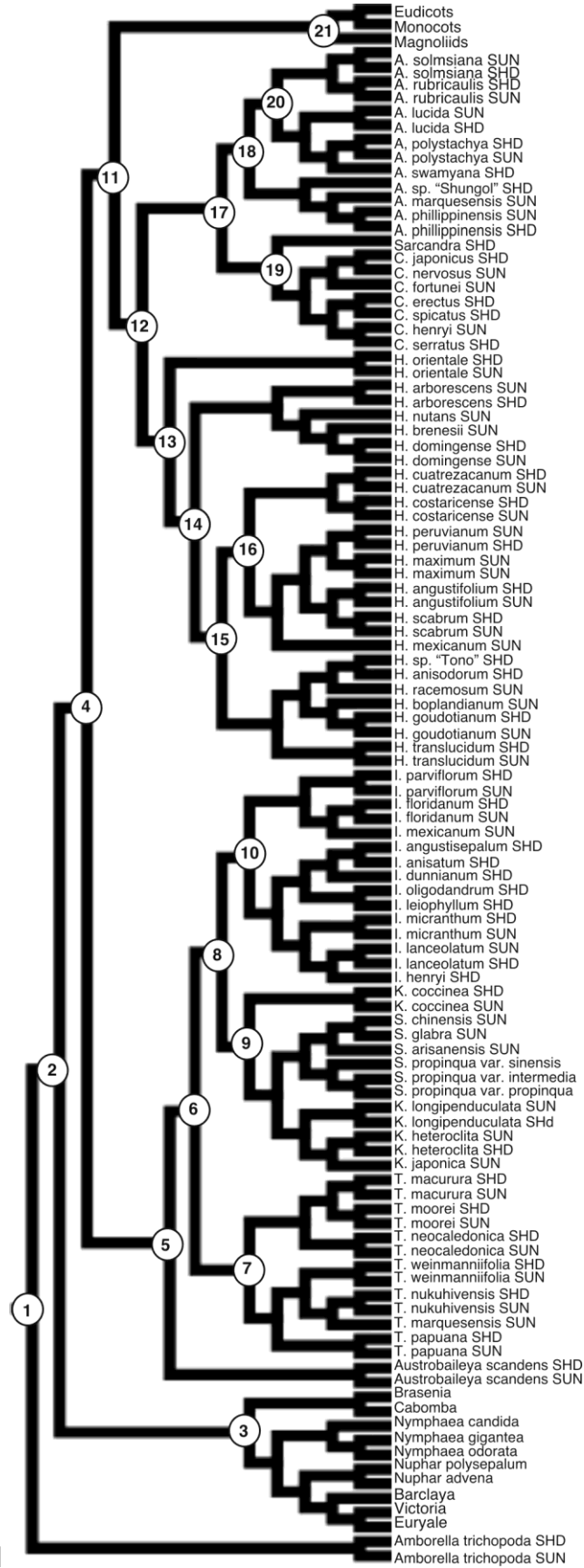


Supplemental Figure 1. Phylogenetic nodes for ancestral functional trait

reconstruction values corresponding to the node numbers in Supplemental Appendix IV.

The topology of extant basal angiosperm lineages was determined as described in

“Materials and Methods.”



Supplemental Figure 1

Supplemental Appendix I

Field sites and ecophysiological trait values for the extant species sampled. Trait values are means of sample sizes provided in the Materials and Methods section. Traits included: vein density (D_v , mm mm⁻²), measured photosynthetic capacity on leaf area basis (P_c ; $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$); measured maximum stomatal conductance to water vapor (g_m , mmol H₂O m⁻² s⁻¹), stomatal density (S_D , number mm⁻²), stomatal guard cell length (S_L , mm), stomatal guard cell width (S_W , mm), stomatal pore length (Pore_L, μm), stomatal pore depth (Pore_D, μm), and stomatal pore area at maximal aperture (SPA, m²). SUN and SHD refer to leaves sampled that expanded fully under exposed conditions and leaves that expanded under shaded conditions (see Methods section for details on habitat designation), respectively.

Species	Study site	D_v	P_c	g_m	S_D	S_L	S_W	Pore _L	Pore _D	SPA x 10 ⁶
<i>Amborella trichopoda</i> SHD	Mt. Aoupinie, 850 m, New Caledonia	2.27	4.84	120	179	31.9	27.2	11.8	13.3	6.51
<i>Amborella trichopoda</i> SUN	Mt. Aoupinie, 850 m, New Caledonia	3.77	7.79	201	212	32.6	27.6	10.8	12.6	6.43
<i>Ascarina lucida</i> SHD	Saltwater Forest, Okarito, New Zealand	1.67	–	–	56	33.1	28.9	8.0	7.2	0.93
<i>Ascarina lucida</i> SUN	Saltwater Forest, Okarito, New Zealand	2.93	6.81	105	97	30.5	26.1	9.3	4.2	2.20
<i>Ascarina maheshwari</i> SUN	Mt. Wilhelm, 2800 m, Simbu Province, Papua New Guinea	5.06	–	–	153	36.5	30.4	9.6	12.3	3.72
<i>Ascarina marquesensis</i> SUN	Mt Oomu, Toovii Plateau, 750 m, Nuku Hiva, French Polynesia	3.87	–	–	121	44.5	32.1	9.8	10.0	3.05
<i>Ascarina philippinensis</i> SHD	Mt. Gumi, 2900 m, Morobe Province, Papua New Guinea	3.98	–	–	46	47.5	36.9	18.9	11.9	4.26
<i>Ascarina philippinensis</i> SUN	Mt. Gumi, 2900 m, Morobe Province, Papua New Guinea	4.70	9.29	202	80	63.2	52.7	16.3	9.3	5.62
<i>Ascarina polystachya</i> SHD	Mt. Marau, 780 m, Tahiti, French Polynesia	2.87	–	–	47	39.1	28.2	8.4	9.6	0.87
<i>Ascarina polystachya</i> SUN	Mt. Marau, 780 m, Tahiti, French Polynesia	3.81	–	–	130	35.9	30.4	10.8	8.3	3.95
<i>Ascarina rubricaulis</i> SHD	Mt. Dzumac, 900 m, Province Sud, New Caledonia	2.41	–	–	101	47.0	31.6	17.6	9.3	8.26
<i>Ascarina rubricaulis</i> SUN	Mt. Dzumac, 900 m, Province Sud, New Caledonia	4.60	10.3	225	95	42.9	33.8	9.2	11.4	2.11
<i>Ascarina solmsiana</i> var. <i>grandifolia</i> SHD	Mt. Dzumac, 900 m, Province Sud, New Caledonia	4.37	–	–	70	36.3	29.2	11.3	14.2	2.33
<i>Ascarina solmsiana</i> var. <i>grandifolia</i> SUN	Mt. Dzumac, 900 m, Province Sud, New Caledonia	4.64	9.23	110	130	36.4	31.2	10.1	9.5	3.47
<i>Ascarina solmsiana</i> var. <i>solmsiana</i> SUN	Mt. Aoupinie, 850 m, Province Nord, New Caledonia	4.19	11.12	115	154	33.4	26.7	9.0	8.5	3.26
<i>Ascarina</i> sp.	Mt. Shungol, 1800 m, Morobe Province, Papua New Guinea	4.31	–	–	118	31.6	26.8	7.1	10.5	1.55
<i>Ascarina swamyana</i> SHD	Des Vouex Peak, 900 m, Taveuni, Fiji		–	–	–	–	–	–	–	–
<i>Austrobaileya scandens</i> SHD	Mt. Bartle Frere, 650 m, Queensland, Australia	1.94	–	–	64	42.1	39.5	11.6	16.1	2.27
<i>Austrobaileya scandens</i> SUN	Mt. Bartle Frere, 650 m, Queensland, Australia	2.20	4.29	80	78	52.2	43.2	18.6	13.3	7.00
<i>Brasenia scherberi</i> SUN floating	Monterey Lake, Tennessee, USA	1.66	24.26	470	258	25.5	25.2	5.0	9.9	1.66
<i>Cabomba caroliniana</i> SUN floating	near Huntsville, Alabama, USA	0.74	–	–	67	26.2	24.3	7.4	10.1	0.96
<i>Chloranthus erectus</i> SHD pop. 1	Mt. Gumi, 1850 m, Morobe Province, Papua New Guinea	2.03	4.23	75	50	49.6	33.1	15.5	13.7	3.15
<i>Chloranthus erectus</i> SHD pop. 2	Ban Maeo Doi Ngo, Mae Teng, Chiang Mai, Thailand 19 10 23.4 N, 98.46 30 E, 1310 m	3.04	4.77	51	49	47.2	33.2	10.2	13.7	1.32

