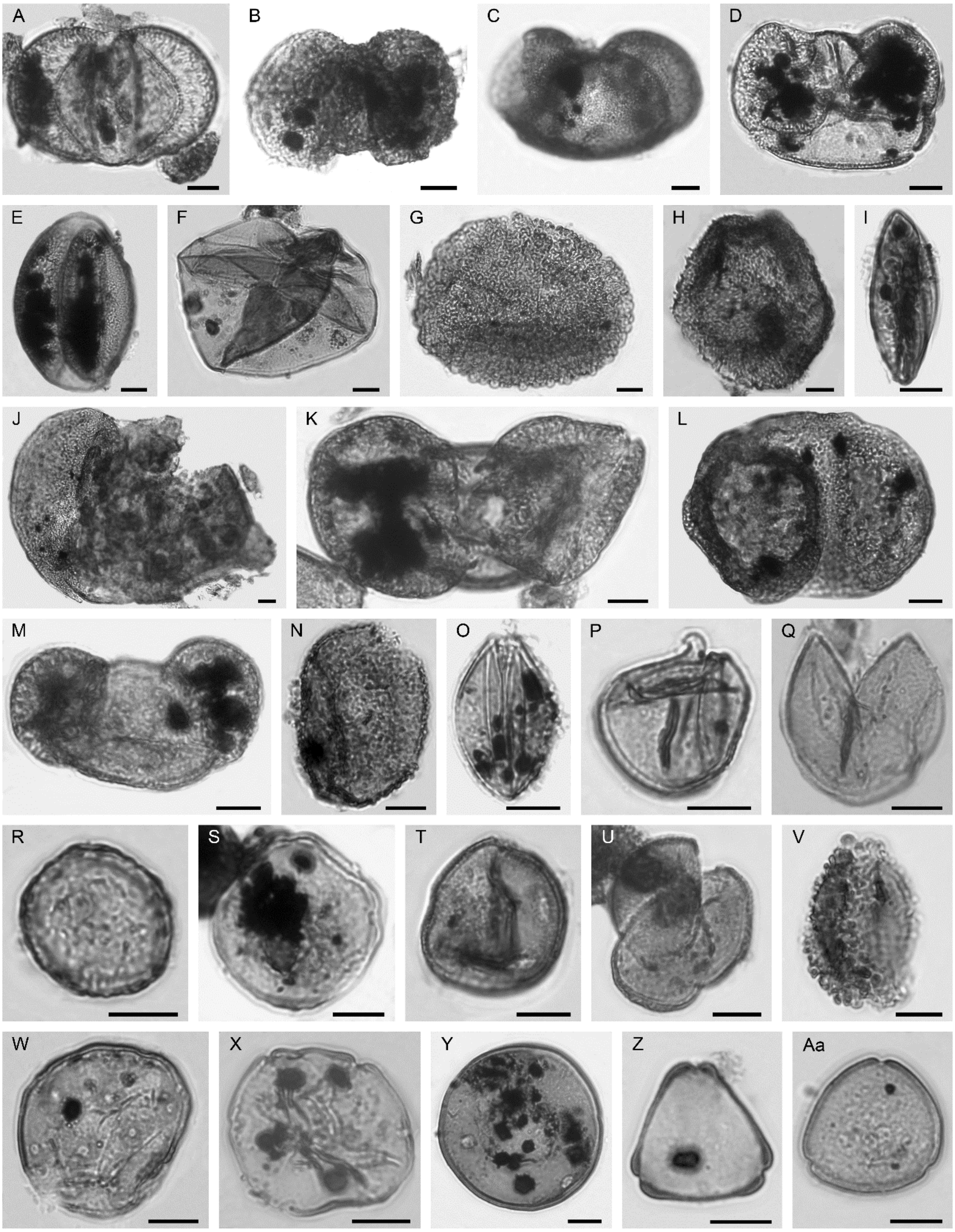
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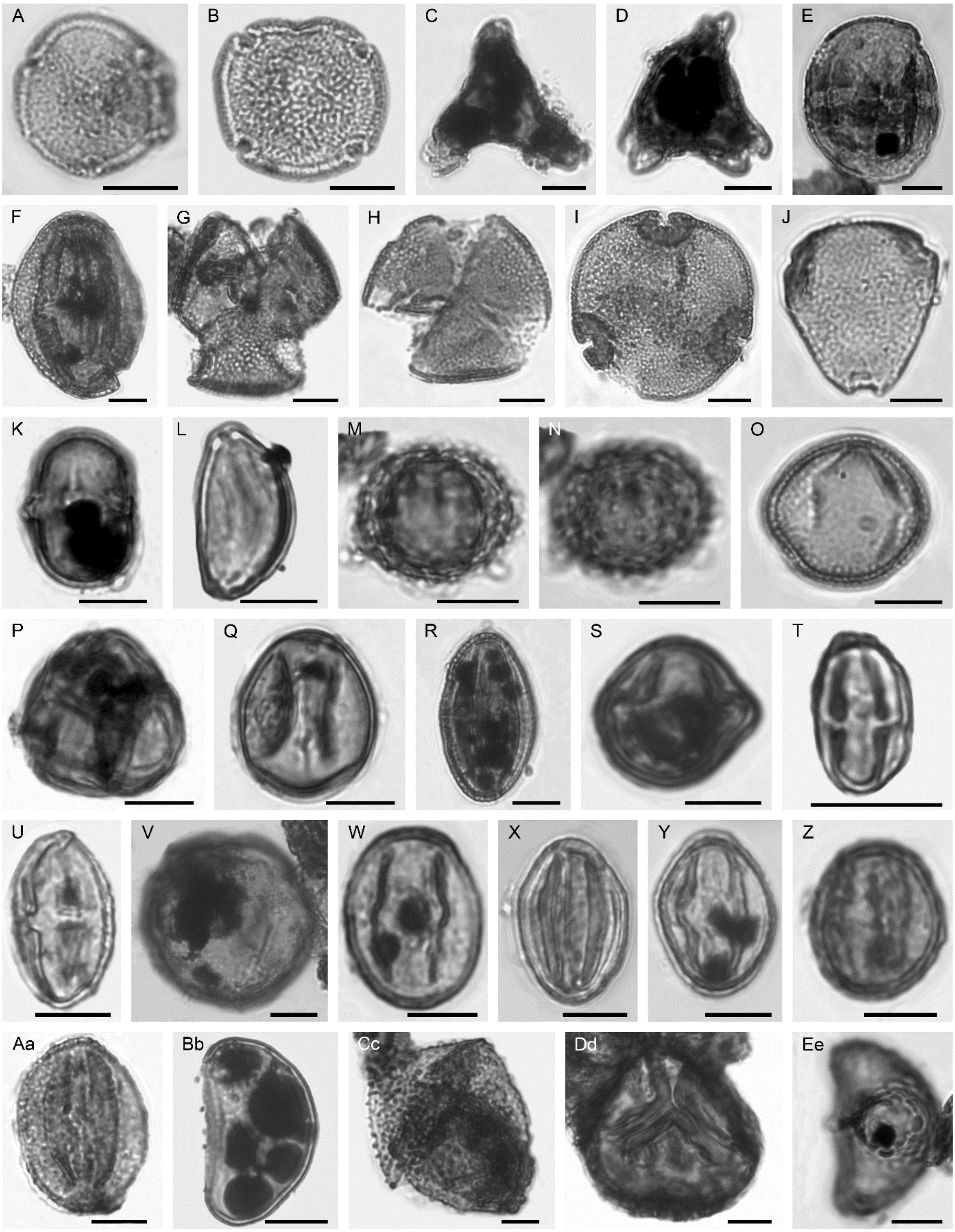
Plate S4-i. LM images of selected pollen grains of identified taxa of Site M0027 (scale bar = 10µm). A. *Cathaya* (535.46 mbsf), B. *Cathaya* (537.38mbsf), *Cedrus* (518.03 mbsf), D. *Picea* (562 mbsf), E. *Picea* (495.91 mbsf), F. *Larix* (495.91 mbsf), G. *Tsuga canadensis* (570.02 mbsf), H. *Tsuga caroliniana* (574.05 mbsf), I. *Ephedra* (582.02 mbsf), J. *Abies* (579.85 mbsf), K. *Pinus* subg. *Pinus* (560.01), L. *Pinus* subg. *Strobus* (584.92), N. *Sciadopitys* (495.91 mbsf), O. Cupressaceae non-papillate (541.5 mbsf), P. Cupressaceae papillate (495.32 mbsf), Q. Cupressaceae presumably with papilla (541.5 mbsf), R. *Ulmus* (498.54 mbsf), S. *Zelkova* (560.01 mbsf), T. *Liquidambar* (574.05), U. *Acer* (601.88 mbsf), V. *Ilex* (601.88), W. *Juglans* (495.91 mbsf), X. *Pterocarya* (495.72 mbsf), Y. *Carya* (540.3 mbsf), Z. Engelhardioideae (540.3 mbsf), Aa. Engelhardioideae (533.54 mbsf).