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Supplementary Data. 1. Floral details at Gran Barranca, Argentina and humidity considerations.

The phytolith record from 39 to ~30 Ma (Mazzoni, 1979) demonstrates the continued coexistence of palms and grasses (i.e., most likely a palm savanna). Prior to the Eocene-Oligocene transition, at ~38-39 Ma, there was an increase in grass phytolith morphotypes and a decrease in palms at Gran Barranca, perhaps reflecting minor cooling and/or drying before the Eocene-Oligocene transition. This hypothesis has some support from the disappearance of nuxolite phytoliths (indicative of aquatic herbs) post 38 Ma. However, across the Eocene-Oligocene transition, palms continue to be present, and proportions of panicoid to festucoid-pooid grasses are essentially constant. This floral constancy implies similar climatic conditions both before and after the transition.

An important element in our interpretations is constancy of mean annual relative humidity. This interpretation partly derives from the persistence of palm savannas across the transition. Today, palm savannas principally occur only where temperature is high, and water is seasonally abundant (Jones, 1995). The African savannas, which can have a comparatively low relative humidity, are commonly considered typical. However, the African savannas cannot be usefully compared with Gran Barranca, because they are generally much farther inland, and occur at much lower latitudes and higher elevations. More relevant examples include parts of the southeastern US and the Pampas of northeastern Argentina, parts of which have palm savannas. These areas uniformly have mean annual relative humidities of 70-75%. In addition, Gran Barranca was a narrow peninsula with low topography, and we argue that relative humidity would be buffered by marine proximity. Peninsular Florida may be the best analogue; it has palm savannas, and a uniform, mean annual relative humidity of 73.1±1.4%. Comparison to other peninsulas or large islands is compromised in most modern settings by high topography, but low elevation sites in the Iberian peninsula, New Zealand, Japan, the Korean peninsula, South Africa, and Italy also suggest mean annual relative humidities of 70-75% (although these areas do not all have palm savannas). Many of these sites are directly adjacent to the ocean, and we assume that because Gran Barranca was interior to the peninsula, it would likely have had a relative humidity towards the lower end of the range, i.e., around 70%. Regardless, a change in mean annual relative humidity greater than ~5% seems unlikely. In fact, cooler modern peninsulas and large islands at higher latitudes (e.g., Nova Scotia, Newfoundland, England) have *higher* relative humidities (up to 80%). If cooling did occur across the Eocene-Oligocene transition at Gran Barranca, one might predict mean annual relative humidity to go up, decreasing the ^{18}O of tooth enamel.

Compilation of relative humidities in mid-latitude areas possibly comparable climatically to Gran Barranca.

Region	Southeast US	Northeast Argentina	Iberian Peninsula	New Zealand	Japan/Korea	South Africa	Italy
Relative Humidity	71%	75%	70%	72%	72%	72%	70%

Data sources: NOAA (2004); Pearce and Smith (1984)

References:

Jones, D.L., 1995, Palms throughout the world: Washington, D. C., Smithsonian Institution Press, 410 p.

NOAA, 2004, Comparative Climatic Data Publication - Relative Humidity: http://www1.ncdc.noaa.gov/pub/data/ccd-data/RELHUM.DAT.

Pearce, E.A., and Smith, C.G., 1984, The Times Books world weather guide: New York, Times Books, 480 p.

Supplementary Data. 2. Isotope compositions of modern precipitation in southern South America, from the IAEA, and statistics of linear regressions of ^{18}O vs. temperature and rainfall amount.