<i>Chloranthus henryi</i> SUN	Xinning, Hunan, China	3.27	–	–	–	–	–	–	–	–
<i>Chloranthus japonicus</i> SHD	Cultivated, collected from China, Knoxville, Tennessee USA	3.10	8.37	110	69	40.7	32.4	11.8	15.4	2.54
<i>Chloranthus multistachys</i> SHD	Cultivated, collected from China, Knoxville, Tennessee USA	3.25	–	–	–	–	–	–	–	–
<i>Chloranthus nervosus</i> SUN pop. 1	Pong, Yaeng, Doi Sutep, 1355 m; 18 55, 98 50'E, Thailand	3.22	–	–	134	39.6	29.2	11.2	10.8	4.40
<i>Chloranthus nervosus</i> SUN pop. 2	Lam Dong Province, Vietnam,	4.47	–	–	79	43.3	34.9	9.3	15.3	1.79
<i>Chloranthus serratus</i> SHD pop. 1	Hong Kong, China	2.53	–	–	97	43.7	29.6	12.8	8.7	4.13
<i>Chloranthus serratus</i> SHD pop. 2	Cultivated, population from China, Knoxville, Tennessee USA	2.25	6.46	86	42	45.2	31.8	14.6	13.7	2.34
<i>Chloranthus sessilifolius</i> SHD	Cultivated, collected from China, Knoxville, Tennessee USA	2.64	–	–	–	–	–	–	–	–
<i>Chloranthus sessilifolius</i> SUN	Cultivated, collected from China, Knoxville, Tennessee USA	2.80	–	–	–	–	–	–	–	–
<i>Chloranthus spicatus</i> SHD	Cultivated, collected from China, Knoxville, Tennessee USA	3.42	6.56	79	90	43.3	30.8	11.1	16.1	2.90
<i>Euryale ferox</i> SUN	Botanical Garden Dresden, Germany	3.48	–	–	493	21.2	17.1	5.9	4.4	4.54
<i>Hedyosmum angustifolium</i> SHD	Wayquechas Reserve, 3000 m, Peru	3.53	–	–	81	46.9	36.6	13.7	11.0	4.01
<i>Hedyosmum angustifolium</i> SUN	Wayquechas Reserve, 3000 m, Peru	3.79	–	–	98	46.0	34.2	11.8	11.8	3.54
<i>Hedyosmum anisodorum</i> SHD	Trocha Union, Peru,	3.78	–	–	118	49.8	34.8	17.2	10.5	9.16
<i>Hedyosmum arborescens</i> SHD	Vinegar Hill Trail, 1500 m, Blue Mountains, Jamaica	2.71	–	–	51	51.1	35.9	20.0	8.8	5.32
<i>Hedyosmum arborescens</i> SUN	Vinegar Hill Trail, 1500 m, Blue Mountains, Jamaica	3.59	–	–	75	50.3	36.8	19.9	11.7	7.77
<i>Hedyosmum bonplandianum</i> SUN	Estación Cacao 1250 m, Guancaste, Costa Rica,	2.26	10.7	160	72	54.2	34.2	23.2	13.3	10.20
<i>Hedyosmum brenesii</i> SUN	Estación Cacao, 900 m, Guancaste, Costa Rica,	4.39	8.37	170	59	45.0	35.0	21.0	9.0	6.78
<i>Hedyosmum costaricense</i> SHD	Tapanti, 900 m, Costa Rica	2.83	–	–	–	–	–	–	–	–
<i>Hedyosmum costaricense</i> SUN	Tapanti, 950 m, Costa Rica	3.11	–	–	–	–	–	–	–	–
<i>Hedyosmum cuatrecazanum</i> SHD	San Pedro, Plot 2, 1750 m, Peru	3.96	–	–	111	44.1	31.3	15.8	8.3	7.29
<i>Hedyosmum cuatrecazanum</i> SUN	Kosnipata road, 2000 m, Peru	4.49	–	–	110	39.2	30.6	15.4	10.7	6.83
<i>Hedyosmum domingense</i> SUN	Pico Duarte, 1500 m, Dominican Republic	3.86	–	–	142	48.4	30.9	14.8	9.7	8.14
<i>Hedyosmum domingense</i> SHD	Pico Duarte, 1500 m, Dominican Republic	3.53	–	–	85	42.3	29.9	12.5	10.0	3.51
<i>Hedyosmum goudotianum</i> SHD	Kosnipata road, 2000 m, Peru	2.86	–	–	53	44.7	33.5	17.4	9.5	4.26
<i>Hedyosmum goudotianum</i> SUN	Kosnipata road, 2000 m, Peru	4.10	–	–	79	48.7	34.7	20.5	9.8	8.63
<i>Hedyosmum maximum</i> SHD	Wayquechas Reserve, 3000 m, Peru	3.24	–	–	47	49.8	39.4	17.6	10.9	3.82
<i>Hedyosmum maximum</i> SUN	Wayquechas Reserve, 3000 m, Peru	3.23	–	–	82	48.9	39.0	15.3	10.5	5.03
<i>Hedyosmum mexicanum</i> SUN	Ojo de Agua, Talamancas, Costa Rica	3.52	–	–	–	–	–	–	–	–
<i>Hedyosmum nutans</i> SUN	Vinegar Hill Trail, 800 m, Blue Mountains, Jamaica	5.02	–	–	97	44.7	31.7	15.4	11.2	5.99
<i>Hedyosmum orientale</i> SHD	Dialoushan, 1150 m, Hainan Island, China	1.61	–	–	–	–	–	–	–	–
<i>Hedyosmum orientale</i> SUN	Dialoushan, 1150 m, Hainan Island, China	2.14	–	–	61	47.5	35.3	21.0	10.5	7.01
<i>Hedyosmum peruvianum</i> SHD	Kosnipata road, 2000 m, Peru	3.20	–	–	132	40.8	33.5	17.1	9.0	10.14
<i>Hedyosmum peruvianum</i> SUN	Kosnipata road, 2000 m, Peru	4.67	–	–	156	34.6	27.7	11.7	8.9	5.60
<i>Hedyosmum racemosum</i> SUN	San Pedro, 1400 m, near Cock-of-the-Rock Lodge, Peru	4.94	–	–	144	45.0	33.7	15.1	9.9	8.63

