Supplement of Clim. Past, 16, 1509–1521, 2020
https://doi.org/10.5194/cp-16-1509-2020-supplement

Climate of the Past
Open Access
EGU

Supplement of

Elevated CO_2, increased leaf-level productivity, and water-use efficiency during the early Miocene

Tammo Reichgelt et al.

Correspondence to: Tammo Reichgelt (tammo.reichgelt@uconn.edu)

- Section S1: Morphotype Identification
- Figure S1: Examples of cuticles of morphotypes A–K
- Figure S2: Examples of cuticles of morphotypes L–V
- Figure S3: Relative Humidity and Vapor Pressure Deficit of Foulden Maar in comparison to modern day New Zealand.
- Table S1: Measurements of stomatal density, pore length, guard cell width, leaf and air carobn isotopic composition of fossil leaves from Foulden Maar.
- Table S2: Assimilation rate range of modern living relatives.
- Table S3: Intrinsic water use efficiency, conductance to water, total annual carbon gain and length of the growing season.
- Table S4: Output of reconstructed atmospheric carbon dioxide, carbon assimilation rates, leaf conductance to water, and intrinsic water use efficiency of Foulden Maar fossil leaves.
- References for morphotype identification.

Morphotype identification

18 distinct leaf morphotypes were identified based on microscopic anatomical features. Some leaf types were assigned to previously described species from surface exposures at Foulden Maar, others were tentatively assigned genera or families. Below are the leaf fossils assigned to different morphotypes, together with defining anatomical characteristics and justification of assignment to a specific plant group.

Morphotype: A.
Samples: (25) 9-09-50-1, 14-02-40-5, 17-91-70-1, 17-91-70-5, 17-91-70-7, 17-91-70-8, 18-19-99-1, 31-19-10-1, 31-19-20-3, 31-19-20-4, 32-20-30-1, 32-20-60-1, 38-97-90-10, 40-93-80-4, 41-88-12-1, 41-88-28-4, 41-88-28-7, 42-85-0-2, 56-31-20-1, 62-19-2-1, 63-19-95-3, 83-48-86-2 (Fig. S1a), 84-43-68-1, 84-43-68-4, and 101-4-16-2.
Distinguishing anatomical features of the abaxial cuticle: Anticlinal walls straight or curved, granulate periclinal cells, stomata with conspicuous polar rods and peristomatal ring. Hydathodes present. Stomatal density: $2.14 \times 10^{8} \pm 7.04 \times 10^{7}$ m^{-2}, epidermal cell density: $2.23 \times 10^{9} \pm 5.37 \times 10^{8}$ m^{-2}, pore length: $1.05 \times 10^{-5} \pm 5.49 \times 10^{-6}$ m, and guard cell width: $3.99 \times 10^{-6} \pm 2.31 \times 10^{-6}$ m.
Affinity: Lauraceae: *Laurophyllum* (*Litsea*) *calicarioides* Bannister, Conran et D.E. Lee (Bannister et al., 2012). The distinguishing anatomical characteristics of morphotype A match the diagnostic features of *Laurophyllum calicarioides* described from the surface sediments at Foulden Maar.

Morphotype: B.
Samples: (8) 17-91-45-5, 18-99-90-2, 37-4-25-4, 40-93-80-1, 41-88-28-5 (Fig. S1b), 42-85-70-3, 43-82-0-1, and 57-31-95-3.
Distinguishing anatomical features of the abaxial cuticle: Anticlinal cell walls straight or curved. Stomata distinctly areolate, with broad, butterfly-shaped scales, and a well-defined peristomatal rim. Trichome bases common, with clearly define collar and round pore. Hydathodes present. Stomatal density: $5.69 \times 10^{8} \pm 1.38 \times 10^{8}$ m^{-2}, epidermal cell density: $3.03 \times 10^{9} \pm 7.62 \times 10^{8}$ m^{-2}, pore length: $7.2 \times 10^{-6} \pm 3.09 \times 10^{-6}$ m, and guard cell width: $2.52 \times 10^{-6} \pm 1.69 \times 10^{-6}$ m.
Affinity: Lauraceae: *Laurophyllum* (*Cryptocarya*) *taieriensis* Bannister, Conran et D.E. Lee (Bannister et al., 2012). The distinguishing anatomical characteristics of morphotype B match the diagnostic features of *Laurophyllum taieriensis* described from the surface sediments at Foulden Maar.

Morphotype: C.
Sample: (1) 42-85-70-12 (Fig. S1c).
Distinguishing anatomical features of the abaxial cuticle: Epidermal cell straight or curved, anticlinal cell walls ridged or knobby. Stomata surrounded by two rings, with very distinct polar rods. Darkened

features on the leaf surface very common, possibly trichome bases with a strongly defined, raised collar. Stomatal density: $4.47 \times 10^8 \pm 3.61 \times 10^7$ m^{-2}, epidermal cell density: $5.55 \times 10^9 \pm 8.73 \times 10^8$ m^{-2}, pore length: $4.9 \times 10^{-6} \pm 8.54 \times 10^{-7}$ m, and guard cell width: $2.54 \times 10^{-6} \pm 6.02 \times 10^{-7}$ m.
Affinity: No affinity defined, other than an angiosperm.

Morphotype: D.
Samples: (4) 38-97-90-9, 42-85-70-4, 63-19-95-1, and 84-43-18-2 (Fig. S1d).
Distinguishing anatomical features of the abaxial cuticle: Anticlinal epidermal cell walls straight or curved, buttressed. Stomata in clusters, cyclocytic, and surrounding epidermal cells seemingly radiating around stomata. Guard cells and apertures often indistinct. Minor vein cells indistinct. Hydathodes present. Stomatal density: $2.76 \times 10^8 \pm 1.29 \times 10^7$ m^{-2}, epidermal cell density: $5.41 \times 10^9 \pm 1.19 \times 10^9$ m^{-2}, pore length: $8.33 \times 10^{-6} \pm 2.89 \times 10^{-6}$ m, and guard cell width: $2.57 \times 10^{-6} \pm 8.65 \times 10^{-7}$ m.
Affinity: The cyclocytic stomata in combination with the hydathodes and clustering of stomata, suggest an affinity to Myrtaceae. This is consistent with fruits, flowers and macrofossils identified from the surface sediments (Conran et al., 2014; Lee et al., 2016). Although the absence of lid cells in morphotype D is conspicuous, this character is not present in all Myrtaceae (e.g. Tarran et al., 2016).

Morphotype: E
Samples: (3) 14-2-40-1, 31-19-56-3, and 40-93-80-50 (Fig. S1e).
Distinguishing anatomical features of the abaxial cuticle: All cells relatively large. Anticlinal epidermal cell walls undulate. Stomata paracytic, with large sinuous walled subsidiary cells, and thick stomatal scales. Stomatal density: $4.22 \times 10^7 \pm 1.72 \times 10^7$ m^{-2}, epidermal cell density: $3.12 \times 10^8 \pm 1.69 \times 10^8$ m^{-2}, pore length: $1.66 \times 10^{-5} \pm 5.33 \times 10^{-6}$ m, and guard cell width: $3.22 \times 10^{-6} \pm 1.48 \times 10^{-6}$ m.
Affinity: cf. Ripogonaceae: *Ripogonum*. The distinguishing anatomical characteristics of morphotype E match the diagnostic features of *Ripogonum* described from the surface sediments at Foulden Maar (Conran et al., 2015).

