Percival, L.M.E., et al., 2023**, Valanginian climate cooling and environmental change driven by Paraná-Etendeka basalt erosion:** Geology, https://doi.org/10.1130/G51202.1

Supplemental Material

Appendices S1–S2

Figure S1

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Appendix S1: Supplementary Text

S1-1: DSDP Sites 534 and 603: Site description and age model construction

Two proto-Atlantic sites are studied here, DSDP Site 603, Hole B (lower continental rise off Cape Hatteras: 35° 29.66' N; 70° 01.70' W) and DSDP Site 534, Hole A (Blake Bahama Basin: 28° 20.6' N, 75° 22.9' W). Both archives record low-latitude, warm (> 32 °C; Littler *et al*., 2011), open marine settings on the continental slope or abyssal plain east of North America. The sedimentary rocks themselves primarily consist of pelagic bioturbated chalks interbedded with more-organic rich laminated marls and sandstones–mudstones, likely including sporadic distal turbidite layers (Sheridan *et al*., 1983b; van Hinte *et al*., 1987). Robust calcareous nannofossil biostratigraphy exists for both sites (Covington and Wise, 1987; Bergen, 1994; Bornemann and Mutterlose, 2008), enabling stratigraphic correlation with other Berriasian–Hauterivian archives. Magnetic polarity timescales have also been generated for the two records (Ogg *et al*., 1987); however, both sites also feature large uncertainties in the lower Valanginian chron boundaries between M14 and M11A.

Age models for the two sites were previously constructed by Littler *et al*. (2011), based on the published magnetostratigraphy for the two records and the determined ages of Early Cretaceous chron boundaries (Ogg, 1987, Gradstein *et al*., 2004). However, the lack of a precise record of chrons M14–M11A at either Site 534 or Site 603 necessitated a simplified age model assuming constant sedimentation rates for ~30–40 m of strata between M15n and M11r.2r, which included the crucial strata that document the run-up to and onset of the Weissert Event. In recent years, the Valanginian–Hauterivian geological timescale has been increasingly refined via cyclostratigraphic analyses of stratigraphic sites (chiefly from the Vocontian Basin; e.g., Charbonnier *et al*., 2013; Martinez *et al*., 2013, 2015, 2023), anchored against radioisotopic dating of bentonite layers (e.g., Aguirre-Urreta *et al*., 2008, 2015, 2017). These new anchors enable refinement of the age models for Valanginian strata at Sites 534 and 603.

Aside from the chron boundary data, stratigraphic constraints for Site 534 and Site 603 are based on calcareous nannofossil biozone data, together with carbonate carbon isotope ($\delta^{13}C_{carb}$) information representative of global trends (Covington and Wise, 1987; Bergen, 1994; Bornemann and Mutterlose, 2008). Durations of 2.84 Myr, 2.01 Myr, and 1.91 Myr have been proposed for the Valanginian calcareous nannofossil zones NK3A, NK3B, and NC4A, respectively, following cyclostratigraphic analyses of four Vocontian Basin records (Martinez *et al*., 2023). Alternatively, slightly different lengths of zones NK3A and NK3B (of 1.46 Myr and 1.9 Myr) have been suggested, based on a floating astrochronological timescale for a separate Vocontian Basin record (Charbonnier *et al*., 2013). Importantly, the Martinez astrochronological timescale has subsequently been anchored to U–Pb radioisotopically determined ages of bentonite layers just above the lower–upper Hauterivian boundary at Agua de la Mula (Neuquén Basin, Argentina). The combined cyclostratigraphic and radioisotopic data give precise dates for the Berriasian–Valanginian boundary (137.06±0.19 Ma), the Valanginian–Hauterivian boundary (131.25±0.19 Ma), and the calcareous nannofossil boundaries, at least in the Vocontian Basin (Martinez *et al*., 2013, 2015, 2023). Here, it is assumed that the dates and durations for Valanginian calcareous nannofossil biozones determined for stratigraphic archives from the Vocontian Basin (from Martinez *et al*., 2023) can also be applied to the relatively nearby proto-Atlantic region.

Unfortunately, a similarly precise cyclostratigraphic age model based on calcareous nannofossil biostratigraphy does not currently exist for the Berriasian Stage, and the ages and durations of the NK2A and NK2B calcareous nannofossil zones are unknown. Consequently, for strata below the base of the NK3A Zone, magnetic chron boundaries are retained as the major stratigraphic constraints, using the updated geomagnetic timescale (Gradstein *et al*., 2020). For Site 603, the M16r–M16n, M16n–M15r, and M15r–M15n chron boundaries are combined with the NK2B–NK3A, NK3A–NK3B, NK3B–NC4A, and NC4B Zone boundaries to form a continuous, robust, timescale for the entire studied interval. The established ages of these stratigraphic horizons are used as anchor points for the studied record, with a constant deposition rate assumed for the sedimentary layers in between (Table S1).