<i>Hedyosmum scabrum</i> SHD	Wayquechas Reserve, 3000 m, Peru	2.72	–	–	41	55.1	38.1	23.7	10.3	6.00
<i>Hedyosmum scabrum</i> SUN	Wayquechas Reserve, 3000 m, Peru	3.25	–	–	68	48.6	40.2	18.4	10.3	6.08
<i>Hedyosmum</i> sp. SHD	850 m, Tono Alto, Peru	3.42	–	–	56	44.6	31.4	13.9	10.3	2.87
<i>Hedyosmum translucidum</i> SHD	Wayquechas Reserve, 3000 m, Peru	2.67	–	–	34	50.2	38.9	16.6	13.8	2.45
<i>Hedyosmum translucidum</i> SUN	Wayquechas Reserve, 3000 m, Peru	5.01	–	–	92	45.2	34.3	13.4	9.8	4.33
<i>Illicium angustisepalum</i> SHD	Sunset Peak, 900 m, Hong Kong China	5.12	–	–	91	65.6	52.8	29.1	14.9	20.13
<i>Illicium anisatum</i> SHD	Cultivated, collected from Japan, at Knoxville, TN, USA	3.79	11.12	125	94	50.4	43.7	12.9	13.8	4.10
<i>Illicium dunnianum</i> SHD	Hong Kong, China	3.87	–	–	59	56.5	48.0	23.2	13.2	8.32
<i>Illicium floridanum</i> SHD	Cultivated, collected from Apalachicola, Florida, and at Knoxville, Tennessee USA	4.94	–	–	40	54.5	38.7	14.9	12.1	2.35
<i>Illicium floridanum</i> SUN	Cultivated, collected from Apalachicola, Florida, and at Knoxville, Tennessee USA	5.13	13.89	144	84	48.6	32.9	15.3	15.7	5.09
<i>Illicium henryi</i> SHD	Cultivated, source unknown, at Knoxville, Tennessee USA	4.82	10.9	130	75	48.5	36.8	12.4	12.6	3.04
<i>Illicium lanceolatum</i> SHD	Cultivated, source unknown, at Knoxville, Tennessee USA	4.40	9.79	110	67	44.0	35.8	13.4	11.5	3.13
<i>Illicium lanceolatum</i> SUN	Xinning, Hunan, China	4.82	–	–	117	36.2	29.1	9.1	8.7	2.53
<i>Illicium leiophyllum</i> SHD	Hong Kong, China	4.96	–	–	50	51.7	36.5	14.5	9.8	2.74
<i>Illicium majus</i> SHD	Xinning, Hunan, China	4.26	–	–	108	39.4	33.0	16.2	13.2	7.48
<i>Illicium mexicanum</i> SUN	Cultivated, source unknown, at Knoxville, Tennessee USA	3.78	–	–	51	62.0	42.2	20.3	13.0	5.48
<i>Illicium micranthum</i> SHD	Ma On Shan, Hong Kong, China	2.9	–	–						
<i>Illicium micranthum</i> SUN	Xinning, Hunan, China	4.19								
<i>Illicium oligandrum</i> SHD	Dialoushan, Hainan, China	2.34	–	–	106	53.5	45.0	16.4	13.2	7.53
<i>Illicium parviflorum</i> SHD	Alexander Springs, Florida, USA	4.08	–	–	76	50.9	34.9	18.4	13.0	6.68
<i>Illicium parviflorum</i> SUN	Cultivated, source unknown, at Knoxville, Tennessee USA	5.71	15.23	180	87	45.4	31.5	16.6	13.0	6.24
<i>Illicium penninsulare</i> SHD	Sri Phangha, Thailand	4.27	–	–	72	61.7	55.8	21.7	11.9	8.86
<i>Illicium penninsulare</i> SUN	Sri Phangha, Thailand	5.16	–	–	73	59.9	49.9	16.5	17.4	5.25
<i>Illicium simonsii</i> SHD	Cultivated, University of California, Botanic Garden, USA	5.12	–	–	129	41.7	36.8	9.5	15.0	3.06
<i>Illicium</i> sp. 1 SHD	Hong Xiao Station, 1500 m, Lam Dong, Vietnam	4.76	–	–	63	48.8	41.0	15.7	8.9	4.08
<i>Illicium</i> sp. 2 SHD	1100 m, Lam Dong, Vietnam	4.49	–	–						
<i>Illicium ternstroemioides</i>	Dialoushan, Hainan, China	4.99								
<i>Kadsura anamosmum</i>	Chaing Mai, Thailand	4.63	–	–	68	53.3	44.7	15.7	15.8	4.38
<i>Kadsura coccinea</i> SHD	Lamma Island, Hong Kong, China	3.88	–	–	49	67.3	55.1	20.3	18.5	5.28
<i>Kadsura coccinea</i> SUN	Lamma Island, Hong Kong, China	5.92	–	–	33	102.1	72.4	43.9	22.0	16.42
<i>Kadsura heteroclita</i> SHD pop. 1	Khao Leung Thailand	2.28	–	–	36	61.7	41.8	25.5	9.1	6.12
<i>Kadsura heteroclita</i> SUN pop. 1	Khao Leung Thailand	6.02	–	–	85	54.3	38.3	18.6	12.4	7.75
<i>Kadsura heteroclita</i> SUN pop. 2	Lam Dong, Vietnam	6.35	–	–	71	56.5	45.5	21.5	13.9	8.61
<i>Kadsura japonica</i> SUN	Cultivated, population from South Korea, at Knoxville, Tennessee, USA	3.45	10.12	150	90	60.1	40.2	18.0	12.4	7.64

<i>Kadsura longipendunculata</i> SUN	Cultivated, population from China, at Knoxville, TN, USA	5.03	14.12	210	90	64.2	48.0	20.2	16.2	9.59
<i>Kadsura oblongifolia</i> SHD	Dialoushan, Hainan, China	2.71	–	–	44	66.6	52.0	20.6	12.6	4.91
<i>Nuphar advena</i> SUN	Botanical Garden Dresden, Germany	6.44	–	–	732	21.3	18.9	5.1	7.2	4.89
<i>Nuphar polysepalum</i> SUN	Monterey Lake, Tennessee, USA	5.85	27.12	520	539	21.2	18.1	3.3	7.1	1.57
<i>Nymphaea candida</i> SUN	Botanical Garden Ghent University, Belgium	1.06	–	–	484	20.4	18.8	5.3	5.8	3.49
<i>Nymphaea gigantea</i> SUN	Bulolo-Wau Rd, Morobe, PNG	1.39	–	–	379	14.4	13.3	4.1	6.9	1.71
<i>Nymphaea odorata</i> SUN	Monterey Lake, Tennessee, USA	0.46	24.12	475	677	17.9	15.3	2.9	6.5	1.47
<i>Sarcandra glabra</i> pop. 1 SHD	Collected Okinawa, Japan, cultivated at Knoxville, Tennessee, USA	2.39	4.03	44	68	44.6	38.7	9.4	13.9	1.58
<i>Sarcandra glabra</i> pop. 2 SHD	Collected Sri Phangha, Thailand, cultivated at Knoxville, Tennessee, USA	2.12	4.18	55	36	48.5	43.5	11.6	17.1	1.29
<i>Sarcandra glabra</i> pop. 3 SUN	Collected Lam Dong, Vietnam, collected at Knoxville, Tennessee, USA	2.00	4.23	45	39	49.8	42.8	9.6	13.3	0.94
<i>Schisandra arisanensis</i> SUN	Cultivated, source unknown, at Knoxville, Tennessee USA	2.53	10.89	178	52	65.1	41.7	21.8	12.9	6.48
<i>Schisandra chinensis</i> SUN	Cultivated, source unknown, at Knoxville, Tennessee USA	3.74	13.5	167	88	53.6	37.0	22.9	13.7	12.06
<i>Schisandra glabra</i> SUN	Cultivated, collected from Arkansas, USA, at Knoxville, Tennessee, USA									
<i>Schisandra propinqua</i> var. <i>sinensis</i> SUN	Source unknown, cultivated, Knoxville Tennessee, USA	4.38	12.47	165	90	61.9	41.1	20.0	11.0	9.47
<i>Schisandra propinqua</i> var. <i>intermedia</i> SUN	Chaing Mai, Thailand	2.89	–	–	27	64.0	47.9	24.5	12.4	4.19
<i>Schisandra propinqua</i> var. <i>propinqua</i> SUN	Source unknown, cultivated, Knoxville Tennessee, USA	4.11	8.35	144	58	64.6	45.8	26.7	18.8	10.89
<i>Schisandra</i> sp. 1	Sri Phangha, Thailand	2.87	–	–	51	64.5	45.0	22.8	10.7	6.89
<i>Schisandra</i> sp. 2	Lam Dong Province, Vietnam	3.78	–	–	45	71.1	57.2	25.0	16.0	7.31
<i>Schisandra</i> sp. 3	Chaing Mai, Thailand	6.31	–	–	81	54.2	42.2	18.8	12.1	7.49
<i>Schisandra</i> sp. 4	Sri Phangha, Thailand	3.11	–	–	50	64.6	48.5	27.3	15.7	9.73
<i>Schisandra</i> sp. 5	Chaing Mai, Thailand	4.05	–	–	51	63.6	47.6	19.8	14.6	5.20
<i>Schisandra henryi</i> SUN	Cultivated, source unknown, at Knoxville, Tennessee, USA	3.20	12.98	163	75	70.0	42.9	25.0	14.5	12.27
<i>Trimenia macrura</i> SHD	Mt. Shungol, 1650 m, Morobe Province, Papua New Guinea	2.72			170	36.0	26.3	10.7	10.4	5.12
<i>Trimenia macrura</i> SUN	Mt. Shungol, 1650 m, Morobe Province, Papua New Guinea	3.68	8.91	120	126	35.2	26.9	11.7	14.1	4.54
<i>Trimenia marquesensis</i> SUN	Mt. Temetiu, 900 m, Hiva Oa, French Polynesia	2.97	–	–	156	43.3	29.8	15.2	17.8	9.44
<i>Trimenia moorei</i> SHD	900 m, Styx River State Forest, New South Wales, Australia	3.96	–	–	112	37.2	28.1	11.2	10.4	3.68
<i>Trimenia moorei</i> SUN	900 m, Styx River State Forest, New South Wales, Australia	4.60	–	–	147	41.2	29.0	12.4	11.7	5.91
<i>Trimenia neocaledonica</i> SHD	Mt. Aoupinie, 850 m, New Caledonia	2.85	–	–	58	64.7	43.5	24.3	13.8	8.97
<i>Trimenia neocaledonica</i> SUN	Mt. Aoupinie, 850 m, New Caledonia	3.77	7.29	157	72	56.7	40.3	21.9	15.0	9.00
<i>Trimenia nukuhivensis</i> SHD	Mt Oomu, Toovii Plateau, 750 m, Nuku Hiva, French Polynesia	3.30	–	–	137	45.5	29.6	17.6	9.8	11.12
<i>Trimenia nukuhivensis</i> SUN	Mt Oomu, Toovii Plateau, 750 m, Nuku Hiva, French	4.59	–	–	184	40.8	27.3	15.0	9.8	10.87