Morphotype: G.
Samples: (2) 38-97-90-11 (Fig. S1f), and 62-19-84-1.
Distinguishing anatomical features of the abaxial cuticle: Anticlinal epidermal cell walls sinuous-undulate. Stomata pericytic with 3–4 additional irregularly shaped surrounding cells, aperture often not well visible. Very distinct circular trichome bases with a ring of 7-8 radial petal-shaped cells. Stomatal density: $1.08 \times 10^8 \pm 2.19 \times 10^7$ m^{-2}, epidermal cell density: $8.11 \times 10^8 \pm 1.21 \times 10^8$ m^{-2}, pore length: $1.09 \times 10^{-5} \pm 2.17 \times 10^{-6}$ m, and guard cell width: $3.43 \times 10^{-6} \pm 8.52 \times 10^{-7}$ m.
Affinity: cf. Primulaceae: *Myrsine*. The distinguishing anatomical characteristics of morphotype G match the diagnostic features of *Myrsine* photographed from surface sediments at Foulden Maar (Lee et al., 2016), in particular the raised or stalked stomatal scales.

Morphotype: H.
Samples: (1) 56-31-85-3 (Fig. S1g).
Distinguishing anatomical features of the abaxial cuticle: Anticlinal epidermal cell walls rounded to somewhat sinuous, beaded. Stomata seemingly tetracytic, with four subsidiary cells that stain darker than other epidermal cells, and with very thin anticlinal walls. Stomatal periclinal wall granulate, making the aperture and guard cells poorly visible. Higher order venation undefined. Scattered trichome bases, with a thick, but not dark, collar. Stomatal density: $3.71 \times 10^8 \pm 3.9 \times 10^7$ m^{-2}, epidermal cell density: $2.05 \times 10^8 \pm 2.23 \times 10^8$ m^{-2}, pore length: $9.25 \times 10^{-6} \pm 4.13 \times 10^{-6}$ m, and guard cell width: $2.0 \times 10^{-6} \pm 1.01 \times 10^{-6}$ m.
Affinity: No affinity defined, other than an angiosperm.

Morphotype: I.
Samples: (7) 14-2-15-1, 14-2-40-6, 18-99-35-1, 18-99-90-5, 38-97-90-8, 57-31-0-2, and 101-4-16-1 (Fig. S1h).

Distinguishing anatomical features of the abaxial cuticle: Anticlinal epidermal cell walls straight to rounded. Stomata anomocytic, in areoles, with defined polar rods. Very large hydathodes present on veins. Stomatal density: $4.75 \times 10^8 \pm 1.18 \times 10^8$ m^{-2}, epidermal cell density: $3.74 \times 10^9 \pm 8.83 \times 10^8$ m^{-2}, pore length: $1.28 \times 10^{-5} \pm 1.01 \times 10^{-5}$ m, and guard cell width: $2.4 \times 10^{-6} \pm 1.31 \times 10^{-6}$ m.
Affinity: cf. Elaeocarpaceae or Cunoniaceae. The distinguishing anatomical characteristics of morphotype I match the diagnostic features of Elaeocarpaceae or Cunoniaceae photographed from surface sediments at Foulden Maar (Lee et al., 2016).

Morphotype: K.
Samples: (3) 31-19-34-1 (Fig. S1i), 62-19-90-1, and 83-48-86-3.
Distinguishing anatomical features of the abaxial cuticle: Anticlinal epidermal cell walls straight, beaded. Stomata paracytic, with distinct butterfly-shaped scales, weakly developed polar rods, but well-defined peristomatal ring. Hydathodes present. Trichome bases common, usually on veins, with small pores and surrounding cells very similar to other epidermal cells. Stomatal density: $4.47 \times 10^8 \pm 1.14 \times 10^8$ m^{-2}, epidermal cell density: $5.64 \times 10^9 \pm 1.28 \times 10^8$ m^{-2}, pore length: $7.99 \times 10^{-6} \pm 3.7 \times 10^{-6}$ m, and guard cell width: $3.3 \times 10^{-6} \pm 1.17 \times 10^{-6}$ m.
Affinity: Lauraceae: *Laurophyllum* (*Cryptocarya*) *maarensis* Bannister, Conran et D.E. Lee (Bannister et al., 2012). The distinguishing anatomical characteristics of morphotype K match the diagnostic features of *Laurophyllum maarensis* described from the surface sediments at Foulden Maar.

Morphotype: L.
Sample: (1) 63-19-30-1 (Fig. S2a).
Distinguishing anatomical features of the abaxial cuticle: Anticlinal epidermal cell walls rounded to sinuous, thin. Stomata paracytic, with narrow but prominent scales and prominent polar rods. Trichome bases common, with surrounding cells arranged radially around the pore. Stomatal density: $2.08 \times 10^8 \pm 2.46 \times 10^7$ m^{-2}, epidermal cell density: $1.74 \times 10^9 \pm 6.81 \times 10^7$ m^{-2}, pore length: $1.15 \times 10^{-5} \pm 5.66 \times 10^{-6}$ m, and guard cell width: $2.5 \times 10^{-6} \pm 1.02 \times 10^{-6}$ m.
Affinity: Lauraceae: *Laurophyllum* (*Beilschmiedia*) *otagoensis* Bannister, Conran et D.E. Lee (Bannister et al., 2012). The distinguishing anatomical characteristics of morphotype L match the diagnostic features of *Laurophyllum otagoensis* described from the surface sediments at Foulden Maar.

Morphotype: M.
Samples: (4) 14-2-15-5, 17-91-80-2 (Fig. S2b), 37-4-25-2, and 83-48-42-1.
Distinguishing anatomical features of the abaxial cuticle: Anticlinal epidermal cell walls sinuous to undulate, beaded. Stomata anisocytic, with well-defined, but narrow scales, and undefined peristomatal ring. Trichome bases present, with a round pore, and multiple rows of angular-round epidermal cells surrounding the pore. Stomatal density: $1.47 \times 10^8 \pm 4.24 \times 10^7$ m^{-2}, epidermal cell density: $2.72 \times 10^9 \pm 5.04 \times 10^8$ m^{-2}, pore length: $9.89 \times 10^{-6} \pm 3.94 \times 10^{-6}$ m, and guard cell width: $1.8 \times 10^{-6} \pm 1.19 \times 10^{-6}$ m.
Affinity: cf. Meliaceae: *Dysoxylum*. Morphotype M has thin cuticle covering the zone between guard cells and subsidiary cells, while prominent scales define the inner margin of the guard cells, characteristic of Meliaceae (Pole, 2008). Conran et al. (2014) also reported flowers and fruits of *Dysoxylum* at the site.

Morphotype: N.
Sample: (1) 32-20-60-20 (Fig. S2c).
Distinguishing anatomical features of the abaxial cuticle: Anticlinal epidermal cell walls undulate, very thin. Stomata paracytic, with prominent butterfly-shaped scales, and peristomatal rings. Trichome bases common, with an angular pore, and a thick collar, surrounded by 5-8 angular-round cells. Stomatal density: $1.92 \times 10^8 \pm 1.06 \times 10^7$ m^{-2}, epidermal cell density: $1.81 \times 10^9 \pm 2.19 \times 10^8$ m^{-2}, pore length: $7.75 \times 10^{-6} \pm 1.03 \times 10^{-6}$ m, and guard cell width: $1.5 \times 10^{-6} \pm 5.04 \times 10^{-7}$ m.
Affinity: cf. Lauraceae: *Cryptocarya*. Morphotype N has not been described from surface sediments at Foulden Maar, as none of the Lauraceae from the surface sediments have the combination of butterfly-

shaped scales, typical of *Cryptocarya* (Cristophel and Rowett, 1996), and very thin-walled undulating epidermal cells.