Coyhaique (45.35 ˚S)

Month	^{18}O	Temp	Amt.
January	-9.96	9.4	41
February	-9.84	9.2	46
March	-10.59	7.8	53
April	-11.86	5.6	55
May	-11.74	3.3	51
June	-11.74	1.8	46
July	-11.76	1.5	38
August	-12.36	2.2	41
September	-11.93	4.1	40
October	-10.82	6.0	35
November	-10.03	7.7	32
December	-10.15	9.0	42
Slope		0.58	-0.04
Error		0.07	0.01
r^2		0.86	0.46

Bariloche (41.15 ˚S)

Month	^{18}O	Temp	Amt.
January	-7.43	13.7	20.4
February	-9.43	14.3	31.7
March	-9.90	12.5	28.6
April	-11.23	7.9	82.0
May	-14.50	5.3	70.1
June	-14.00	2.1	98.4
July	-12.47	3.1	110.7
August	-11.90	3.9	103.2
September	-13.85	5.2	30.8
October	-8.78	8.5	20.7
November	-10.43	10.6	37.1
December	-10.33	13.8	25.6
Slope		0.40	-0.04
Error		0.09	0.02
r^2		0.66	0.40

Puerto Montt (41.17 ˚S)

Month	^{18}O	Temp	Amt.
January	-3.68	14.3	83.0
February	-5.38	13.6	90.0
March	-5.05	12.1	90.0
April	-6.39	10.1	127.0
May	-8.29	8.8	214.0
June	-7.81	6.7	205.0
July	-7.80	6.6	239.0
August	-8.03	6.8	200.0
September	-7.27	7.8	140.0
October	-6.29	9.6	121.0
November	-4.68	11.6	107.0
December	-3.52	13.4	100.0
Slope		0.55	-0.03
Error		0.07	0.00
r^2		0.85	0.78

Ushaia (54.78 ˚S)

Month	^{18}O	Temp	Amt.
January	-9.96	9.4	41
February	-9.84	9.2	46
March	-10.59	7.8	53
April	-11.86	5.6	55
May	-11.74	3.3	51
June	-11.74	1.8	46
July	-11.76	1.5	38
August	-12.36	2.2	41
September	-11.93	4.1	40
October	-10.82	6.0	35
November	-10.03	7.7	32
December	-10.15	9.0	42
Slope		0.28	-0.03
Error		0.04	0.04
r^2		0.83	0.05

Note: ^{18}O is the weighted mean value for all months measured; Temp is mean monthly temperature in ˚C, Amt is mean monthly precipitation amount in mm, Slope, Error, and r^2 are the slope (‰/˚C and ‰/mm), 1 uncertainty, and r^2 of linear regressions of ^{18}O vs. temperature and rainfall amount. The latitude of our study (46 ˚S) is closest to Coyhaique, but we show data for stations to the north and south to illustrate that Coyhaique is not anomalous. Farther north, there is a correlation between rainfall amount and mean monthly temperature because of precipitation seasonality, but this is distinct from areas that show an “amount effect” to isotope compositions, in which ^{18}O is correlated with rainfall amount, but temperature variations are minimal. As described by Kohn and Welker (2003), use of mean monthly temperatures rather than temperatures during actual rainfall events underestimates temperature coefficients, so regressed values are minima.

Kohn, M.J., and Welker, J.M., 2003, A new perspective on the temperature-dependence of stable isotopes in modern precipitation: EOS, v. 84, p. F283-284.

Supplementary Data. 3. Sampling and analytical techniques.

Sampling and analytical techniques are described in detail in Kohn et al. (2002). Briefly, a 2-5 mm-wide strip of enamel was cut lengthwise from each tooth and sectioned every 1-2 mm along the length. Sampling the entire thickness of enamel likely integrates 1-2 months' time required for the outward growth and maturation of enamel (Kohn and Cerling, 2002). Adhering dentine was removed using a dental drill. Every third sample (i.e., approximately every 5 mm) was dissolved in HF. This caused precipitation of CaF_2, which was discarded. Ag_3PO_4 was then precipitated from the remaining solution and analyzed for ^{18}O (O'Neil et al., 1994; Dettmann et al., 2001). This chemical processing isolates the PO_4 component for analysis, which minimizes potential diagenetic alteration (see discussion in Kohn and Cerling, 2002). Sample sizes were 5-10 mg, and reproducibility was ~±0.3‰ (±1). Raw compositions were corrected for accuracy (Vennemann et al., 2002), based on intralaboratory standards, as well as the international phosphate standard NIST-120c.