Stratigraphic interval	Base (mbsf)	Top (mbsf)	Thickness (m)	Start (Ma)	End (Ma)	Duration (kyr)	Time by strata (kyr/m)
NC 4A	1486.075	1445.885	40.19	132.00	130.09	1910	47.52
NK 3B	1519.66	1486.075	33.585	134.01	132.00	2010	59.85
NK 3A	1545.465	1519.66	25.805	136.85	134.01	2840	110.06
M15n (below NK3A)	1553.46	1545.465	7.995	138.02	136.85	1170	146.34
M15r	1558.02	1553.46	5.16	138.48	138.02	462	89.53
M16n	1572.055	1558.02	13.435	139.65	138.48	1167	86.86

Table S1: Determined ages, durations, and stratigraphic depths of anchor points used to construct the Berriasian–Valanginian timescale for Site 603.

It has been hypothesized that uppermost Berriasian strata in cores 81–82 at Site 534 feature a hiatus (~1250 mbsf; Sheridan *et al*., 1983a), based on seismic reflectance data. It should be noted that this hiatus has not been clearly detected in the recovered sedimentary material from cores 81–82, likely resulting from the incomplete recovery of core 81. However, the presence of a stratigraphic gap within those strata is consistent with the sharp shift to higher $^{187}Os/^{188}Os_{(i)}$ values recorded between 1251.82 mbsf and 1247.86 mbsf at Site 534, with this jump not documented at Site 603.

The postulated position of the hiatus places it entirely within the NK2B Zone and M15 chron, hindering determination of the amount of unrecorded late Berriasian time at Site 534. However, whilst the position of the M15r–M15n boundary is not precisely constrained, previously published data suggest that it is no higher than 1253.42 mbsf (Ogg, 1987), in which case the hiatus falls within M15n. As the lowest strata that can be identified as part of M15n with some degree of confidence, 1253.42 mbsf is taken as an approximate position of the M15r–M15n boundary (age 138.02 Ma). The rate of sediment deposition is then calculated for M15r using this anchor point and the better defined M16n–M15r boundary at 1263.43 mbsf (138.482 Ma). Extrapolating this sedimentation rate into M15n gives an age of 137.95 Ma for the uppermost sample from below the hiatus (1251.82 mbsf). Determining a sedimentation rate for strata between the hiatus and the NK2B–NK3A boundary is more difficult. If the sedimentation rate calculated for strata immediately below the hiatus is also applied to those directly above it, the lowest sample from above the disconformity (1247.86 mbsf) can be dated to 137.36 Ma. However, if the sedimentation rate determined for NK3A is extrapolated down to the hiatus, 1247.86 mbsf has an age of 137.96 Ma. With no further information available, for each depth the mean age from these two age models is taken for strata between the hiatus and the NK2B–NK3A boundary.

The full set of anchor points and sedimentation rates used to construct the age model for Site 534 are shown in Table S2. However, the assumptions inherent in this age model, and the possible presence of other cryptic hiatuses in Berriasian strata at Site 534 (potentially hinted from the presence of graded sediment layers deposited by distal turbidites; Sheridan *et al*., 1983b), mean that the determined ages for samples deposited below the NK3A Zone at that site should be treated with caution. The upper Berriasian hiatus has not been detected at Site 603, nor is any other disconformity visible, suggesting that the presented age model for that site is more robust.

Stratigraphic interval	Base (mbsf)	Top (mbsf)	Thickness (m)	Start (Ma)	End (Ma)	Duration (kyr)	Time by strata (kyr/m)
NC 4A	1161.315	1123.68	37.635	132.00	130.09	1910	50.75
NK 3B	1208.415	1161.315	47.10	134.01	132.00	2010	42.67
NK 3A	1236.79	1208.415	28.375	136.85	134.01	2840	100.09
NK 2B (above HIATUS)	1247.46	1236.79	10.67	*Sedimentation rate assumed to be the same as NK 3A or M15r*			
M15r	1263.43	*1253.42?*	10.01	138.48	138.02	462	*46.15*
M16n	1269.425	1263.43	5.995	139.65	138.48	1167	194.66
M16r	1276.59	1269.425	7.165	140.19	139.65	537	74.95
M17n	1283.665	1276.59	7.075	140.49	140.19	306	43.25

Table S2: Determined ages, durations, and stratigraphic depths of anchor points used to construct the Berriasian–Valanginian timescale for Site 534.

Despite the assumptions inherent in these timescales (particularly for Berriasian strata), when $\delta^{13}C_{carb}$ and nutrient indicator taxa trends generated by Bornemann and Mutterlose (2008) are plotted against time using these age models, they show excellent comparability. Furthermore, the calculated ages of strata that record the base of the carbon isotope excursion (134.65 Ma and 134.74 Ma for Sites 603 and 534, respectively) are broadly consistent with the most recently determined date for the onset of the Weissert Event based on cylostratigraphic durations of nannofossil zones (134.56±0.19 Ma; Martinez *et al*., 2023). Thus, the timescales used for these sites in this study appear to be reliable, especially for the Valanginian part of the record.