Morphotype: O.
Samples: (5) 15-0-9-1, 31-19-20-5, 32-20-60-3 (Fig. S2d), 41-88-12-9, and 83-48-50-1.
Distinguishing anatomical features of the abaxial cuticle: Anticlinal epidermal cell walls straight-round, periclinal walls appear thickened, granulate. Stomata paracytic, with subsidiary cells staining distinctly darker than surrounding epidermal cells, thickened ledges between the two subsidiary cells, and stomatal complexes appearing sunken. Aperture indistinct. Stomatal density: $8.97 \times 10^{7} \pm 2.12 \times 10^{7}$ m^{-2}, epidermal cell density: $7.11 \times 10^{8} \pm 1.65 \times 10^{8}$ m^{-2}, pore length: $1.75 \times 10^{-5} \pm 6.01 \times 10^{-6}$ m, and guard cell width: $4.68 \times 10^{-6} \pm 1.52 \times 10^{-6}$ m.
Affinity: No affinity defined, other than an angiosperm.

Morphotype: P.
Samples: (3) 9-9-70-4, 31-19-100-4, and 42-85-70-1 (Fig. S2e).
Distinguishing anatomical features of the abaxial cuticle: Cuticle thin, breaks apart easily. Anticlinal epidermal cell walls straight-sinuous, ridged. Stomata apparently cyclocytic, with very prominent broad stomatal scales. Trichome bases common, staining darker than the surrounding tissue, pore circular, with 4-6 surrounding cells that are also much darker than other cells. Stomatal density: $2.18 \times 10^{8} \pm 1.34 \times 10^{7}$ m^{-2}, epidermal cell density: $4.1 \times 10^{9} \pm 1.21 \times 10^{9}$ m^{-2}, pore length: $9.67 \times 10^{-6} \pm 2.13 \times 10^{-6}$ m, and guard cell width: $2.0 \times 10^{-6} \pm 5.98 \times 10^{-7}$ m.
Affinity: No affinity defined, other than an angiosperm.

Morphotype: Q.
Sample: (1) 31-19-100-2 (Fig. S2f).
Distinguishing anatomical features of the abaxial cuticle: Anticlinal epidermal cell walls round-sinuous, beaded. Stomata appear anisocytic, but often complicated to tell, as subsidiary cells stain lighter than regular epidermal cells and appear sunken. Stomata have thick prominent scales. Stomatal density: $2.69 \times 10^{8} \pm 2.65 \times 10^{7}$ m^{-2}, epidermal cell density: $9.04 \times 10^{8} \pm 8.07 \times 10^{7}$ m^{-2}, pore length: $1.08 \times 10^{-5} \pm 4.58 \times 10^{-6}$ m, and guard cell width: $3.0 \times 10^{-6} \pm 7.78 \times 10^{-7}$ m.
Affinity: No affinity defined, other than an angiosperm.

Morphotype: R.
Sample: (1) 37-4-25-1 (Fig. S2g).
Distinguishing anatomical features of the abaxial cuticle: Anticlinal epidermal cell walls sinuous-undulate. Stomata paracytic, staining a lighter color than other epidermal cells. Stomata have distinct inner and outer scales on the guard cells. Stomatal density: $2.95 \times 10^{8} \pm 5.8 \times 10^{7}$ m^{-2}, epidermal cell density: $1.35 \times 10^{9} \pm 3.88 \times 10^{8}$ m^{-2}, pore length: $7.75 \times 10^{-6} \pm 1.03 \times 10^{-6}$ m, and guard cell width: $2.0 \times 10^{-6} \pm 4.98 \times 10^{-7}$ m.
Affinity: cf. Lauraceae: *Endiandra*. This leaf type is not described in Lauraceae leaves described from the surface sediments at Foulden Maar (Bannister et al., 2012), but the distinct inner and outer scales on the guard cells are synapomorphies for *Endiandra* (Christophel and Rowett, 1996). *Endiandra* has also been recognized in other New Zealand sediments of Miocene age (Pole, 2007). However, we did not observe the prominent polar rods which are supposedly characteristic of *Endiandra* (Christophel and Rowett, 1996).

Morphotype: U.
Sample: (1) 18-99-90-13 (Fig. S2h).
Distinguishing anatomical features of the abaxial cuticle: Anticlinal epidermal cell walls straight-sinuous. Stomata staurocytic, with varying numbers of subsidiary cells and occasionally two rows. Hydathodes

present. Stomatal density: $7.25 \times 10^{7} \pm 9.01 \times 10^{6}$ m^{-2}, epidermal cell density: $1.14 \times 10^{9} \pm 2.93 \times 10^{7}$ m^{-2}, pore length: $2.03 \times 10^{-5} \pm 3.71 \times 10^{-6}$ m, and guard cell width: $4.0 \times 10^{-6} \pm 7.51 \times 10^{-7}$ m.
Affinity: Atherospermataceae: *Laurelia otagoensis* Conran, Bannister et D.E. Lee (Conran et al., 2013). The distinguishing anatomical characteristics of morphotype U match the diagnostic features of *Laurelia otagoensis* described from the surface sediments at Foulden Maar.

Morphotype: V.
Sample: (1) 31-19-56-2 (Fig. S2i).
Distinguishing anatomical features of the abaxial cuticle: Epidermal cell straight-round. Stomata paracytic, with prominent stomatal scales, but absent polar rods. Subsidiary cells large and often uneven sized. Stomatal density: $7.92 \times 10^{7} \pm 2.01 \times 10^{7}$ m^{-2}, epidermal cell density: $8.38 \times 10^{8} \pm 2.72 \times 10^{7}$ m^{-2}, pore length: $1.33 \times 10^{-5} \pm 1.65 \times 10^{-6}$ m, and guard cell width: $2.7 \times 10^{-6} \pm 4.42 \times 10^{-7}$ m.
Affinity: Monimiaceae: *Hedycarya pluvisilva* Conran, Bannister, Mildenhall et D.E. Lee (Conran et al., 2016). The distinguishing anatomical characteristics of morphotype V match the diagnostic features of *Hedycarya pluvisilva* described from the surface sediments at Foulden Maar.