	Polynesia									
<i>Trimenia papuana</i> SHD	Mt. Gumi, 2300 m, Morobe Province, Papua New Guinea	3.27	–	–	90	41.2	26.5	15.8	9.7	5.85
<i>Trimenia papuana</i> SUN	Mt. Gumi, 2300 m, Morobe Province, Papua New Guinea	4.57	8.9	171	171	35.3	25.5	14.3	10.2	9.20
<i>Trimenia weinmanniifolia</i> SHD	Des Vouex Peak, 900 m, Taveuni, Fiji	3.37	–	–	150	38.3	26.6	12.1	11.5	5.72
<i>Trimenia weinmanniifolia</i> SUN	Des Vouex Peak, 900 m, Taveuni, Fiji	5.69	–	–	255	37.9	26.2	11.8	13.2	9.26
<i>Victoria cruziana</i>	Botanical Garden Dresden, Germany	3.51	–	–	303	21.3	24.3	5.3	6.0	2.25

Supplemental Appendix II. Leaf impression, compression, and cuticle fossils sampled for comparative reconstructions of leaf gas exchange capacities. Previous discussions on the systematic affinities of the fossils based on venation and/or cuticular anatomy can be found in the references cited.

	Systematics	Fossil type	Age and locality	References
<i>Celastrorhynchium latifolium</i>	Uncertain	Impression, venation	Early Albian, upper Zone I, Baltimore, MD, Potomac Group, USA	Hickey and Doyle (1977)
<i>Celastrorhynchium</i> cf. <i>C. obovatum</i>	Chloranthoid?	Compression, venation and cuticle	Early Albian, upper Zone I, Drewry's Bluff, VA, Potomac Group, USA	Upchurch (1984b)
<i>Celastrorhynchium</i> sp. Drewry's Bluff	Chloranthoid	Compression, venation and cuticle	Early Albian, upper Zone I, Drewry's Bluff, VA, Potomac Group, Virginia, USA	Upchurch (1984a)
<i>Crassidenticulum decurrens</i> Upchurch and Dilcher	Chloranthoid	Impression, venation	Latest Albian, Braun Ranch, KS and Rose Creek, NE, Dakota Formation, USA	Upchurch and Dilcher (1990); Wang and Dilcher (2006)
<i>Crassidenticulum cracendentis</i> Dilcher and Wang	Chloranthoid	Impression, venation	Middle-Late Cenomanian, Courtland, MN, Dakota Formation, USA	Wang and Dilcher (2009)
<i>Crassidenticulum landisae</i> Dilcher & Wang	Chloranthoid	Impression, venation	Latest Albian, Braun Ranch, KS, Dakota Formation, USA	Wang and Dilcher (2006)
Drewry's Bluff Leaf Type no. 1 (most likely <i>Moutonia</i>)	Chloranthoid	Compression, venation and cuticle	Early Albian, upper Zone I, Drewry's Bluff, VA, Potomac Group, USA	Upchurch (1984a, b)
<i>Densinervum kaulii</i> Upchurch and Dilcher	Chloranthoid	Impression, venation	Latest Albian, Rose Creek, NE, and middle to late Cenomanian, Courtland I, MN, Dakota Formation, USA	Upchurch and Dilcher (1990), Wang and Dilcher (2009)
<i>Eucalyptorhynchium oblongifolium</i> Fontaine	Austrobaileyoid or chloranthoid	Compression, venation and cuticle	Early Albian, upper Zone I, Fredericksburg, VA, and Drewry's Bluff, VA, Potomac Group, USA	Fontaine (1889); Doyle and Hickey (1976); Hickey and Doyle (1977); Upchurch (1984a, b)
<i>Ficorhynchium</i> cf. Fontaine	Uncertain	Compression, venation and cuticle	Early Albian, upper Zone I, Drewry's Bluff, VA, Potomac Group, USA	Upchurch (1984a, b)
<i>Ficorhynchium crassinerve</i> Fontaine	Austrobaileyoid	Compression, venation and cuticle	Early Albian, upper Zone I, Fredericksburg, VA, Potomac Group, USA	Fontaine (1889); Doyle and Hickey (1976); Hickey and Doyle (1977); Upchurch (1983)
Illiciales Type 1 Upchurch	Illicioid	Dispersed cuticle	Uppermost Maastrichtian, Sugarite Coal, NM, Raton Formation, USA	Upchurch (1995)
Illiciales Type 2 Upchurch	Illicioid	Dispersed cuticle	Uppermost Maastrichtian, Sugarite Coal, NM, Raton Formation, USA	Upchurch (1995)
<i>Longstrethia aspera</i> (Lesquereux) Hongshan Wang comb. nov.	Austrobaileyoid	Compression, venation	Latest Albian, Hoisington III, Kansas, Dakota Formation, USA	Wang (2002)
<i>Longstrethia varidentata</i> Upchurch & Dilcher	Austrobaileyoid	Compression, venation and cuticle	Latest Albian, Rose Creek, NE, Dakota Formation, USA	Upchurch and Dilcher (1990)