S1-2: Analytical methodology

Seventeen samples from Site 603 and twenty-two from Site 534 were analyzed in this study. Most studied samples consisted of fine-grained laminated calcareous rocks with some organic matter present, plus five very carbonate-rich pale chalks from Site 534 also analyzed. Some strata that fall within or include turbiditic mudstones were also investigated, including the uppermost four samples from Site 603, and it cannot be discounted that other samples had been affected by similar sediment remobilization and transport. However, these thin turbidite layers still likely record a primary seawater osmium-isotope composition, as any remobilization and transport must have taken place on a small scale and over a brief geological time interval, shorter than the residence time of osmium in the ocean (10s kyr; see Peucker-Ehrenbrink and Ravizza, 2000). A previous study of turbiditic sediments across the Ordovician–Silurian boundary at Dobs Linn has highlighted their capacity to faithfully record seawater osmium-isotope trends (Finlay *et al*., 2010). Indeed, for the Cenomanian–Turonian transition, the geologic time interval that has been most studied for osmium isotope trends across the highest number of globally distributed stratigraphic archives, the same overarching trends in $^{187}Os/^{188}Os_{(i)}$ are generally documented. This consistency is irrespective of variability between different sites or within a single record in terms of either their sedimentary facies (e.g., organic-rich shales *vs* calcareous marls or nearshore *vs* distal pelagic sediments) or redox settings (spanning well oxygenated to euxinic) (see e.g., Du Vivier *et al*., 2014, 2015; Jones *et al*., 2021).

Geochemical preparation of the sedimentary rock samples from was performed at Durham University (UK), following digestion and purification procedures adapted from Selby and Creaser (2003) and Cumming *et al*. (2013). Briefly, Re and Os were leached from powdered bulk sedimentary rock samples via Carius-tube digestion with $Cr^{VI}O_3$-H_2SO_4 over 48 hours at 220 °C. Following digestion, Os purification was achieved through solvent extraction by $CHCl_3$ and microdistillation into HBr, whilst Re was purified using NaOH and acetone solvent extraction and anion chromatography. Concentrations and isotopic compositions of Re and Os were determined by isotope dilution and negative thermal ionisation mass spectrometry (N-TIMS) on a ThermoScientific Triton, with in-house standards used to monitor analytical reproducibility (see Nowell *et al*., 2008; and supplementary information in Du Vivier *et al*., 2014, and Sproson *et al*., 2022). Procedural blanks were 11.3±3.8 pg for Re and 0.096±0.081 pg for Os, with a $^{187}Os/^{188}Os$ ratio of 0.206±0.017 (1σ; n = 9). Analytical precision for the lab was monitored through repeated analysis of 50 pg DROsS and 125 pg ReSTD solution standards, which yielded a mean $^{187}Os/^{188}Os$ ratio of 0.16087±0.00014 (1σ; n = 11) and $^{187}Re/^{185}Re$ value of 0.59832±0.00075 (1σ; n = 7) over the course of the study, consistent with long-term running averages of 0.1608±0.0006 (1σ; n = 850) and 0.5986±0.0015 (1σ; n = 740), respectively.

As outlined in the main text, the past seawater Os isotope composition at the time of deposition ($^{187}Os/^{188}Os_{(i)}$) was determined using the estimated age of the sample (see section above on age model construction) and the measured modern-day $^{187}Os/^{188}Os$ and $^{187}Re/^{188}Os$ ratios (Cohen et al., 1999). To calculate the initial sedimentary concentration of osmium at the time of deposition prior to any production of post-depositional radiogenic ^{187}Os (i.e., total Os minus radiogenic ^{187}Os), the $^{187}Os/^{188}Os_{(i)}$ ratios were combined with Os molar abundances, assuming $^{192}Os/^{188}Os$ of 3.08261 (c.f., Percival *et al*., 2021).

S1-3: Calculating the changes in Late Berriasian radiogenic *vs* unradiogenic osmium influx

A basic estimation of the maximum change in input of either radiogenic or unradiogenic osmium to the marine realm (assuming that the other was unchanged) can be made via a simple box model of the global ocean. The residence time of osmium in seawater on the order of 10s kyr allows for this simple approach, with the fractional increase in radiogenic osmium influx to the ocean calculated as follows (Dickson *et al*., 2015; Percival *et al*., 2016):

1. $F_{radiogenic} = ({}^{187}Os/{}^{188}Os_{seawater} - {}^{187}Os/{}^{188}Os_{unradiogenic})/({}^{187}Os/{}^{188}Os_{radiogenic} - {}^{187}Os/{}^{188}Os_{unradiogenic})$

2. $1 = F_{radiogenic} + F_{unradiogenic}$

3. $\Delta F_{radiogenic} = ((F_{unradiogenic\ (pre\text{-}event)}/ F_{unradiogenic\ (event)}) - F_{unradiogenic\ (pre\text{-}event)})/ F_{radiogenic\ (pre\text{-}event)}$

Where $F_{radiogenic}$ and $F_{unradiogenic}$ represent the radiogenic and unradiogenic fractions of the osmium flux to seawater, respectively, and ${}^{187}Os/{}^{188}Os_{seawater}$, ${}^{187}Os/{}^{188}Os_{radiogenic}$, and ${}^{187}Os/{}^{188}Os_{unradiogenic}$ the average isotopic compositions of osmium in seawater (as determined analytically), radiogenic riverine runoff (1.4 today; Peucker-Ehrenbrink and Jahn, 2001) and unradiogenic mantle-derived sources (0.13; Allègre *et al*., 1999).