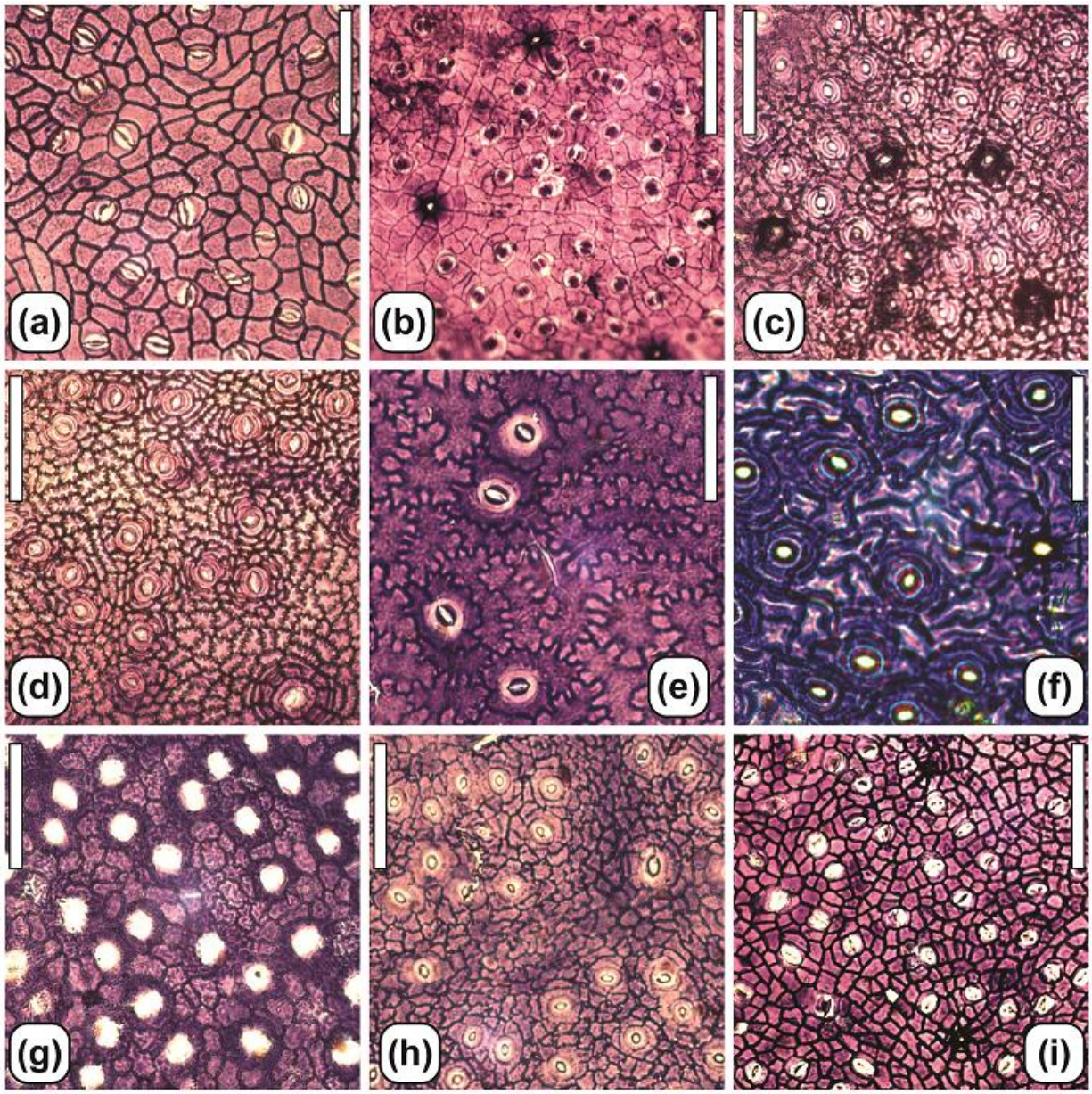

Figure S1. Examples of cuticles of morphotypes A–K, scalebar is 100 μm. (a) Sample 83-48-86-2, Morphotype A: *Laurophyllum (Litsea) calicarioides*. (b) Sample 41-88-28-5, Morphotype B: *Laurophyllum (Cryptocarya) taieriensis*. (c) Sample 42-85-70-12, Morphotype C. (d) Sample 84-43-18-2, Morphotype D: cf. Myrtaceae. (e) Sample 40-93-80-50, Morphotype E: cf. *Ripogonum*. (f) Sample 38-97-90-11, Morphotype G: cf. *Myrsine*. (g) Sample 56-31-85-3, Morphotype H. (h) Sample 101-4-16-1, Morphotype I: cf. Elaeocarpaceae/Cunoniaceae. (i) Sample 31-19-34-1, Morphotype K, *Laurophyllum (Cryptocarya) maarensis*.

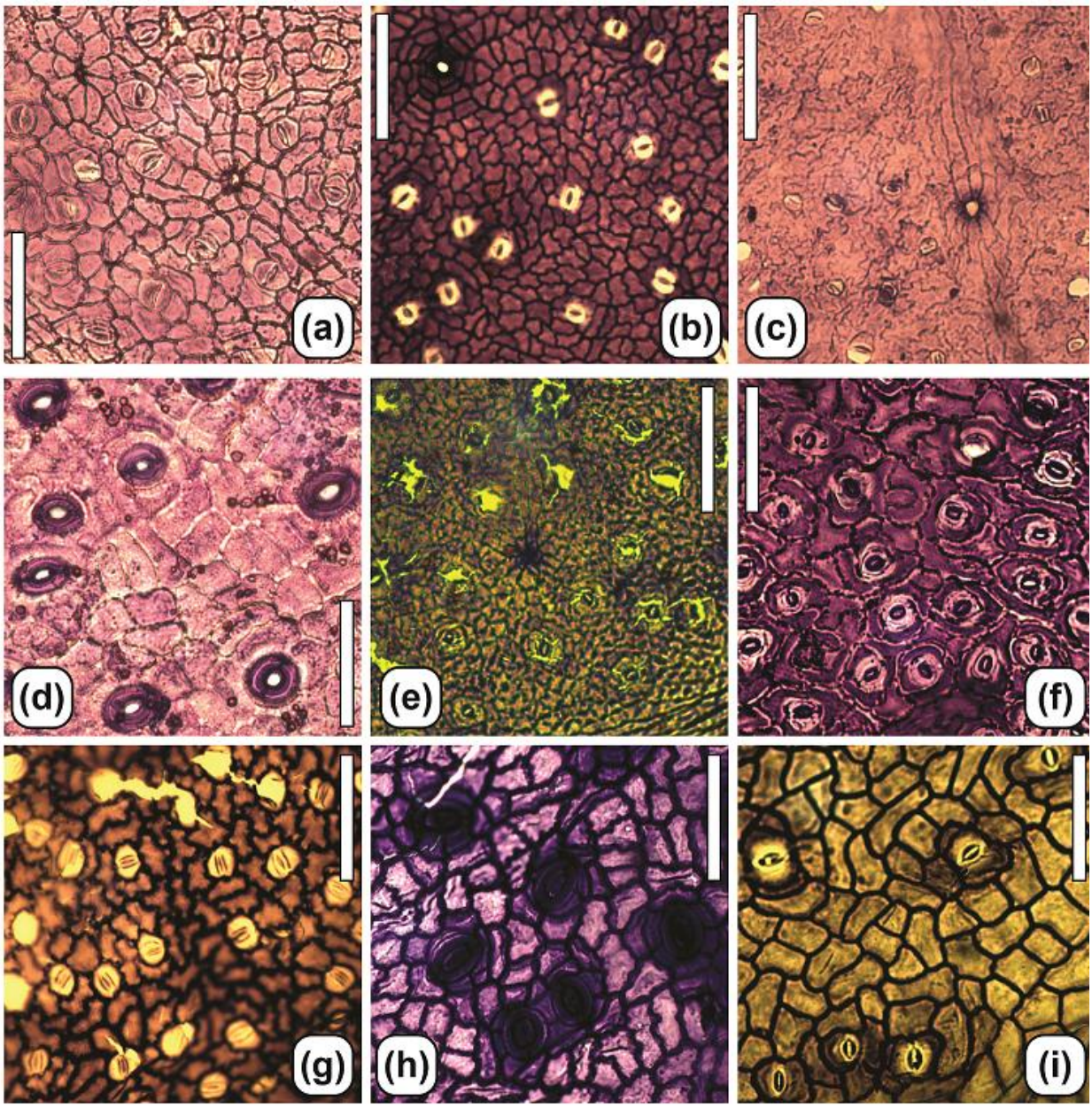

Figure S2. Examples of cuticles of morphotypes L–V, scalebar is 100 µm. (a) Sample 63-19-30-1, Morphotype L: *Laurophyllum (Beilschmiedia) otagoensis*. (b) Sample 17-91-80-2, Morphotype M: cf. *Dysoxylum*. (c) Sample 32-20-60-20, Morphotype N, cf. *Cryptocarya*. (d) Sample 32-20-60-3, Morphotype O. (e) Sample 42-85-70-1, Morphotype P. (f) Sample 31-19-100-2, Morphotype Q. (g) Sample 37-4-25-1, Morphotype R, cf. *Endiandra*. (h) Sample 18-99-90-13, Morphotype U: *Laurelia otagoensis*. (i) Sample 31-19-56-2, Morphotype V, *Hedycarya pluvisilva*.