References:

Dettman, D.L., Kohn, M. J., Quade, J., Ryerson, F.J., Ojha, T.P., Hamidullah, S., 2001, Seasonal stable isotope evidence for a strong Asian monsoon throughout the past 10.7 m.y.: Geology, v. 29, p. 31-34.

Kohn, M.J., and Cerling, T.E., 2002, Stable Isotopes of biological apatite. Reviews in Mineralogy, v. 48, 455-488.

Kohn, M. J., Miselis, J. L. & Fremd, T. J., 2002, Oxygen isotope evidence for progressive uplift of the Cascade Range, Oregon. Earth and Planetary Science Letters, v. 204, 151-165.

O'Neil, J.R., Roe, L.J., Reinhard, E., Blake, R.E., 1994, A rapid and precise method of oxygen isotope analysis of biogenic phosphate: Israel Journal of Earth Sciences, v. 43, p. 203-212.

Vennemann, T.W., Fricke, H.C., Blake, R.E., O'Neil, J.R., Colman, A. ,2002, Oxygen isotope analysis of phosphates: a comparison of techniques for analysis of Ag_3PO_4: Chemical Geology,v. 185, p. 321-336.

Supplementary Data. 4. Tooth ^{18}O compositions of fossil Notoungulate teeth from Gran Barranca, Argentina.

Age: Barrancan, 39.3±0.5 Ma

Sample	Distance	^{18}O	Sample	Distance	^{18}O	Sample	Distance	^{18}O
99-268a	0.5	15.97	99-268j	12.5	16.22	99-269a	1.25	14.78
99-268d	4.75	15.31	99-268m	16.5	16.64	99-269f	11.0	15.37
99-268g	8.25	16.06				99-269i	15.5	11.13
						AVERAGE		15.19

99-268 = Isotemnidae; 99-269 = Isotemnidae (?)

Age: Upper Barrancan/Lower Mustersan, 38.0±0.1 Ma

Sample	Distance	^{18}O	Sample	Distance	^{18}O	Sample	Distance	^{18}O
99-117#1a	0.5	16.19	99-117#2l	20.5	16.69	01-500#2a	0.5	16.04
99-117#1d	4.5	16.44	99-117#2o	27.0	16.60	01-500#2k	18.0	14.68
99-117#1g	8.0	16.54				01-504f	10.0	16.38
99-117#1j	12.5	16.04	01-500#1c	4.25	14.55	01-504j	16.75	14.54
99-117#2a	0.75	16.95	01-500#1e	8.0	14.66	01-504l	20.25	15.93
99-117#2a	3.75	18.25	01-500#1g	12.25	13.74	01-504p	28.0	15.52
99-117#2g	11.25	17.30	01-500#1i	15.75	14.88	01-504r	32.0	15.86
99-117#2j	17.0	16.88				01-504y	36.0	15.52
						AVERAGE		15.94

99-117 = Isotemnidae (?), 01-500 = Notoungulate, 01-504 = Isotemnidae or Leontiniidae