Pre-Late Berriasian shift:

$${}^{187}Os/{}^{188}Os_{seawater} = 0.56$$
$$\therefore$$
$$F_{radiogenic} = (0.56 - 0.13)/(1.4 - 0.13)$$
$$1 = F_{radiogenic} + F_{unradiogenic}$$
$$\therefore$$
$$F_{radiogenic} = 0.34,\ F_{unradiogenic} = 0.66$$

Post-Late Berriasian shift:

$${}^{187}Os/{}^{188}Os_{seawater} = 0.71$$
$$\therefore$$
$$F_{radiogenic} = (0.71 - 0.13)/(1.4 - 0.13)$$
$$1 = F_{radiogenic} + F_{unradiogenic}$$
$$\therefore$$
$$F_{radiogenic} = 0.46,\ F_{unradiogenic} = 0.54$$

$$\text{Thus, } \Delta F_{radiogenic} = ((0.66/0.54) - 0.66)/0.34$$
$$\therefore$$
$$\Delta F_{radiogenic} = 1.62$$

Assuming that the input of unradiogenic Os was unchanged, runoff of radiogenic Os **increased** by **~62%** during the Latest Berriasian.

Alternatively, if the flux of radiogenic osmium is assumed to have been constant, the change in input of unradiognic osmium required to have caused the documented radiogenic shift in Os isotope compositions can be calculated as follows:

4. $\Delta F_{unradiogenic} = F_{radiogenic\ (pre\text{-}event)}/ ((F_{unradiogenic\ (pre\text{-}event)}/ F_{unradiogenic\ (event)}) - F_{unradiogenic\ (pre\text{-}event)})$

$$\text{Thus, } \Delta F_{unradiogenic} = 0.34/((0.66/0.54) - 0.66)$$
$$\therefore$$
$$\Delta F_{unradiogenic} = 0.62$$

Assuming that the runoff of radiogenic Os was unchanged, input of unradiogenic Os **decreased** by **~38%** during the Latest Berriasian.

S1-4: Calculating the changes in average Valanginian $^{187}Os/^{188}Os$ composition of riverine runoff

Following the Late Berriasian shift to a more radiogenic Os-isotope composition of seawater, it is assumed that global riverine runoff still had an average $^{187}Os/^{188}Os$ composition of 1.4, as is the case today (Peucker-Ehrenbrink and Jahn, 2001). The eruption of Paraná-Etendeka basalts over an area of at least 10^6 km^2 during the Valanginian would have significantly altered the make-up of the Earth's surface crust. Given the relatively unradiogenic composition of Paraná-Etendeka basalts (~0.13; Rocha-Júnior *et al*., 2012), erosion of igneous rocks from that province in place of the continental crust that they had been extruded onto should have resulted in a change in the average $^{187}Os/^{188}Os$ ratio of riverine runoff.

As outlined above, the fluxes of radiogenic osmium from riverine runoff ($^{187}Os/^{188}Os = 1.4$) and unradiogenic Os from mid-ocean ridge activity, submarine basalt alteration, and cosmogenic material ($^{187}Os/^{188}Os = 0.13$) were as follows after the Late Berriasian rise in weathering rates:

$$F_{radiogenic} = 0.46,\ F_{unradiogenic} = 0.54$$

At the point of maximum basalt weathering, the oceanic $^{187}Os/^{188}Os$ ratio decreased to ~0.44. Assuming that the molar flux of osmium to the ocean from riverine runoff and unradiogenic sources did not change, the average riverine $^{187}Os/^{188}Os$ composition can be calculated as follows:

1. $F_{radiogenic} = (^{187}Os/^{188}Os_{seawater} - {}^{187}Os/^{188}Os_{unradiogenic})/(^{187}Os/^{188}Os_{radiogenic} - {}^{187}Os/^{188}Os_{unradiogenic})$

$$^{187}Os/^{188}Os_{seawater} = 0.44$$
$$\therefore$$
$$0.46 = (0.44 - 0.13)/(^{187}Os/^{188}Os_{radiogenic} - 0.13)$$

$$\text{Thus, } ^{187}Os/^{188}Os_{radiogenic} = ((0.44 - 0.13)/0.46) + 0.13$$
$$\therefore$$
$$\mathbf{^{187}Os/^{188}Os_{radiogenic} = 0.81}$$