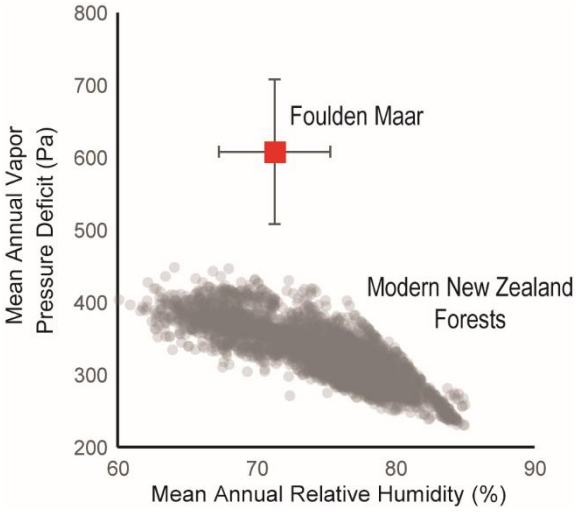

Fig. S3. Reconstructed Relative Humidity (RH) and Vapor Pressure Deficit (VPD) at Foulden Maar using the Climate Leaf Analysis Multivariate Program (Reichgelt et al., 2019) indicated by the red square, compared to modern New Zealand forest biomes. Ranges of modern New Zealand forest biomes obtained from Leathwick (2001), each point representing a different 0.01 × 0.01° grid cell, and the RH and VPD at those sites (Fick and Hijmans, 2017). The data shows that while there is almost no overlap of VPD between early Miocene Foulden Maar and modern New Zealand forests, RH strongly overlaps.

Table S1. Measurements of stomatal density (SD), pore length (p_l), guard cell width (gcw), leaf and air carobn isotopic composition ($\delta^{13}C$), and associated standard deviation (σ) of fossil leaves from Foulden Maar, affinity (aff) referring to the closest living relative based on anatomical features, *Litsea calicarioides* (Lcal), *Cryptocarya taieriensis* (Ctai), cf. Myrtaceae (Myrt), cf. *Ripogonum* (Rip), cf. *Myrsine* (Myrs), cf. Elaeocarpaceae/Cunoniaceae (E/C), *Cryptocarya maarensis* (Cmaa), *Beilschmiedia otagoensis* (Bota), cf. *Dysoxylum* (Dys), cf. *Cryptocarya* (cfC), cf. *Endiandra* (cfE), *Laurelia otagoensis* (Lota), and *Hedycarya pluvisilva* (Hplu), and five unassigned leaf types: “C”, “H”, “O”, “P”, and “Q”.

Sample#	aff.	SD (m^{-2})	σ	p_l (m)	σ	gcw (m)	σ	$\delta^{13}C$ leaf	σ	$\delta^{13}C$ air	σ
9-09-50-1	Lcal	1.72E+08	2.94E+07	7.98E-06	1.53E-06	5.18E-06	9.21E-07	-28.2	0.3	-6.0	0.7
9-9-70-4	"P"	7.04E+07	3.57E+07	1.17E-05	1.59E-06	2.33E-06	5.90E-07	-29.3	0.4	-6.0	0.7
14-2-15-5	Dys	9.44E+07	3.20E+07	9.67E-06	5.18E-06	2.33E-06	1.62E-06	-32.2	0.4	-6.0	0.7
14-2-15-1	E/C	6.22E+08	4.08E+07	3.36E-05	2.45E-05	3.00E-06	7.70E-07	-29.0	0.4	-6.0	0.7
14-2-40-1	Rip	4.87E+07	7.63E+06	2.30E-05	6.48E-06	5.00E-06	1.95E-06	-37.8	0.4	-6.0	0.7
14-02-40-5	Lcal	1.59E+08	4.21E+07	8.55E-06	7.61E-07	4.28E-06	9.00E-07	-25.4	0.4	-6.0	0.7
14-2-40-6	E/C	3.43E+08	5.65E+07	1.04E-05	5.22E-06	1.63E-06	8.73E-07	-27.7	0.4	-6.0	0.7
15-0-9-1	"O"	7.50E+07	1.14E+07	1.34E-05	2.60E-06	3.86E-06	1.18E-06	-32.4	0.1	-6.0	0.7
17-91-45-5	Ctai	5.82E+08	1.33E+08	1.16E-05	5.17E-06	2.60E-06	1.39E-06	-28.7	0.4	-6.0	0.7
17-91-70-1	Lcal	2.80E+08	2.88E+07	6.91E-06	1.09E-06	4.63E-06	8.22E-07	-29.5	0.2	-6.0	0.7
17-91-70-5	Lcal	1.87E+08	6.50E+07	7.97E-06	8.55E-07	4.20E-06	8.91E-07	-27.1	0.4	-6.0	0.7
17-91-70-7	Lcal	2.40E+08	2.30E+07	8.60E-06	2.59E-06	2.40E-06	1.06E-06	-26.3	0.2	-6.0	0.7