<i>Moutonia</i> sp.	Chloranthoid	Dispersed cuticle	Late Albian, KS, Longford Member, Kiowa Formation, USA	Upchurch (1995)
Aff. <i>Moutonia</i> sp.	Chloranthoid	Dispersed cuticle	Late Albian, KS, Longford Member, Kiowa Formation, USA	Upchurch (1995)
<i>Proteaephyllum reniforme</i> Fontaine	Probable ANITA grade, Nymphaeales?	Compression, venation	Early Albian, upper Zone I, Fredericksburg, VA, Potomac Group, USA	Hickey and Doyle (1977)
Protoilliciales Type I	Cf. Illiciaceae	Dispersed cuticle	Lowermost Paleocene, Sugarite Coal, Raton Formation, New Mexico, USA	Upchurch (1995)
<i>Quercophyllum tenuinerve</i> Fontaine	Chloranthoid	Impression, venation	Aptian, lower Zone I, Dutch Gap, VA, Potomac Group, Dutch Gap, USA	Hickey and Doyle (1977)
<i>Reynoldsiophyllum nebrascense</i> Upchurch and Dilcher	Chloranthoid	Impression, venation	Latest Albian, Rose Creek, NE, Dakota Formation, USA	Upchurch and Dilcher (1990)
<i>Rogersia angustifolia</i> Fontaine	Magnoliid?	Compression, venation	Early Albian, Upper Zone I, Fredericksburg, VA, Potomac Group, Virginia, USA	Fontaine (1889); Wolfe et al. (1975); Hickey and Doyle (1977)
" <i>Sapindopsis</i> " <i>elliptica</i> Fontaine	Magnoliid?	Impression, venation	Early Albian, Upper Zone I, Fredericksburg, VA, Potomac Group, USA	Fontaine (1889); Wolfe et al. (1975)
<i>Vitiphyllum multifidum</i> Fontaine	Uncertain	Impression, venation	Early Albian, Upper Zone I, Federal Hill, Baltimore, MD, Potomac Group, USA	Fontaine (1889); Doyle and Hickey (1976); Hickey and Doyle (1977)

Supplemental Appendix III**Stratigraphic ages for fossils, criteria for selection of fossils for vein measurements, and systematics of fossil leaves**

Stratigraphic ages for fossils. - Critical to any discussion of angiosperm evolution is the assumed stratigraphic age models. We base our age assignments on previous studies that correlated terrestrial angiosperm-bearing sequences with marine sections that have independent age control. For the Potomac Group, we follow the age model of Hochuli and colleagues (2006), which is based on palynological correlation between terrestrial sequences of the Atlantic Coastal Plain and marine sequences of Portugal that are dated based on invertebrates, carbon isotopes, and dinoflagellates. Zone I ranges in age from Aptian to lower Albian, with lower Zone I assigned to the Aptian, and upper Zone I assigned to the lower Albian. Position of leaf localities within Zone I follows Doyle and Hickey (1976). For the Dakota Formation of Kansas and Nebraska, we follow the age model of Gröcke et al. (2006), who recognize the Albian-Cenomanian boundary and Oceanic Anoxic Event 1D near the top of the Dakota Formation in southeast Nebraska, based on a pronounced carbon isotopic excursion and a depositional hiatus that they correlate to the D2 sequence boundary. We tentatively date the Dakota leaf megafossils from Kansas and Nebraska as latest Albian, based on the placement of the Albian-Cenomanian boundary in southeast Nebraska and the Late Albian age of the underlying Kiowa Formation in Kansas. The Dakota Formation of Minnesota is dated as middle to upper Cenomanian, based on the occurrence of late Cenomanian macroinvertebrates at the top of the Dakota sequence in Minnesota and an inferred Cenomanian age for a weathering surface that underlies the Dakota sequence (Merewether 1983). The latest Cretaceous and earliest Paleocene leaf cuticles from the Raton Formation of Colorado and New Mexico are dated on the basis of palynology and their position relative to the Cretaceous-Tertiary boundary clay in the Sugarite Coal, New Mexico

(Beerling et al. 2001). The K-T boundary clay is a datum that occurs in both marine and terrestrial sections (e.g., Nichols and Johnson 2008).

Criteria for selection of fossils for vein measurements. - An error potentially leading to an underestimation of D_v in leaf fossils is loss of higher order veins by taphonomic processes. For example, deposition in coarse-grained sediments could potentially scour or obscure veins. Such a taphonomic effect is relevant for most Zone I fossil leaves because these are contained in coarse-grained sediments (Doyle and Hickey 1976; Hickey and Doyle 1977). To minimize errors, we combined two approaches. First, we worked with organically preserved leaves that possessed well preserved venation because many Zone I leaves are preserved as impressions with only a visible midvein (Fig. 1). Such fossils provide the most accuracy for determining D_v (Fig. 1). Second, we used a comparative approach to determine the minimum number of vein orders that would likely be present in samples with minimal distortion. To do so, we conducted a phylogenetic analysis of the number of vein orders in cleared leaves across two supertrees of extant angiosperm phylogeny (see below; Ellis et al. 2009). These results indicated that leaves possessing at least five vein orders and reticulated freely ending veinlets (i.e., two to five veinlets on the terminal vein order) represented the ancestral state for extant angiosperms as well as for all major successive nodes within the tree up (observations not shown). Veins with six vein orders were rare in the extant basal angiosperm species sampled, and some taxa had three or four vein orders and reticulated freely ending veinlets (observations not shown). In addition, we found that D_v was not well correlated with the number of vein orders across angiosperms ($r^2 = 0.24$, $n = 75$ species). Thus, we only sampled fossils that possessed a minimum of five vein orders and freely ending veinlets. Our sampling procedures suggest that we have probably overestimated D_v for Cretaceous angiosperm leaves.

Systematics of fossil leaves. - A detailed discussion of the systematics of fossil leaves used in our analysis is needed for three reasons. First, many of the fossil taxa used in our study were erroneously assigned to living families and genera by early workers, and have not yet been

formally revised using modern methods of leaf architecture and cuticular anatomy. This means that their generic names are misleading. Second, many of the systematic comparisons made between fossil and living angiosperms were made prior to the advent of molecular systematics, and in particular before molecular systematics provided the arrangement of basal angiosperm taxa currently accepted by botanists (*Amborella*, Nymphaeales, and Austrobaileyales). Third, many observations of the systematic distribution of leaf architectural and cuticular characters have not been published and need to be discussed in detail.

In our discussion we reference the publications that first discuss relationships of fossil species and update the discussion in terms of the current molecular phylogenies for basal angiosperms. We base our discussions of the systematic distribution of leaf architectural features on Hickey and Wolfe (1975), Upchurch and Dilcher (1990), Doyle (2007), and our unpublished observations. We base our discussions of the systematic distribution of leaf cuticular characters on Upchurch (1984a, b), Upchurch and Dilcher (1990), Carpenter (2005, 2006), and our own unpublished observations.

Two cuticular characters important in our discussion are the presence or absence of ridges on the abaxial (or lower) cuticle (e.g., striations) and the presence or absence of oil cells on the leaf epidermis or in the mesophyll. Both these characters are absent in *Amborella* and Nymphaeales, the two basalmost clades of living angiosperms, but are present in Austrobaileyales and later diverging branches of the angiosperm family tree. Carpenter (2006) argued that the low diversity of extant *Amborella* and Nymphaeales could mask extinction of these characters, and that they may have been present in the common ancestor of all living angiosperms. We take a different approach and assume that if characteristics were absent from the basalmost lineages of extant angiosperms, then they were absent from the common ancestor of all extant angiosperms.

Discussion of Individual Taxa

Celastrorphyllum—The genus *Celastrorphyllum* has been used for leaves with presumed affinities to living Celastraceae, especially Cretaceous leaves with serrate margins. The name *Celastrorphyllum* cannot be used for these leaves because the type species of *Celastrorphyllum* is entire-margined and Miocene in age (Upchurch and Dilcher 1990). Most Cretaceous leaves with serrate margins have a different tooth type from Celastraceae and represent different taxa. Therefore, we use the name *Celastrorphyllum* because a better taxonomic name has not yet been proposed, and discuss the taxonomic affinities of each species separately.

Celastrorphyllum latifolium—*C. latifolium* is a pinnately veined from the upper Zone I (lower Albian) Baltimore locality of the Potomac Group. It has poorly organized (first rank) venation and an uncertain phylogenetic position.