Appendix S2-2: Age-depth model for DSDP Site 603 and DSDP Site 534

DSDP Site 603 B – Lower contiental rise off Cape Hatteras

Nannofossil Zone boundary	Depth (mbsf)	Age (Ma)	Magnetic chron boundary	Notes
4A–4B	1445.885	130.09		
	1446	130.10		
	1447	130.14		
	1448	130.19		
	1449	130.24		
	1450	130.29		
	1451	130.33		
	1452	130.38		
	1453	130.43		
	1454	130.48		
	1455	130.52		
	1456	130.57		
	1457	130.62		
	1458	130.67		
	1459	130.71		
	1460	130.76		
	1461	130.81		
	1462	130.86		
	1463	130.90		
	1464	130.95		
	1465	131.00		
	1466	131.05		
	1467	131.09		
	1468	131.14		
	1469	131.19		
	1470	131.24		
	1471	131.28		
	1472	131.33		
	1473	131.38		
	1474	131.43		
	1475	131.47		
	1476	131.52		
	1477	131.57		
	1478	131.62		
	1479	131.66		
	1480	131.71		
	1481	131.76		
	1482	131.81		
	1483	131.85		
	1484	131.90		
	1485	131.95		
	1486	132.00		
3B–4A	1486.075	132.00		
	1487	132.06		
	1488	132.12		
	1489	132.18		
	1490	132.23		
	1491	132.29		
	1492	132.35		
	1493	132.41		
	1494	132.47		
	1495	132.53		
	1496	132.59		
	1497	132.65		
	1498	132.71		
	1499	132.77		
	1500	132.83		
	1501	132.89		
	1502	132.95		
	1503	133.01		
	1504	133.07		
	1505	133.13		
	1506	133.19		
	1507	133.25		
	1508	133.31		
	1509	133.37		
	1510	133.43		
	1511	133.49		
	1512	133.55		
	1513	133.61		
	1514	133.67		
	1515	133.73		
	1516	133.79		
	1517	133.85		
	1518	133.91		
	1519	133.97		
3A–3B	1519.66	134.01		
	1520	134.05		
	1521	134.16		
	1522	134.27		
	1523	134.38		
	1524	134.49		
	1525	134.60		
base CIE	1525.5	134.65		base CIE (134.56±0.19; Martinez et al., 2023)
	1526	134.71		
	1527	134.82		
	1528	134.93		
	1529	135.04		
	1530	135.15		
	1531	135.26		
	1532	135.37		
	1533	135.48		
	1534	135.59		
	1535	135.70		
	1536	135.81		
	1537	135.92		
	1538	136.03		
	1539	136.14		
	1540	136.25		
	1541	136.36		
	1542	136.47		
	1543	136.58		
	1544	136.69		
	1545	136.80		
2B–3A	1545.465	136.85		
	1546	136.93		
	1547	137.07		
	1548	137.22		
	1549	137.37		
	1550	137.51		
	1551	137.66		
	1552	137.81		
	1553	137.95		
	1553.46	138.020	M15r–M15n	
	1554	138.04		
	1555	138.16		
	1556	138.22		
	1557	138.34		
	1558	138.40		
	1558.62	138.482	M16n–M15r	
	1559	138.52		
	1560	138.60		
	1561	138.69		
	1562	138.78		
	1563	138.86		
	1564	138.95		
	1565	139.04		
	1566	139.12		
	1567	139.21		
	1568	139.30		
	1569	139.38		
	1570	139.47		
	1571	139.56		
	1572.055	139.649	M16r–M16n	