17-91-70-8	Lcal	1.53E+08	3.28E+07	1.02E-05	5.05E-06	2.00E-06	6.64E-07	-28.1	0.4	-6.0	0.7
17-91-80-2	Dys	1.64E+08	1.45E+07	1.18E-05	4.55E-06	1.80E-06	9.87E-07	-28.3	0.4	-6.0	0.7
18-99-35-1	E/C	5.18E+08	1.31E+08	1.02E-05	4.61E-06	2.20E-06	1.50E-06	-29.4	0.4	-6.0	0.7
18-99-90-1	Lcal	1.48E+08	2.31E+07	9.67E-06	3.23E-06	2.00E-06	8.81E-07	-27.3	0.3	-6.0	0.7
18-99-90-2	Ctai	5.25E+08	7.83E+07	8.50E-06	3.18E-06	1.67E-06	8.37E-07	-31.3	0.5	-6.0	0.7
18-99-90-5	E/C	4.22E+08	5.44E+07	1.15E-05	3.23E-06	2.75E-06	1.29E-06	-27.7	0.3	-6.0	0.7
18-99-90-13	Lota	7.25E+07	9.01E+06	2.03E-05	3.71E-06	4.00E-06	7.51E-07	-29.8	0.4	-6.0	0.7
31-19-10-1	Lcal	2.20E+08	2.53E+07	9.05E-06	1.01E-06	4.87E-06	9.95E-07	-25.7	0.4	-6.0	0.7
31-19-20-3	Lcal	2.33E+08	4.87E+07	9.83E-06	2.32E-06	1.65E-06	1.44E-06	-33.5	0.4	-6.0	0.7
31-19-20-4	Lcal	2.21E+08	9.08E+07	1.61E-05	7.02E-06	2.29E-06	1.14E-06	-29.8	0.4	-6.0	0.7
31-19-20-5	"O"	9.17E+07	3.61E+06	2.00E-05	5.12E-06	4.67E-06	1.28E-06	-28.0	0.7	-6.0	0.7
31-19-34-1	Cmaa	3.52E+08	5.34E+07	1.07E-05	5.35E-06	2.67E-06	1.20E-06	-27.4	0.4	-6.0	0.7
31-19-56-3	Rip	3.20E+07	2.88E+07	1.17E-05	2.45E-06	2.33E-06	1.02E-06	-31.3	0.1	-6.0	0.7
31-19-56-2	Hplu	7.92E+07	2.01E+07	1.33E-05	1.65E-06	2.67E-06	4.42E-07	-31.1	0.4	-6.0	0.7
31-19-100-4	"P"	3.73E+08	2.44E+07	8.67E-06	2.05E-06	2.00E-06	5.00E-07	-28.6	0.4	-6.0	0.7
31-19-100-2	"Q"	2.69E+08	2.65E+07	1.08E-05	4.58E-06	3.00E-06	7.78E-07	-27.1	0.2	-6.0	0.7
32-20-30-1	Lcal	1.53E+08	2.28E+07	8.97E-06	1.02E-06	4.53E-06	7.42E-07	-28.5	0.3	-6.0	0.7
32-20-60-1	Lcal	2.07E+08	3.74E+07	8.45E-06	1.12E-06	5.16E-06	9.74E-07	-28.4	0.4	-6.0	0.7
32-20-60-2	cfC	1.92E+08	1.06E+07	7.75E-06	1.26E-06	1.50E-06	5.04E-07	-26.9	0.4	-6.0	0.7
32-20-60-3	"O"	7.34E+07	5.98E+06	1.55E-05	2.31E-06	3.75E-06	5.92E-07	-28.5	0.4	-6.0	0.7
37-4-25-4	Ctai	6.84E+08	1.26E+08	5.50E-06	9.57E-07	1.18E-06	3.27E-07	-28.7	0.4	-6.0	0.7
37-4-25-1	cfE	2.95E+08	5.80E+07	7.75E-06	1.03E-06	2.00E-06	4.98E-07	-29.5	0.4	-6.0	0.7
37-4-25-2	Dys	1.80E+08	1.45E+07	9.60E-06	1.26E-06	1.12E-06	2.98E-07	-30.4	0.4	-6.0	0.7
38-97-90-10	Lcal	2.56E+08	3.60E+07	1.46E-05	5.67E-06	3.00E-06	1.53E-06	-27.6	0.4	-6.0	0.7
38-97-90-9	Myrt	2.15E+08	2.70E+07	1.08E-05	3.80E-06	1.75E-06	5.04E-07	-27.8	0.4	-6.0	0.7
38-97-90-11	Myrs	1.08E+08	1.13E+07	1.20E-05	1.24E-06	3.25E-06	7.62E-07	-27.6	0.5	-6.0	0.7
38-97-90-8	E/C	3.80E+08	4.78E+07	9.75E-06	4.08E-06	2.50E-06	1.26E-06	-28.9	0.4	-6.0	0.7
40-93-80-4	Lcal	1.85E+08	4.59E+07	8.79E-06	8.28E-07	5.25E-06	6.47E-07	-26.8	0.4	-6.0	0.7
40-93-80-1	Ctai	7.52E+08	1.11E+08	5.51E-06	9.44E-07	3.48E-06	5.52E-07	-28.9	0.4	-6.0	0.7
40-93-80-5	Rip	4.58E+07	7.22E+06	1.50E-05	2.63E-06	2.33E-06	6.90E-07	-31.3	0.4	-6.0	0.7
41-88-12-1	Lcal	3.20E+08	4.33E+07	7.68E-06	1.04E-06	4.24E-06	7.99E-07	-27.6	0.1	-6.0	0.7
41-88-12-9	"O"	1.05E+08	2.98E+07	1.86E-05	8.29E-06	5.40E-06	1.69E-06	-27.6	0.2	-6.0	0.7
41-88-28-4	Lcal	2.00E+08	4.71E+07	1.03E-05	1.63E-06	1.75E-06	5.57E-07	-26.1	0.5	-6.0	0.7
41-88-28-7	Lcal	2.80E+08	1.26E+08	2.93E-05	2.05E-05	2.13E-06	1.81E-06	-27.3	0.4	-6.0	0.7
41-88-28-5	Ctai	5.91E+08	4.26E+07	7.00E-06	3.02E-06	1.60E-06	8.85E-07	-29.9	0.4	-6.0	0.7
42-85-0-2	Lcal	3.04E+08	5.59E+07	9.88E-06	9.31E-07	6.43E-06	6.56E-07	-27.4	0.4	-6.0	0.7
42-85-70-3	Ctai	6.39E+08	3.90E+07	5.25E-06	1.01E-06	1.25E-06	4.79E-07	-28.8	0.8	-6.0	0.7
42-85-70-12	"C"	4.47E+08	4.48E+07	4.90E-06	9.23E-07	2.54E-06	4.18E-07	-26.7	0.0	-6.0	0.7
42-85-70-4	Myrt	4.72E+08	9.88E+07	7.27E-06	1.73E-06	2.75E-06	7.16E-07	-27.5	0.4	-6.0	0.7
42-85-70-1	"P"	2.11E+08	3.33E+07	8.67E-06	1.30E-06	1.67E-06	4.18E-07	-30.1	0.4	-6.0	0.7
43-82-0-1	Ctai	4.16E+08	6.41E+07	6.03E-06	9.69E-07	5.57E-06	1.07E-06	-28.4	0.3	-6.0	0.7

56-31-20-1	Lcal	2.04E+08	5.75E+07	8.40E-06	1.02E-06	5.33E-06	7.81E-07	-29.7	0.4	-6.0	0.7
56-31-85-3	"H"	3.71E+08	3.90E+07	9.25E-06	4.13E-06	2.00E-06	1.01E-06	-28.4	0.4	-6.0	0.7
57-31-0-2	E/C	5.78E+08	5.93E+07	6.80E-06	3.28E-06	1.40E-06	7.41E-07	-28.7	0.6	-6.0	0.7
57-31-95-3	Ctai	3.62E+08	7.31E+07	8.20E-06	2.95E-06	2.80E-06	1.04E-06	-28.3	0.4	-6.0	0.7
62-19-02-1	Lcal	2.00E+08	3.95E+07	8.99E-06	1.22E-06	5.17E-06	7.80E-07	-27.7	0.4	-6.0	0.7
62-19-84-1	Myrs	1.09E+08	1.91E+07	9.83E-06	1.13E-06	3.60E-06	5.89E-07	-32.7	0.4	-6.0	0.7
62-19-90-1	Cmaa	4.07E+08	3.30E+07	7.25E-06	1.01E-06	3.88E-06	5.46E-07	-30.2	0.0	-6.0	0.7
63-19-30-1	Bota	2.08E+08	2.46E+07	1.15E-05	5.66E-06	2.50E-06	1.02E-06	-29.1	0.9	-6.0	0.7
63-19-95-3	Lcal	1.33E+08	4.71E+07	1.06E-05	1.30E-06	5.89E-06	1.10E-06	-28.1	1.2	-6.0	0.7
63-19-95-1	Myrt	1.78E+08	9.43E+07	6.50E-06	9.42E-07	2.29E-06	4.53E-07	-25.7	0.4	-6.0	0.7
83-48-42-1	Dys	1.47E+08	3.67E+07	8.50E-06	1.71E-06	1.75E-06	5.64E-07	-29.5	0.4	-6.0	0.7
83-48-50-1	"O"	1.03E+08	1.79E+07	1.98E-05	7.96E-06	5.75E-06	2.04E-06	-28.5	0.4	-6.0	0.7
83-48-86-2	Lcal	2.47E+08	1.99E+07	1.04E-05	1.75E-06	5.24E-06	9.79E-07	-27.8	0.4	-6.0	0.7
83-48-86-3	Cmaa	5.82E+08	7.31E+07	6.06E-06	1.09E-06	3.38E-06	5.33E-07	-27.5	0.1	-6.0	0.7
84-43-18-2	Myrt	2.41E+08	5.01E+07	8.81E-06	6.47E-07	3.49E-06	8.81E-07	-28.0	1.3	-6.0	0.7
84-43-68-1	Lcal	3.15E+08	3.39E+07	9.71E-06	1.29E-06	4.42E-06	1.05E-06	-26.4	0.4	-6.0	0.7
84-43-68-4	Lcal	1.43E+08	4.19E+07	1.25E-05	2.60E-06	2.00E-06	7.82E-07	-28.3	0.4	-6.0	0.7
101-4-16-2	Lcal	1.86E+08	5.56E+06	8.13E-06	1.74E-06	5.73E-06	1.31E-06	-26.9	0.4	-6.0	0.7
101-04-16-1	E/C	4.61E+08	2.94E+07	7.40E-06	9.54E-07	3.62E-06	6.46E-07	-27.3	0.4	-6.0	0.7

Table S2 Assimilation rate range of modern living relatives (A_0) and atmospheric carbon dioxide level at which A_0 was determined (C_{a0}). Also included is whether the abaxial epidermal cells are undulating (Und; Y/N).