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F Plate S4-ii. LM images of selected pollen grains of identified taxa of Site M0027A (scale bar = 10µm). A. *Reevesia* (591.98 mbsf), B. *Reevesia* (603.58 mbsf), C. *Elaeagnus* (601.88 mbsf), D. *Elaeagnus* (597.94 mbsf), E. Sapotaceae (597.94 mbsf), F. *Gordonia* (600.16 mbsf), G. *Gordonia* (509 mbsf), H. *Gordonia* same pollen grain as in Plate I (574.05 mbsf), I. *Tilia* (597.94 mbsf), J. *Symplocos* (570.02 mbsf), K. Fabaceae (579.85 mbsf), L. *Itea* (584.92 mbsf), M. *Arthemisia*: middle view (521.62 mbsf), N. *Artemisia*: upper view (521.62 mbsf), O. *Fraxinus* (611.76 mbsf), P. Ericaceae (520.9 mbsf), Q. *Eucommia* (521.62 mbsf), R. *Parthenocissus* (495.91 mbsf), S. *Clethra* (574.05 mbsf), T. Castaneoideae (494.91 mbsf), U. *Eotrigonobalanus;* same pollen grain as in Plate I (574.05 mbsf), V. *Fagus*; same pollen grain as in Plate I (574.05 mbsf), W. *Quercus* Group Quercus/ Lobatae; same pollen grain as in Plate I, E-F (574.05 mbsf), X. Quercus Group aff. Protobalanus; same pollen grain as in Plate I, I-J (574.05 mbsf), Y. *Quercus* Group Quercus same pollen grain as in Plate I C-D (574.05 mbsf), Z. *Quercus* (574.05 mbsf), Aa. *Quercus* (585.7 mbsf), Bb. Polypodiaceae (584.73 mbsf), Cc. *Osmunda* (574.05 mbsf), Dd. Trilete spore indet (509 mbsf), Ee. Spore indet (532.62 mbsf).