DSDP Site 534 A – Blake Bahama Basin

Nannofossil Zone boundary	Depth (mbsf)	Age (Ma)	Magnetic chron boundary	Notes
4A–4B	1123.68	130.09		
	1124	130.11		
	1125	130.16		
	1126	130.21		
	1127	130.26		
	1128	130.31		
	1129	130.36		
	1130	130.41		
	1131	130.46		
	1132	130.51		
	1133	130.56		
	1134	130.61		
	1135	130.66		
	1136	130.72		
	1137	130.77		
	1138	130.82		
	1139	130.87		
	1140	130.92		
	1141	130.97		
	1142	131.02		
	1143	131.07		
	1144	131.12		
	1145	131.17		
	1146	131.22		
	1147	131.27		
	1148	131.32		
	1149	131.38		
	1150	131.43		
	1151	131.48		
	1152	131.53		
	1153	131.58		
	1154	131.63		
	1155	131.68		
	1156	131.73		
	1157	131.78		
	1158	131.83		
	1159	131.88		
	1160	131.93		
	1161	131.98		
3B–4A	1161.315	132		
	1162	132.03		
	1163	132.07		
	1164	132.11		
	1165	132.16		
	1166	132.20		
	1167	132.24		
	1168	132.29		
	1169	132.33		
	1170	132.37		
	1171	132.41		
	1172	132.46		
	1173	132.50		
	1174	132.54		
	1175	132.58		
	1176	132.63		
	1177	132.67		
	1178	132.71		
	1179	132.75		
	1180	132.80		
	1181	132.84		
	1182	132.88		
	1183	132.93		
	1184	132.97		
	1185	133.01		
	1186	133.05		
	1187	133.10		
	1188	133.14		
	1189	133.18		
	1190	133.22		
	1191	133.27		
	1192	133.31		
	1193	133.35		
	1194	133.39		
	1195	133.44		
	1196	133.48		
	1197	133.52		
	1198	133.57		
	1199	133.61		
	1200	133.65		
	1201	133.69		
	1202	133.74		
	1203	133.78		
	1204	133.82		
	1205	133.86		
	1206	133.91		
	1207	133.95		
	1208	133.99		
3A–3B	1208.415	134.01		
	1209	134.07		
	1210	134.17		
	1211	134.27		
	1212	134.37		
	1213	134.47		
	1214	134.57		
	1215	134.67		
	1215.69	134.74		base CIE (134.56±0.19; Martinez et al., 2023)
	1216	134.77		
	1217	134.87		
	1218	134.97		
	1219	135.07		
	1220	135.17		
	1221	135.27		
	1222	135.37		
	1223	135.47		
	1224	135.57		
	1225	135.67		
	1226	135.77		
	1227	135.87		
	1228	135.97		
	1229	136.07		
	1230	136.17		
	1231	136.27		
	1232	136.37		
	1233	136.47		
	1234	136.57		
	1235	136.67		
	1236	136.77		
2B–3A	1236.79	136.85		
	1237	136.87		between 136.86–136.87 Ma
	1238	136.94		between 136.91–137.97 Ma
	1239	137.01		between 137.95–137.07 Ma
	1240	137.08		between 137.00–137.17 Ma
	1241	137.16		between 137.04–137.27 Ma
	1242	137.23		between 137.09–137.37 Ma
	1243	137.30		between 137.14–137.47 Ma
	1244	137.38		between 137.18–137.57 Ma
	1245	137.45		between 137.23–137.67 Ma
	1246	137.52		between 137.28–137.77 Ma
	1247	137.60		between 137.32–137.87 Ma
	1247.86	137.66		between 137.36–137.96 Ma
			HIATUS	
	1251.82	137.95		
	1252	137.95		
	1253	138.00		
	1253.42	138.02	lowest clear M15n	
	1254	138.05		
	1255	138.09		
	1256	138.14		
	1257	138.19		
	1258	138.23		
	1259	138.28		
	1260	138.32		
	1261	138.37		
	1262	138.42		
	1263	138.46		
	1263.43	138.482	M16n–M15r	
	1264	138.59		
	1265	138.79		
	1266	138.98		
	1267	139.18		
	1268	139.37		
	1269	139.57		
	1269.425	139.649	M16r–M16n	
	1270	139.69		
	1271	139.77		
	1272	139.84		
	1273	139.92		
	1274	139.99		
	1275	140.07		
	1276	140.14		
	1276.59	140.186	M17n–M16r	
	1277	140.20		
	1278	140.25		
	1279	140.29		
	1280	140.33		
	1281	140.38		
	1282	140.42		
	1283	140.46		
	1283.665	140.492	M17r–M17n	

References:

Aguirre-Urreta, M.B., Pazos, P.J., Lazo, D.G., Fanning, C.M. and Litvak, V.D., 2008, First U–Pb SHRIMP age of the Hauterivian stage, Neuquén Basin, Argentina: Journal of South American Earth Sciences, v. 26, p. 91–99, https://doi.org/10.1016/j.jsames.2008.01.001.

Aguirre-Urreta, B., Lescano, M., Schmitz, M.D., Tunik, M., Concheyro, A., Rawson, P.F. and Ramos, V.A., 2015, Filling the gap: new precise Early Cretaceous radioisotopic ages from the Andes: Geological Magazine, v. 152, p. 557–564, https://doi.org/10.1017/S001675681400082X.

Aguirre-Urreta, B., Schmitz, M., Lescano, M., Tunik, M., Rawson, P.F., Concheyro, A., Buhler, M. and Ramos, V.A., 2017, A high precision U–Pb radioisotopic age for the Agrio Formation, Neuquén Basin, Argentina: Implications for the chronology of the Hauterivian Stage. Cretaceous Research, 75, p. 193–204, https://doi.org/10.1016/j.cretres.2017.03.027.

Allègre, C.J., Birck, J.L., Capmas, F. and Courtillot, V., 1999, Age of the Deccan traps using ^{187}Re–^{187}Os systematics: Earth and Planetary Science Letters, v. 170, p. 197–204, https://doi.org/10.1016/S0012-821X(99)00110-7.

Bergen, J.A., 1994, Berriasian to early Aptian calcareous nannofossils from the Vocontian Trough (SE France) and Deep Sea Drilling Site 534: new nannofossil taxa and a summary of low-latitude biostratigraphic events: Journal of Nannoplankton Research, v. 16, p. 59–69.