Type	Modern living	Und	Habit	Habitat	A_0 (μmol m^{-2} s^{-1})	C_{a0} (ppm)	Reference
Lcal	Lauraceae	N	Canopy	Rainforest	6.86 ± 1.22	400	This study
Ctai	Lauraceae	N	Canopy	Rainforest	6.86 ± 1.22	400	This study
“C”	Eudicot	N	Unclear	Rainforest	6.91 ± 1.27	400	This study
Myrt	Myrtaceae	N	Canopy	Rainforest	7.51 ± 1.90	400	This study
Rip	Angiosperms	Y	Understory	Rainforest	8.29 ± 1.05	400	This study
Myrs	Primulaceae	Y	Understory	Rainforest	6.90 ± 0.72	400	This study
“H”	Eudicot	N	Unclear	Rainforest	6.91 ± 1.27	400	This study
E/C	Elaeocarpaceae & Cunoniaceae	N	Canopy	Rainforest	7.31 ± 1.89	400	This study
Cmaa	Lauraceae	N	Canopy	Rainforest	6.86 ± 1.22	400	This study
Bota	Lauraceae	N	Unclear	Rainforest	6.91 ± 1.27	400	This study
Dys	Meliaceae	Y	Understory	Rainforest	8.26 ± 0.90	400	This study
cfC	Lauraceae	Y	Unclear	Rainforest	6.91 ± 1.27	400	This study
“O”	Angiosperms	N	Understory	Rainforest	8.29 ± 1.05	400	This study
“P”	Eudicot	N	Unclear	Rainforest	6.91 ± 1.27	400	This study
“Q”	Eudicot	N	Unclear	Rainforest	6.91 ± 1.27	400	This study
cfE	Lauraceae	Y	Unclear	Rainforest	6.91 ± 1.27	400	This study
Lota	Atherospermataceae	N	Unclear	Rainforest	5.30 ± 1.04	400	This study
Hplu	Laurales	N	Unclear	Rainforest	6.64 ± 1.17	400	This study
“Mu”	Salicaceae	No	Canopy	Open Forest	10.63 ± 2.4	400	Tesfamichael et al. (2017)
M2	Eudicot	Y	Unclear	Forest	10.6 ± 4.2	400	Londoño et al. (2018)
M3	Eudicot	N	Unclear	Forest	10.6 ± 4.2	400	Londoño et al. (2018)

M4	Eudicot	Y	Unclear	Forest	10.6 ± 4.2	400	Londoño et al. (2018)
M5	Eudicot	Y	Unclear	Forest	10.6 ± 4.2	400	Londoño et al. (2018)
M6	Eudicot	N	Unclear	Forest	10.6 ± 4.2	400	Londoño et al. (2018)

Table S3 Intrinsic water use efficiency (iWUE), conductance to water (G_w), total annual carbon gain (A_{tot}) and length of the growing season (t_g) for five canopy trees at Foulden Maar, *Litsea calicarioides* (Lcal), *Cryptocarya taieriensis* (Ctai), cf. Myrtaceae (Myrt), cf. Elaeocarpaceae/Cunoniaceae (E/C), *Cryptocarya maarensis* (Cmaa), and fossil specimens Mu (Tesfamichael et al., 2017) and M2 – 6 (Londoño et al., 2018).

Type	**iWUE**	**G_w (mol m^{-2} s^{-1})**	**A_{tot} (gC m^{-2} yr^{-1})**	**t_g (months)**
Lcal	99 (73–136)	0.07 (0.04–0.10)	480 (255–711)	10.3
Ltai	75 (58–101)	0.09 (0.05–0.14)	478 (268–700)	10.3
Myrt	94 (68–133)	0.08 (0.04–0.12)	517 (242–814)	10.3
E/C	71 (54–98)	0.10 (0.04–0.16)	488 (213–787)	10.3
Lmaa	79 (62–105)	0.09 (0.05–0.12)	469 (262–692)	10.3
“Mu”	90 (76–110)	0.13 (0.09–0.18)	918 (686–1151)	12
M2	95 (80–111)	0.12 (0.09–0.15)	895 (514–1276)	12
M3	175 (138–216)	0.07 (0.05–0.09)	970 (566–1374)	12
M4	130 (105–157)	0.09 (0.07–0.11)	938 (540–1337)	12
M5	97 (81–118)	0.11 (0.08–0.14)	869 (494–1243)	12
M6	114 (95–134)	0.11 (0.08–0.13)	962 (561–1363)	12

Table S4 Raw output of reconstructed atmospheric carbon dioxide (C_a), carbon assimilation rates (A_n), leaf conductance to water (G_w), and intrinsic water use efficiency (iWUE) for each leaf fossil (±1σ).

Sample#	aff.	pCO_2 (ppm)	A_n (µmol s^{-1} m^{-2})	G_w (mol s^{-1} m^{-2})	iWUE
9-09-50-1	Lcal	601 – 1274	6.4 – 9.5	0.04 – 0.08	97 – 193
9-9-70-4	"P"	747 – 2169	6.7 – 10.1	0.03 – 0.08	98 – 261
14-2-15-5	Dys	1971 – 12101	9.6 – 11.7	0.02 – 0.09	109 – 424
14-2-15-1	E/C	290 – 747	5.3 – 9.6	0.07 – 0.17	40 – 97
14-2-40-1	Rip	-2454 – -1118	10.5 – 13.4	0.05 – 0.1	119 – 228
14-02-40-5	Lcal	369 – 762	5.7 – 8.9	0.04 – 0.08	86 – 171
14-2-40-6	E/C	302 – 829	5.3 – 9.9	0.05 – 0.13	52 – 136
15-0-9-1	"O"	2146 – 6567	8.3 – 11.2	0.05 – 0.08	115 – 210
17-91-45-5	Ctai	316 – 771	5.6 – 8.7	0.07 – 0.14	46 – 106

17-91-70-1	Lcal	664 – 1336	6.5 – 9.6	0.05 – 0.09	83 – 152
17-91-70-5	Lcal	451 – 1016	6.1 – 9.3	0.04 – 0.08	85 – 182
17-91-70-7	Lcal	301 – 675	5.5 – 8.6	0.05 – 0.1	63 – 137
17-91-70-8	Lcal	434 – 1303	6.1 – 9.3	0.04 – 0.1	70 – 199
17-91-80-2	Dys	451 – 1066	8 – 10.4	0.06 – 0.12	70 – 157
18-99-35-1	E/C	385 – 989	5.8 – 10.3	0.07 – 0.15	49 – 118
18-99-90-1	Lcal	406 – 946	5.9 – 9.1	0.05 – 0.09	74 – 164
18-99-90-2	Ctai	640 – 1871	6.6 – 9.6	0.07 – 0.15	52 – 110
18-99-90-5	E/C	285 – 628	5.2 – 9.6	0.07 – 0.14	49 – 102
18-99-90-13	Lota	570 – 1211	4.8 – 7.4	0.05 – 0.08	68 – 127
31-19-10-1	Lcal	315 – 601	5.5 – 8.6	0.06 – 0.09	71 – 131
31-19-20-3	Lcal	-7200 – 11056	7.3 – 10.6	0.07 – 0.13	67 – 130
31-19-20-4	Lcal	453 – 1257	6.2 – 9.3	0.06 – 0.13	53 – 131
31-19-20-5	"O"	435 – 919	6.9 – 9.7	0.06 – 0.11	73 – 140
31-19-34-1	Cmaa	284 – 763	5.4 – 8.6	0.06 – 0.12	51 – 133
31-19-56-3	Rip	1420 – 9280	9.4 – 12.2	0 – 0.06	119 – 631
31-19-56-2	Hplu	1120 – 2752	6.7 – 9.8	0.05 – 0.08	96 – 179
31-19-100-4	"P"	370 – 774	5.8 – 8.9	0.07 – 0.12	55 – 108
31-19-100-2	"Q"	331 – 842	7.4 – 10.9	0.06 – 0.13	62 – 152
32-20-30-1	Lcal	613 – 1164	6.4 – 9.5	0.05 – 0.08	94 – 165
32-20-60-1	Lcal	536 – 1083	6.3 – 9.4	0.05 – 0.09	84 – 156
32-20-60-2	cfC	379 – 723	5.8 – 8.8	0.06 – 0.09	74 – 134
32-20-60-3	"O"	644 – 1209	7.4 – 10.2	0.05 – 0.08	99 – 168
37-4-25-4	Ctai	354 – 747	5.8 – 8.8	0.07 – 0.13	53 – 101
37-4-25-1	cfE	507 – 1064	6.2 – 9.3	0.06 – 0.11	65 – 120
37-4-25-2	Dys	768 – 1566	8.8 – 10.9	0.08 – 0.12	81 – 132
38-97-90-10	Lcal	290 – 702	5.4 – 8.5	0.06 – 0.12	51 – 118
38-97-90-9	Myrt	359 – 844	5.8 – 10.4	0.06 – 0.12	61 – 135
38-97-90-11	Myrs	487 – 886	6.7 – 8.6	0.05 – 0.08	87 – 145
38-97-90-8	E/C	384 – 956	5.7 – 10.3	0.06 – 0.14	54 – 126
40-93-80-4	Lcal	432 – 868	6 – 9.1	0.05 – 0.08	85 – 162
40-93-80-1	Ctai	402 – 839	5.9 – 9	0.07 – 0.12	58 – 109