Celastrorphyllum cf. *C. obovatum*—Cf. *C. obovatum* is an obovate leaf with cuticle from the upper Zone I (lower Albian) Drewry's Bluff locality of the Potomac Group. It has mesophyll secretory cells that look like the remains of oil cells. Oil cells are absent from *Amborella* and Nymphaeales, but oil cells occur in present in Austrobaileyales, Chloranthaceae, and magnoliids clade (Magnoliales, Canellales, Laurales, and Piperales). The relationship of the Drewry's Bluff taxon with these orders is unclear.

Celastrorphyllum sp. of Drewry's Bluff—*Celastrorphyllum* sp. is a serrate-margined leaf from the upper Zone I (lower Albian) Drewry's Bluff locality of the Potomac Group.

Celastrorphyllum sp. may be related to *Quercophyllum tenuinerve* (see below) and is possibly congeneric.

Celastrorphyllum sp. appears to be related to Chloranthaceae. Its teeth conform to a variant of the chloranthoid type in which the accessory veins fuse with the medial vein at the level of the gland. It has a decurrent wing of laminar tissue on the petiole, pinnate venation, and festooned craspedodromous secondary venation where each secondary vein forms an irregular set of festooned brochidodromous loops then enters a tooth. This pattern of secondary venation

is specialized within primitive angiosperms and is characteristic of extant Chloranthaceae, especially *Ascarina* and *Hedyosmum*. It is also present in the fossil genera *Crassidenticulum* and *Reynoldsiophyllum*, which were related to Chloranthaceae by Upchurch and Dilcher (1990) on the basis of leaf architecture. Consistent with chloranthaceous affinities of *Celastrophyllum* sp. is the presence of mesophyll secretory cells comparable to oil cells. Oil cells are absent from *Amborella* and Nymphaeales but present in Austrobaileyales, Chloranthaceae, and eumagnoliids. The chloranthoid teeth illustrated by Upchurch (1984a 1984b) have dark material over the veins, but whether this dark material consists of sclerenchyma as in some species of *Hedyosmum* remains to be determined (Todzia and Keating 1991).

Crassidenticulum cracendentis—*C. cracendentis* is a pinnately veined leaf from the middle to upper Cenomanian Courtland I locality in the Dakota Formation of Minnesota. It resembles *C. decurrens*, the type species of the genus, in most features of leaf architecture, but differs in having the thickenings of sclerenchyma confined to the apex of each tooth and details of tertiary and quaternary venation. It is related to Chloranthaceae on the basis of foliar architectural similarities seen between it, the type species *C. decurrens*, and Chloranthaceae (see below).

Crassidenticulum decurrens—*C. decurrens* is a pinnately veined leaf with small crenations known from the uppermost Albian Dakota Formation of Kansas and Nebraska. The best characterized material comes from the Rose Creek locality of southeastern Nebraska and was collected below the unconformity recognized as the Albian-Cenomanian boundary. Other material comes from the Hoisington III locality of the Dakota Formation of Kansas.

C. decurrens is related to Chloranthaceae (Upchurch and Dilcher 1990). It has a suite of leaf architectural features most similar to those found in *Ascarina* and *Hedyosmum*, but in a combination unknown within any living species. Features most supportive of a relationship include: 1) pinnately veined leaves with a decurrent wing of laminar tissue, 2) festooned craspedodromous secondary venation with numerous secondary veins, 3) chloranthoid teeth, and

4) the presence of sclerenchyma at the apex of each chloranthoid tooth. This latter feature characterizes the chloranthoid teeth of *Hedyosmum* but no other living genus. In *C. decurrens*, the sclerenchyma at the tooth apex often extends along the full width of each tooth, forming a continuous marginal reinforcement; in *Hedyosmum*, the sclerenchyma is restricted to the tooth apex. In *C. cracendentis*, the sclerenchyma is restricted to the tooth apex.

Crassidenticulum landisae—*C. landisae* is a pinnately veined leaf from the uppermost Albian Braun's Ranch locality of the Dakota Formation of Kansas. It is very similar to *C. decurrens* in its leaf architecture and differs in such features as fewer secondary veins and the tendency for the teeth to have a more asymmetric shape. This species is related to Chloranthaceae on the basis of features that it shares with *C. decurrens*.

Drewry's Bluff Leaf Type 1—This unnamed taxon is the dominant angiosperm leaf type at the upper Zone I (lower Albian) Drewry's Bluff locality of the Potomac Group. It probably represents *Moutonia*, a chloranthoid genus described by Pons (1988) from the Albian of Colombia.

Drewry's Bluff leaf type 1 may be related to Chloranthaceae. The leaves of this taxon are pinnately veined with numerous simple craspedodromous secondary veins, each of which terminates in a chloranthoid tooth. The tertiary and quaternary venation is reticulate and encloses exmedially elongate regions reminiscent of those in *Ascarina* (Chloranthaceae). The simple craspedodromous secondary venation is unknown in extant Chloranthaceae, but could easily be derived from the festooned craspedodromous system characteristic of many Early Cretaceous chloranthoid leaves. The leaf cuticle has striations on the abaxial surface and rare radiostriate secretory cells (oil cells), features that are absent in *Amborella* and Nymphaeales and first appear at the level of Austrobaileyales. Striations and broader cuticular ridges are present in many Chloranthaceae, as are oil cells in the mesophyll and epidermis (the latter often quite rare). The stomatal complex is irregularly organized but the subsidiary cells have a tendency to form a ring as in many living Chloranthaceae.

Drewry's Bluff Leaf Type 1 is known from many specimens, one of which has two leaves attached to a single node of a stem, implying that phyllotaxy was opposite decussate. Opposite decussate phyllotaxy is found in extant Chloranthaceae.

Carpenter (2006) states that epidermal oil cells are absent in Chloranthaceae and are not illustrated in the literature. However, we have observed them in both *Ascarina* and *Sarcandra*, and Upchurch illustrates an epidermal oil cell in *Sarcandra glabra* (Upchurch 1984a, fig. 33).

Densinervum kaulii—*D. kaulii* is known from the uppermost Albian Dakota Formation of Kansas and Nebraska, and the middle to upper Cenomanian Dakota Formation of Minnesota. *D. kaulii* closely resembles *Crassidenticulum decurrens* in its venation but differs in having a more distinct petiole, an entire margin, a solid (rather than multistranded) midvein, and more regular secondary venation. The venational similarities to *C. decurrens* suggest that *Densinervum kaulii* may be related to Chloranthaceae.

Eucalyptophyllum oblongifolium—*E. oblongifolium* is an enigmatic taxon known from the upper Zone I (lower Albian) Fredericksburg and Drewry's Bluff localities of the Potomac Group. The leaf is entire-margined and pinnately veined, with a midvein that, in some specimens, consists of two separate vascular strands. The secondary veins are decurrent on the midvein, irregularly spaced, and connect with a strong intramarginal vein. The tertiary venation is reticulate and encloses areas that are elongate more or less perpendicular to the midvein and/or parallel to the secondary veins. The abaxial cuticle has distinct ridges and radiostriate secretory cells (oil cells). The stomatal complex has an irregular arrangement of subsidiary cells that includes a large proportion of paracytic.

A relationship to either Austrobaileyales or Chloranthaceae is possible. The presence of abaxial cuticular ridges and radiostriate epidermal secretory cells appears to exclude *Eucalyptophyllum* from the *Amborella* and Nymphaealean clades and indicates a relationship with more advanced clades. A relationship to Austrobaileyales is supported by similarities with Trimeniaceae, especially the presence of an intramarginal vein and a high proportion of paracytic

stomata. A relationship to Chloranthaceae is supported by exmedially elongate regions enclosed by the tertiary veins (cf. *Ascarina*). Extant Trimeniaceae have admedially ramified, rather than reticulate, tertiary venation.