Bornemann, A. and Mutterlose, J., 2008, Calcareous nannofossil and δ13C records from the Early Cretaceous of the Western Atlantic Ocean: evidence for enhanced fertilization across the Berriasian–Valanginian transition: Palaios, v. 23, p. 821–832, https://doi.org/10.2110/palo.2007.p07-076r.

Charbonnier, G., Boulila, S., Gardin, S., Duchamp-Alphonse, S., Adatte, T., Spangenberg, J.E., Föllmi, K.B., Colin, C. and Galbrun, B., 2013, Astronomical calibration of the Valanginian "Weissert" episode: the Orpierre marl–limestone succession (Vocontian Basin, southeastern France): Cretaceous Research, v. 45, p. 25–42, https://doi.org/10.1016/j.cretres.2013.07.003.

Cohen, A.S., Coe, A.L., Bartlett, J.M. and Hawkesworth, C.J., 1999, Precise Re-Os ages of organic-rich mudrocks and the Os isotope composition of Jurassic seawater: Earth and Planetary Science Letters, v. 167, p. 159–173, https://doi.org/10.1016/S0012-821(99)00026-6.

Covington, J.M. and Wise, S.W., 1987, Calcareous nannofossil biostratigraphy of a lower Cretaceous deep-sea fan complex: Deep Sea Drilling Project Leg 93 Site 603, lower continental rise off Cape Hatteras, USA, *in* van Hinte, J.E., Wise, S.W. Jr. et al., Initial Reports of the Deep Sea Drilling Project, Volume 93: Washington, D.C., U.S. Government Printing Office, p. 617–660.

Cumming, V.M., Poulton, S.W., Rooney, A.D. and Selby, D., 2013, Anoxia in the terrestrial environment during the late Mesoproterozoic: Geology, v. 41, p. 583–586, https://doi.org/10.1130/G34299.1.

Dickson, A.J., Cohen, A.S., Coe, A.L., Davies, M., Shcherbinina, E.A. and Gavrilov, Y.O., 2015, Evidence for weathering and volcanism during the PETM from Arctic and Peri-Tethys osmium isotope records: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 438, p. 300–307, https://doi.org/10.1016/j.palaeo.2015.08.019.

Du Vivier, A.D., Selby, D., Sageman, B.B., Jarvis, I., Gröcke, D.R. and Voigt, S., 2014, Marine $^{187}Os/^{188}Os$ isotope stratigraphy reveals the interaction of volcanism and ocean circulation during Oceanic Anoxic Event 2: Earth and Planetary Science Letters, v. 389, p. 23–33, https://doi.org/10.1016/j.epsl.2013.12.024.

Du Vivier, A.D.C., Selby, D., Condon, D.J., Takashima, R. and Nishi, H., 2015, Pacific $^{187}Os/^{188}Os$ isotope chemistry and U–Pb geochronology: Synchroneity of global Os isotope change across OAE 2: Earth and Planetary Science Letters, v. 428, p. 204–216, https://doi.org/10.1016/j.epsl.2015.07.020.

Finlay, A.J., Selby, D. and Gröcke, D.R., 2010, Tracking the Hirnantian glaciation using Os isotopes. Earth and Planetary Science Letters, 293, p. 339–348, https://doi.org/10.1016/j.epsl.2010.02.049.

Gradstein, F.M., Ogg, J.G. and Smith, A., 2004, A Geological Time Scale 2004: Cambridge, UK, Cambridge University Press.

Gradstein, F.M., Ogg, J.G., Schmitz, M.D. and Ogg, G.M., 2020, Geological Time Scale 2020: Amsterdam, Netherlands, Elsevier.

Jones, M.M., Sageman, B.B., Selby, D., Jicha, B.R., Singer, B.S. and Titus, A.L., 2021, Regional chronostratigraphic synthesis of the Cenomanian-Turonian oceanic anoxic event 2 (OAE2) interval, Western Interior Basin (USA): New Re-Os chemostratigraphy and $^{40}Ar/^{39}Ar$ geochronology: GSA Bulletin, v. 133, p. 1090–1104, https://doi.org/10.1130/B35594.1.

Littler, K., Robinson, S.A., Bown, P.R., Nederbragt, A.J. and Pancost, R.D., 2011, High sea-surface temperatures during the Early Cretaceous Epoch: Nature Geoscience, v. 4, p. 169–172, https://doi.org/10.1038/ngeo1081.

Martinez, M., Deconinck, J.F., Pellenard, P., Reboulet, S. and Riquier, L., 2013, Astrochronology of the Valanginian Stage from reference sections (Vocontian Basin, France) and palaeoenvironmental implications for the Weissert Event: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 376, p. 91–102, https://doi.org/10.1016/j.palaeo.2013.02.021.

Martinez, M., Deconinck, J.F., Pellenard, P., Riquier, L., Company, M., Reboulet, S. and Moiroud, M., 2015, Astrochronology of the Valanginian–Hauterivian stages (Early Cretaceous): Chronological relationships between the Paraná–Etendeka large igneous province and the Weissert and the Faraoni events: Global and Planetary Change, v. 131, p. 158–173, https://doi.org/10.1016/j.gloplacha.2015.06.001.