Age: Upper Mustersan, 33.3±0.2 Ma

Sample	Distance	^{18}O	Sample	Distance	^{18}O	Sample	Distance	^{18}O
99-020a	0.5	18.02	01-313#1a	30.0	15.37	01-420#2l	14.0	16.48
99-020d	4.5	18.53	01-313#1d	26.75	14.67	01-420#2o	8.0	16.71
99-020g	8.25	18.35	01-313#1m	9.25	13.02	01-544#1a	36.5	16.61
99-020j	12.0	18.04	01-313#1p	3.5	13.20	01-544#1g	25.0	15.83
99-020m/n	16.0	17.76	01-313#2b	25.5	14.88	01-544#1h	23.0	16.88
99-031a	1.0	16.35	01-313#2e	19.75	16.98	01-544#1n	10.5	16.66
99-031d	5.25	16.89	01-313#2e	19.75	16.83	01-544#1p	6.5	16.47
99-031g	9.25	17.84	01-313#2k	8.5	17.36	01-544#2b	20.0	15.97
99-031j	12.5	16.37	01-313#2n	2.5	16.44	01-544#2e	15.0	16.61
99-031m	16.25	17.27	01-420#1d	40.0	16.78	01-544#2h	9.0	15.86
99-031p	20.5	18.34	01-420#1g	33.0	17.09	01-544#2k	3.0	16.18
99-031s	25.0	16.25	01-420#1j	27.0	15.72			
99-031v	28.75	16.95	01-420#1m	21.5	16.49			
99-031y	33.5	16.91	01-420#1p	16.0	16.01			
			01-420#1s	10.0	15.67			
						AVERAGE		16.48

99-020 = Archeohyracidae, 99-031 = Isotemnidae (?), 01-313, 01-420, 01-544 = Notoungulate

Age: Deseadan, 30.2±0.8 Ma

Sample	Distance	^{18}O	Sample	Distance	^{18}O	Sample	Distance	^{18}O
99-107a	1	17.36	99-107j	13.5	15.42	99-106e	19.0	15.29
99-107d	5.5	16.22	99-107m	18.25	16.29	99-106h	13.0	16.98
99-107g	9.5	17.08	00-292#2g	12.75	17.31	99-106n	1.5	14.51
						AVERAGE		16.57

99-107 = Notoungulata, 99-106 = Leontiniidae

Note: Distances are in mm from occlusal surface (wear surface) of each tooth. Values for ^{18}O are in ‰, relative to V-SMOW. Samples with a #1 or #2 designation are from composites – these different teeth may have come from 1 individual, or from different individuals.

Supplementary Data. 5. Model and interpretation details

The ^{18}O of tooth enamel generally depends on 3 factors – meteoric water composition, the composition of atmospheric O_2, and relative humidity. The two coefficients we have assumed, based on modern isotope systematics, are the dependencies on relative humidity (-0.15‰/%) and on meteoric water composition (0.85‰/‰). This yields the full isotope model:

$$^{18}O(PO_4) = 0.85\ ^{18}O(MW) - 0.15‰/\% \cdot r.h. + 0.15\ ^{18}O(O_2, air) + constant.$$

where MW is meteoric water, and the constant is a taxon specific value (which we argue must be similar for all taxa studied). In differential form, changes of isotope composition are given by:

$$^{18}O(PO_4) = 0.85\ ^{18}O(MW) - 0.15‰/\% \cdot\ r.h. + 0.15\ ^{18}O(O_2, air).$$

We assume that:

$$^{18}O(MW) \sim\ ^{18}O(SW) + 0.3‰/^{\circ}C \cdot\ T$$

and

$$^{18}O(O_2, air) \sim\ ^{18}O(SW)$$

where SW refers to seawater. Both MW and air O_2 depend directly on seawater ^{18}O because of coupling between hydrologic reservoirs and atmospheric gases that contain oxygen (e.g., Bender et al., 1985). Combining terms yields:

$$^{18}O(PO_4) =\ ^{18}O(SW) - 0.15‰/\% \cdot\ r.h. + 0.3‰/^{\circ}C \cdot\ T$$

Changes in the ^{18}O of seawater due to changes in ice volume attending EOT cooling would therefore contribute a 1:1 shift to tooth ^{18}O, whereas changes resulting from relative humidity and temperature changes have contributions as described in the text.

References:

Bender, M., Labeyrie, L.D., Raynaud, D., and Lorius, C., 1985, Isotopic composition of atmospheric O2 in ice linked with deglaciation and global primary productivity: Nature, v. 318, p. 349-352.