The presence of two vascular strands in the midvein of *Eucalyptophyllum* suggests that leaf was supplied by two leaf traces. In extant primitive angiosperms, two leaf traces are associated with opposite decussate phyllotaxy, which occur in both Austrobaileyales and Chloranthaceae.

Ficophyllum—*Ficophyllum* is a genus proposed by Fontaine (1889) for leaves with affinities to extant *Ficus* (Moraceae). As has been discussed elsewhere, early paleobotanists assigned a large number of fossil leaves to extant *Ficus* because the extant genus has a high diversity of shape. The relationship of Cretaceous leaves to extant *Ficus* has not withstood scrutiny; where examined, the fossils do not have the highly orthogonal higher-order venation and numerous (up to nine) vein orders that characterize extant *Ficus*. Leaves assigned to *Ficophyllum* are not related to *Ficus* and Moraceae but instead have the poorly organized venation characteristic of primitive angiosperms.

Leaves from the Potomac Group assigned to *Ficophyllum* are problematic taxonomically. Individual species can have different relationships to modern families. We describe the relationship of each species separately.

Cf. *Ficophyllum*—This leaf fragment comes from the upper Zone I (lower Albian) Drewry's Bluff locality of the Potomac Group. It was proposed as related to *Ficophyllum* by Upchurch (1984a, b) because its reticulate tertiary and higher order venation have a pattern similar to that of leaves assigned to *Ficophyllum*. Cf. *Ficophyllum* has oil cells in the mesophyll, which appear to exclude it from the *Amborella* and Nymphaeales clades and instead relate it to Austrobaileyales or more advanced clades. Otherwise, its taxonomic affinities are poorly understood.

Ficophyllum crassinerve—*F. crassinerve* is a pinnately veined leaf type from the upper Zone I (lower Albian) Fredericksburg locality of the Potomac Group. It mostly consists of fragmentary remains, with one nearly complete leaf formed from two specimens that were originally described as separate genera (Hickey and Doyle 1977, figs. 11 and 13). The variation seen between leaf fragments may indicate more than one species, but for this discussion we treat *F. crassinerve* as a single species.

Ficophyllum crassinerve may have affinities with magnoliid clade or Austrobaileyales. Hickey and Doyle (1977) compared the foliar architecture of *Ficophyllum* with that of Magnoliales (now divided into Magnoliales and Canellales in the magnoliid clade). Characters compared with primitive families of Magnoliales and Canellales include poorly organized festooned brochidodromous secondary venation, and reticulate tertiary and higher order venation where the veins originate at broad acute angles, are deflected at points of branching, and tend to enclose quadrangular areas of irregular size and shape. (Compare the venation of *Ficophyllum* in Figure 16 of Hickey and Doyle [1977] with that of Winteraceae and Magnoliales illustrated by Upchurch and Dilcher [1990].) Upchurch (1983) expanded the comparison to include Austrobaileyaceae, noting the tendency in some specimens for the secondary veins to be closely spaced at the base of the lamina yet enclose wide intercostal regions above the base, and the tendency for the tertiary and quaternary venation to be both reticulate and admedially oriented, as in Austrobaileyaceae. The specimen illustrated by Hickey and Doyle (1977: Figs. 11, 13) has these latter features, but whether they indicate a phylogenetic relationship to Austrobaileyales, or simply were retained from the *Amborella*-Nymphaeales-Austrobaileyales grade of organization, is unclear.

Illiciales types 1 & 2—Illiciales types 1 & 2 are dispersed cuticle types from the latest Cretaceous part of the Sugarite Coal, Raton Formation of New Mexico. They show close similarity to extant Illiciaceae in their surface sculpture and stomatal anatomy. Upchurch (1995) compared them to the families of Illiciales, which at the time consisted of Illiciaceae and

Schisandraceae. Today both families are merged into the Illiciaceae, which is placed within the order Austrobaileyales.

Both Illiciales types 1 & 2 comprise abaxial cuticle. Diagnostic features include prominent striations that are concentric over the guard cells, parallel over other cells, and traverse cell boundaries on non-stomatal cells, large (>30 μm long) stomata that have a nearly circular shape, broad lamellar thickenings on the guard cells, and T-pieces at the stomatal poles. Radiostriate secretory cells (oil cells) are present on the epidermis.

The suite of features found in Illiciales types 1 & 2 characterizes extant Illiciaceae, though no extant genus is a perfect match. In the Sugarite coal at the same level as the dispersed cuticles are rare palynomorphs belonging to *Trisectoris*, an extinct genus related to Illiciaceae (Doug Nichols, written communication 1985).

Lonstrethia aspera—*L. aspera* is a species known from the uppermost Albian Hoisington III locality of the Dakota Formation of Kansas. It consists solely of leaf impressions. It is related to Austrobaileyales because it is congeneric with *L. varidentata*, a species that preserves both venation and cuticular anatomy (see below).

Longstrethia varidentata—*L. varidentata* is a leaf type from the uppermost Albian of the Rose Creek locality, Dakota Formation, Nebraska. It has a mosaic of features found in Illiciaceae and Trimeniaceae (Upchurch and Dilcher 1990), which together form a clade within Austrobaileyales. Leaves of *L. varidentata* are elongate, with numerous secondary veins that can connect with an intramarginal vein. Within Austrobaileyales, an intramarginal vein only occurs in Trimeniaceae. The cuticle of *L. varidentata* is very similar to that of Illiciaceae, with concentric striations over the guard cells, large circular stomata with prominent T-pieces, laterocytic stomata, and radiostriate epidermal cells (oil cells).

Moutonia sp. and aff. *Moutonia*—These two types of dispersed cuticle comprise the abaxial epidermis and occur in samples from the Schoewe lignite of the upper Albian Kiowa Formation of Kansas, which underlies the Dakota Formation. *Moutonia* sp. is very similar to the

cuticle of Drewry's Leaf Type 1, which probably belongs to the genus *Moutonia* (see above).

Points of resemblance include a finely striate cuticle where the striations are concentric over the guard cells, non-concentric over non-stomatal cells, and traverse cell boundaries, cells with curved to weakly undulate wall contour, similar size and shape to the stomata, stomatal complexes where the subsidiary cells form a weakly developed ring and have faint cuticular flanges, and radiostriate epidermal secretory cells (oil cells). Papillae are present on some cells. *Aff. Moutonia* occurs in the same samples as *Moutonia* sp. but differs in having straighter walls, more frequent and prominent papillae on both subsidiary cells and non-stomatal cells, and uniseriate hairs.

The similarities seen between these two dispersed cuticles and the cuticle of Drewry's Bluff Leaf Type 1 suggest a relationship with Chloranthaceae (see above).

Proteaephyllum reniforme—*P. reniforme* is a pinnately veined leaf type with basally crowded secondary veins that was described from the upper Zone I (lower Albian) Fredericksburg locality of the Potomac Group. Although Fontaine (1889) compared the leaf with Proteaceae, it has the poorly organized venation that characterizes Zone I angiosperms and distinguishes them from Proteaceae and other primitive eudicots.

Proteaephyllum reniforme and Zone I leaves with similar venation were compared by Hickey and Doyle (1977) to Nymphaeales and Nelumbonales (the latter of which were allied with Nymphaeales prior to molecular systematics). *P. reniforme* has a lobate base (reniform shape), a petiole and midrib that consist of multiple vascular strands, and irregularly organized festooned brochidodromous secondary venation with crowding of the secondary veins at the base of the leaf. The crowding of secondary veins at the base of the leaf is interpreted to represent a trend towards palmate venation. *Nuphar*, which forms the sister lineage to other extant Nymphaeaceae, is pinnate, with a multistranded midvein and a more developed and better organized version of this vein pattern. All other Nymphaeaceae and the related Cabombaceae are truly palmate with actinodromous primary venation.