Martinez, M., Aguirre-Urreta, B., Dera, G., Lescano, M., Omarini, J., Tunik, M., O'Dogherty, L., Aguado, R., Company, M. and Bodin, S., 2023, Synchrony of carbon cycle fluctuations, volcanism and orbital forcing during the Early Cretaceous. Earth-Science Reviews, 104356, https://doi.org/10.1016/j.earscirev.2023.104356.

Nowell, G.M., Luguet, A., Pearson, D.G. and Horstwood, M.S.A., 2008, Precise and accurate $^{186}Os/^{188}Os$ and $^{187}Os/^{188}Os$ measurements by multi-collector plasma ionisation mass spectrometry (MC-ICP-MS) part I: Solution analyses: Chemical Geology, v. 248, p. 363–393, https://doi.org/10.1016/j.chemgeo.2007.10.020.

Ogg, J.G., 1987, Early Cretaceous magnetic polarity time scale and the magnetostratigraphy of Deep Sea Drilling Project sites 603 and 534, western central Atlantic, *in* van Hinte, J.E., Wise, S.W. Jr. et al., Initial Reports of the Deep Sea Drilling Project, Volume 93: Washington, D.C., U.S. Government Printing Office, p.849–879.

Percival, L.M.E., Cohen, A.S., Davies, M.K., Dickson, A.J., Hesselbo, S.P., Jenkyns, H.C., Leng, M.J., Mather, T.A., Storm, M.S. and Xu, W., 2016, Osmium isotope evidence for two pulses of increased continental weathering linked to Early Jurassic volcanism and climate change: Geology, v. 44, p. 759–762, https://doi.org/10.1130/G37997.1.

Percival, L.M.E., Tedeschi, L.R., Creaser, R.A., Bottini, C., Erba, E., Giraud, F., Svensen, H., Savian, J., Trindade, R., Coccioni, R. and Frontalini, F., 2021b, Determining the style and provenance of magmatic activity during the Early Aptian Oceanic Anoxic Event (OAE 1a): Global and Planetary Change, v. 200, 103461, https://doi.org/10.1016/j.gloplacha.2021.103461.

Peucker-Ehrenbrink, B. and Jahn, B.M., 2001, Rhenium-osmium isotope systematics and platinum group element concentrations: Loess and the upper continental crust: Geochemistry, Geophysics, Geosystems, v. 2, 2001GC000172, https://doi.org/10.1029/2001GC000172.

Rocha-Júnior, E.R., Puchtel, I.S., Marques, L.S., Walker, R.J., Machado, F.B., Nardy, A.J., Babinski, M. and Figueiredo, A.M., 2012, Re–Os isotope and highly siderophile element systematics of the Paraná continental flood basalts (Brazil): Earth and Planetary Science Letters, v. 337, p. 164–173, https://doi.org/10.1016/j.epsl.2012.04.050.

Selby, D. and Creaser, R.A., 2003, Re–Os geochronology of organic rich sediments: an evaluation of organic matter analysis methods: Chemical Geology, v. 200, p. 225–240, https://doi.org/10.1016/S0009-2541(03)00199-2.

Sheridan, R.E., Bates, L.G., Shipley, T.H. and Crosby, J.T., 1983a, Seismic stratigraphy in the Blake-Bahama Basin and the Origin of Horizon D, *in* Sheridan, R.E., Gradstein, F.M. et al., Initial Reports of the Deep Sea Drilling Project, Volume 76: Washington, D.C., U.S. Government Printing Office, p. 667–683.

Sheridan, R.E. *et al*., 1983b, Site 534: Blake-Bahama Basin, *in* Sheridan, R.E., Gradstein, F.M. et al., Initial Reports of the Deep Sea Drilling Project, Volume 76: Washington, D.C., U.S. Government Printing Office, p. 141–340.

Smoliar, M.I., Walker, R.J. and Morgan, J.W., 1996, Re-Os ages of group IIA, IIIA, IVA, and IVB iron meteorites: Science, v. 271, p. 1099–1102, https://doi.org/10.1126/science.271.5252.1099.

Sproson, A.D., Pogge von Strandmann, P.A.E., Selby, D., Jarochowska, E., Frýda, J., Hladil, J., Loydell, D.K., Slavík, L., Calner, M., Maier, G., Munnecke, A. and Lenton, T.M., 2022, Osmium and lithium isotope evidence for weathering feedbacks linked to orbitally paced organic carbon burial and Silurian glaciations: Earth and Planetary Science Letters, v. 577, 117260, https://doi.org/10.1016/j.epsl.2021.117260.

van Hinte, J.E. *et al*., 1987, Site 603, *in* van Hinte, J.E., Wise, S.W. Jr. et al., Initial Reports of the Deep Sea Drilling Project, Volume 93: Washington, D.C., U.S. Government Printing Office, p. 25–276.