40-93-80-5	Rip	1817 – 4340	9.2 – 12	0.04 – 0.07	146 – 256
41-88-12-1	Lcal	385 – 746	5.8 – 8.9	0.06 – 0.1	68 – 125
41-88-12-9	"O"	395 – 1161	6.8 – 9.8	0.04 – 0.11	68 – 198
41-88-28-4	Lcal	284 – 583	5.3 – 8.3	0.06 – 0.1	61 – 120
41-88-28-7	Lcal	234 – 647	5.1 – 8.3	0.06 – 0.14	43 – 113
41-88-28-5	Ctai	452 – 1159	6.2 – 9.3	0.06 – 0.14	52 – 120
42-85-0-2	Lcal	349 – 691	5.6 – 8.7	0.06 – 0.1	64 – 118
42-85-70-3	Ctai	372 – 814	5.8 – 8.8	0.07 – 0.13	55 – 105
42-85-70-12	"C"	347 – 696	5.7 – 8.9	0.06 – 0.1	69 – 133
42-85-70-4	Myrt	320 – 705	5.6 – 10.1	0.06 – 0.13	57 – 119
42-85-70-1	"P"	645 – 1394	6.5 – 9.7	0.06 – 0.11	72 – 129
43-82-0-1	Ctai	497 – 1012	6.2 – 9.3	0.05 – 0.09	77 – 147
56-31-20-1	Lcal	720 – 1580	6.6 – 9.7	0.05 – 0.09	88 – 171
56-31-85-3	"H"	342 – 866	5.7 – 9	0.06 – 0.13	53 – 127
57-31-0-2	E/C	353 – 956	5.6 – 10.2	0.06 – 0.14	52 – 129
57-31-95-3	Ctai	368 – 891	5.8 – 9	0.06 – 0.12	58 – 133
62-19-02-1	Lcal	463 – 932	6.1 – 9.2	0.05 – 0.09	80 – 151
62-19-84-1	Myrs	2195 – 9398	8 – 9.9	0.05 – 0.08	114 – 190
62-19-90-1	Cmaa	604 – 1257	6.4 – 9.5	0.07 – 0.12	65 – 119
63-19-30-1	Bota	431 – 1320	6.1 – 9.3	0.05 – 0.12	60 – 157
63-19-95-3	Lcal	534 – 1401	6.3 – 9.5	0.04 – 0.08	89 – 194
63-19-95-1	Myrt	373 – 1077	5.9 – 10.8	0.03 – 0.08	83 – 236
83-48-42-1	Dys	760 – 1649	8.8 – 11	0.05 – 0.1	96 – 186
83-48-50-1	"O"	459 – 1220	7 – 9.9	0.05 – 0.11	69 – 170
83-48-86-2	Lcal	382 – 761	5.8 – 8.9	0.06 – 0.1	66 – 122
83-48-86-3	Cmaa	327 – 662	5.6 – 8.6	0.06 – 0.11	58 – 113
84-43-18-2	Myrt	408 – 973	6 – 10.7	0.06 – 0.11	71 – 134
84-43-68-1	Lcal	278 – 555	5.3 – 8.3	0.06 – 0.11	58 – 110
84-43-68-4	Lcal	430 – 953	6 – 9.1	0.06 – 0.1	68 – 139
101-4-16-2	Lcal	461 – 963	6.1 – 9.2	0.04 – 0.08	90 – 180
101-04-16-1	E/C	317 – 639	5.2 – 9.7	0.06 – 0.12	58 – 111

References

Bannister, J. M., Conran, J. G., and Lee, D. E.: Lauraceae from rainforest surrounding an early Miocene maar lake, Otago, southern New Zealand, Review of Palaeobotany and Palynology, 178, 13–34, 2012.

Christophel, D. C. and Rowett, A. I.: Leaf and cuticle atlas of Australian leafy Lauraceae, Flora of Australia Supplementary Series, 6, 217, 1996.

Conran, J. G., Bannister, J. M., and Lee, D. E.: Fruits and leaves with cuticle of *Laurelia otagoensis* sp. nov. (Atherospermataceae) from the early Miocene of Otago (New Zealand), Alcheringa, 37, 1–14, 2013.

Conran, J. G., Bannister, J. M., Lee, D. E., Carpenter, R. J., Kennedy, E. M., Reichgelt, T., and Fordyce, R. E.: An update of monocot macrofossil data from New Zealand and Australia, Botanical Journal of the Linnean Society, 178, 394–420, 2015.

Conran, J. G., Bannister, J. M., Mildenhall, D. C., and Lee, D. E.: *Hedycarya* macrofossils and associated *Planarpollenites* pollen from the early Miocene of New Zealand, American Journal of Botany, 103, 938–956, 2016.

Fick, S. E. and Hijmans, R.J.: WorldClim 2: new 1km spatial resolution climate surfaces for global land areas, International Journal of Climatology, 37, 4302–4315, 2017.

Leathwick, J. R.: New Zealand's potential forest pattern as predicted from current species-environment relationships. New Zealand Journal of Botany, 39, 447–464, 2001.

Londoño, L., Royer, D. L., Jaramillo, C. A., Escobar, J., Foster, D. A., Cárdenas-Rozo, A. L., and Wood, A.: Early Miocene CO_2 estimates from a Neotropical fossil leaf assemblage exceed 400 ppm, American Journal of Botany, 105, 1929–1937, 2018.

Pole, M. S.: Lauraceae macrofossils and dispersed cuticle from the Miocene of southern New Zealand, Palaeontologia Electronica, 10, 3A:38 p, 2007.

Pole, M. S.: Dispersed leaf cuticle from the Early Miocene of southern New Zealand, Palaeontologia Electronica, 11, 15A:117 p, 2008.

Tarran, M., Wilson, P. G., and Hill, R. S.: Oldest record of *Metrosideros* (Myrtaceae): Fossil flowers, fruits, and leaves from Australia, American Journal of Botany, 103, 754–768, 2016.

Tesfamichael, T., Jacobs, B. F., Tabor, N. J., Michel, L., Currano, E. D., Feseha, M., Barclay, R. S., Kappelman, J., and Schmitz, M.: Settling the issue of "decoupling" between atmospheric carbon dioxide and global temperature: $[CO_2]_{atm}$ reconstructions across the warming Paleogene-Neogene divide, Geology, 45, 999–1002, 2017.