Protoilliciales Type 1—Protoilliciales is an informal term coined by Wolfe and Upchurch (1987) for dispersed cuticles that show points of resemblance to Illiciaceae (formerly two families placed within the order Illiciales) but are more primitive in their features of stomatal anatomy. They are known from upper Zone I (early Albian) of the Potomac Group (Dispersed cuticle type 3 of Upchurch 1984a, b) and extent into the Paleocene. Protoilliciales Type 1 is a species that occurs in the basalmost Paleocene of the Raton Formation, in the Sugarite Coal of New Mexico. Other species in this group occur in the Cretaceous, but are too fragmentary and too sporadically preserved to be included in our analysis.

Protoilliciales probably belong to Austrobaileyales because of their resemblance to Illiciaceae. They resemble Illiciaceae in having round stomata with large lamellar thickenings, T-pieces, and radiostriate epidermal secretory cells (oil cells), but differ in having smaller stomata (usually <30 microns long vs. >30 microns long in most Illiciaceae; Appendix I) and stomata with a more irregular subsidiary cell arrangement that includes a significant fraction of laterocytic stomatal complexes (up to 5 lateral subsidiary cells per stomatal complex). Striations can be present but tend to be weakly developed.

Quercophyllum tenuinerve—*Q. tenuinerve* is a species that was named from the upper Zone I (lower Albian) Fredericksburg locality of the Potomac Group. Our analyzed specimen comes from the lower Zone I (Aptian) Dutch Gap locality of the Potomac Group and is photographically illustrated by Hickey and Doyle (1977, fig. 17).

Although *Quercophyllum* was compared with *Quercus* by Fontaine (1889), *Quercophyllum tenuinerve* clearly does not belong to *Quercus*, Fagaceae, or even Fagales. Instead, it most probably is related to Chloranthaceae. Characters suggestive of this relationship include a serrate margin with chloranthoid teeth and festooned craspedodromous secondary venation where each secondary vein forms a series of irregular brochidodromous loops then terminates in a tooth. A dark substance occurs over the apex of each tooth, but whether this constitutes sclerenchyma as in extant *Hedyosmum* is uncertain.

Reynoldsiophyllum nebrascense—*R. nebrascense* is a pinnately veined leaf described from the uppermost Albian part of the Rose Creek locality, Dakota Formation of Nebraska. It strongly resembles *Crassidenticulum* in its shape, primary and secondary venation, and tooth structure, but differs in having more widely spaced secondary veins, a different pattern of tertiary and quaternary venation, and fewer and significantly larger teeth. Its strong similarity to *Crassidenticulum* suggests that it is related to Chloranthaceae (see above).

Rogersia angustifolia—*R. angustifolia* is an elongate obovate leaf described from the upper Zone I (lower Albian) Fredericksburg locality of the Potomac Group. It is entire-margined, pinnately veined, and has poorly organized festooned brochidodromous secondary venation. The tertiary and higher order venation is reticulate and has a pattern of organization that Wolfe et al. (1975) compared with that of the old Magnoliales (now Magnoliales and Canellales, two orders in the magnoliid clade). The obovate shape, irregular festooned brochidodromous secondary venation, and pattern of tertiary and higher order venation together resemble what is found in some primitive Magnoliales (e.g., Degeneriaceae) and Canellales (Canellaceae and Winteraceae).

“*Sapindopsis*” *elliptica*—“*S.*” *elliptica* is a simple elliptic leaf described from the upper Zone I (lower Albian) Fredericksburg locality of the Potomac Group. It is neither congeneric nor confamilial with the pinnatifid to pinnately compound leaves of *Sapindopsis* that form the basis for the generic name. No alternative generic name has yet been proposed for the species, so quotation marks are used with the generic name.

“*Sapindopsis*” *elliptica* is entire margined and pinnate, with festooned brochidodromous secondary venation and reticulate tertiary and higher order venation. Wolfe et al. (1975) compare its venation to that of families of the old Magnoliales (now Magnoliales and Canellales).

Vitiphyllum multifidum—*V. multifidum* is an enigmatic lobed leaf with palmate venation from the upper Zone I (lower Albian) Federal Hill locality of Baltimore, Potomac Group. It is

characterized by a ternate pattern of lobation and a pattern of primary venation resembling leaflets of compound-leaved Ranunculales, the most primitive order in the eudicots. Its secondary venation shows points of resemblance to Ranunculales, in particular the tendency for the basalmost pair of secondary veins on each primary vein to enclose intercostal regions elongate parallel to the primary vein. However, its tertiary and higher order venation is irregular as compared to that of extant Ranunculales.

The ternate pattern of lobation in *Vitiphyllum multifidum* is similar to that of *Archaeofructus*, an early angiosperm with finely dissected leaves adapted to the aquatic habit. Cladistic analyses place *Archaeofructus* as either basal to all living angiosperms (Sun et al. 2002) or nested within extant angiosperms at various positions (e.g., Endress and Doyle 2009).

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Supplemental Appendix IV. Ancestral state reconstructions for ecophysiological traits across the base of the extant angiosperm phylogeny depicted in Supplemental Figure 1. Reconstructions of ancestral trait values were determined as described in the Methods section. Abbreviations for variables are: D_v , vein density (mm mm^{-2}); g_c^{VEIN} , maximum stomatal conductance to water vapor calculated from vein density ($\text{mmol H}_2\text{O m}^{-2} \text{s}^{-1}$); P_C , leaf photosynthetic capacity based on vein density ($\mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$). SPA, stomatal pore area at maximal stomata aperture ($\text{m}^2 \times 10^6$); S_D , stomatal density (number mm^{-2}); Pore_L , length of the stomatal pore opening (μm); g_c^{STOMA} , maximum stomatal conductance to water vapor calculated on stomatal complex anatomy ($\text{mmol H}_2\text{O m}^{-2} \text{s}^{-1}$). "Max." refers to calculations of ancestral state reconstructions with maximum trait values used at the species terminals. "NA" means not available.

Node	Name	D_v	Max. D_v	g_c^{VEIN}	Max. g_c^{VEIN}	P_C	Max. P_C	SPA	Max. SPA	S_D	Max. S_D	Pore_L	Max. Pore_L	g_c^{STOMA}	Max. g_c^{STOMA}
1	Common ancestor of extant angiosperms	3.36	3.51	119	123	8.74	9.07	5.26	5.85	192	204	33	35	267	284
2	Nymphaeales+ remaining angiosperms	3.06	3.14	109	112	8.03	8.23	4.45	5.2	190	197	27	36	NA	NA
3	Nymphaeales	2.38	2.41	87	88	6.25	6.33	NA	3.9	247	250	22	28	NA	NA
4	Austrobaileyales-remaining angiosperms	3.43	3.48	121	122	8.90	9.01	4.54	5.86	131	136	41	44	238	255
5	Austrobaileyales	3.16	3.2	112	114	8.27	8.37	5.25	6.98	104	107	46	51	217	247
6	Illiciales- <i>Trimenia</i>	3.62	3.92	127	136	9.31	9.93	6.37	8.11	99	108	50	56	243	276
7	<i>Trimenia</i>	3.67	4.05	128	140	9.42	10.18	6.95	8.23	113	130	47	51	277	316
8	Illiciales	4.03	4.52	139	153	10.14	11.01	6.91	9.08	79	86.7	56	65	236	265
9	Schisandraceae	4.22	5.02	145	166	10.49	11.78	8.41	11.94	65	69	65	79	249	286
10	<i>Illicium</i>	4.2	4.61	144	155	10.46	11.16	5.94	7.21	75	83	55	60	215	232
11	Common ancestor of Mesangiosperms	4.08	4.11	140	141	10.23	10.29	NA	NA	NA	NA	NA	NA	NA	NA
12	Chloranthaceae	3.52	3.54	124	124	9.10	9.14	3.91	5.39	99.8	104	44	46	230	236
13	<i>Hedyosmum</i>	3.08	3.1	110	110	8.08	8.13	4.12	6.34	80.4 9	84	46	49	253	261
14	within <i>Hedyosmum</i>	3.44	3.62	121	127	8.92	9.31	4.73	6.62	80.8 3	87	46	49	249	269

