The Middle Miocene Flora of the Chalk Mountain Formation, Warrumbungle Volcano Complex, NSW, Australia

Holmes, W.B.K.[1] and Anderson, H.M.[2]

[1][wbkholmes@hotmail.com] 46 Kurrajong Street, Dorrigo, NSW 2453, Australia, University of New England, Armidale, NSW 2351

[2][hmsholmes@googlemail.com], Evolutionary Studies Institute, University of the Witwatersrand, Johannesburg 20150, South Africa

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A Miocene flora from the Chalk Mountain Formation occurring on a spur of the Warrumbungle Volcano Complex to the north-west of Coonabarabran, near Bugaldie is described. The flora consists of representatives in the families Equisetaceae (*Equisetum* sp. indet.), Isoetaceae and Araucariaceae (*Agathis* sp.). Among the angiosperm families are Cunoniaceae (*Ceratopetalum priscum*), Moraceae, Myrtaceae (*Eucalyptus bugaldiensis*), Urticaceae (*Dendrocnide* sp. A aff. *D. excelsa*). This paper describes the first fossil record of *Dendrocnide* (Urticaceae) leaves from Australia and the second post-Cretaceous record of the genus *Equisetum,* the first from the Miocene. The flora includes rainforest, swamp and sclerophyll plant forms and indicates a warming and drying climate as the Australian plate moved northwards during the Middle Miocene.

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Key Words: Chalk Mountain, *Equisetum*, *Eucalyptus*, fossil plants, Miocene, Warrumbungle volcano.

INTRODUCTION

The Chalk Mountain Formation occurs on a spur of the Warrumbungle Volcano Complex to the north-west of Coonabarabran, near Bugaldie. It is a caldera deposit of diatomite, tuffs and a band of lignite underlain by basalt dated at 17.2 million years and overlain by basalt dated at 13.7 million years, confirming the Miocene age. The Formation was well-known for the numerous fossils of small Macquarie codfish (Hills 1946) and a fossil owlet-nightjar (Rich and McEvey 1977). The senior author and his family visited Chalk Mountain in the 1970's to collect plant fossils. Papers describing the eucalypt and *Ceratopetalum* collected material were published by Holmes et al. (1983), Holmes and Holmes (1992). The eucalypt paper (Holmes et al. 1983) included a comprehensive palynological study by Dr Helene Martin of the spores and pollen from the Chalk Mountain diatomite and lignite beds that revealed the presence of ferns, gymnosperms and angiosperms and evidence of still extant Australian genera. This paper describes additional rainforest and sclerophyll macrofossil plant material and the second post-Cretaceous record of the genus *Equisetum,* the first record of *Dendrocnide* (Urticaceae) leaves from Australia. The diatomite and lignite beds of the Chalk Mountain Formation are now weathered, overgrown with weeds and natural regrowth. The location is closed to the public and further collecting is unlikely to eventuate.

CHALK MOUNTAIN GEOLOGY

The Chalk Mountain Formation (Grid reference 199148 Gilgandra 1:250 000 Geological Series Sheet SH 55–16) comprises 15–18 metres of lacustrine sediments of siltstone, mudstone, clay, tuff, lignite and mostly of pure diatomite underlain and overlain by volcanic flows (Griffin 1961, Herbert 1968).

The unit is exposed in the now abandoned quarry on Chalk Mountain (Fig. 1) situated on private property approximately 6 kilometres south of the

Figure 1. Chalk Mountain Formation exposure in the abandoned quarry ca 1980.

village of Bugaldie and at the northern margin of the Warrumbungle Volcano complex (White 1994, Kenny 1924). The Formation covers an area of approximately 38 hectares. The rich deposit of pure diatomite was worked from 1919 to 1968 by the Davis Gelatine Co. and produced over 85,000 tonnes to be transported by rail to Sydney for use as an abrasive, filter, insulation material and many other purposes. The Formation is underlain by a thick bed of volcanic basalt, andesite and trachyte and overlain by a basalt flow. K/Ar dating was carried out by Dr A. Ewart of the University of Queensland (Holmes and Holmes, 1992). The underlying basalt was dated at 17.2 mya and the overlying basalt at 13.7 mya, both results at ± 2%, thus confirming the Middle Miocene age.

MATERIAL

The fossil flora is based on collections of past published material housed in the Australian Museum (AMF) and the Geological and Mining Museum (MMF) and from private collections now also registered with the Australian Museum. The fossils are preserved as impressions and no cuticles are available for study. If carbonaceous material is present then it is very friable and breaks into tiny, granular fragments.

SYSTEMATIC PALAEOBOTANY

Order Equisetales
Family Equisetaceae
Genus *Equisetum*
Equisetum sp. indet.
Figs. 2A–E

Material.
AMF 145067.

Description

This taxon is based on an impression of an equisetalean stem fragment. Length preserved 120 mm, base and apex missing; margins almost parallel; average width 6 mm with ca 15 longitudinal striations; impressions of four nodes located from the stem base at 25 mm, 55 mm, 85 mm and 104 mm (Fig. 2A). Branch scars are not well preserved (Figs 2D, C). One node shows five scars each ca 1mm roundish-square (Fig. 2E). No leaf whorls or nodal diaphragms are evident.

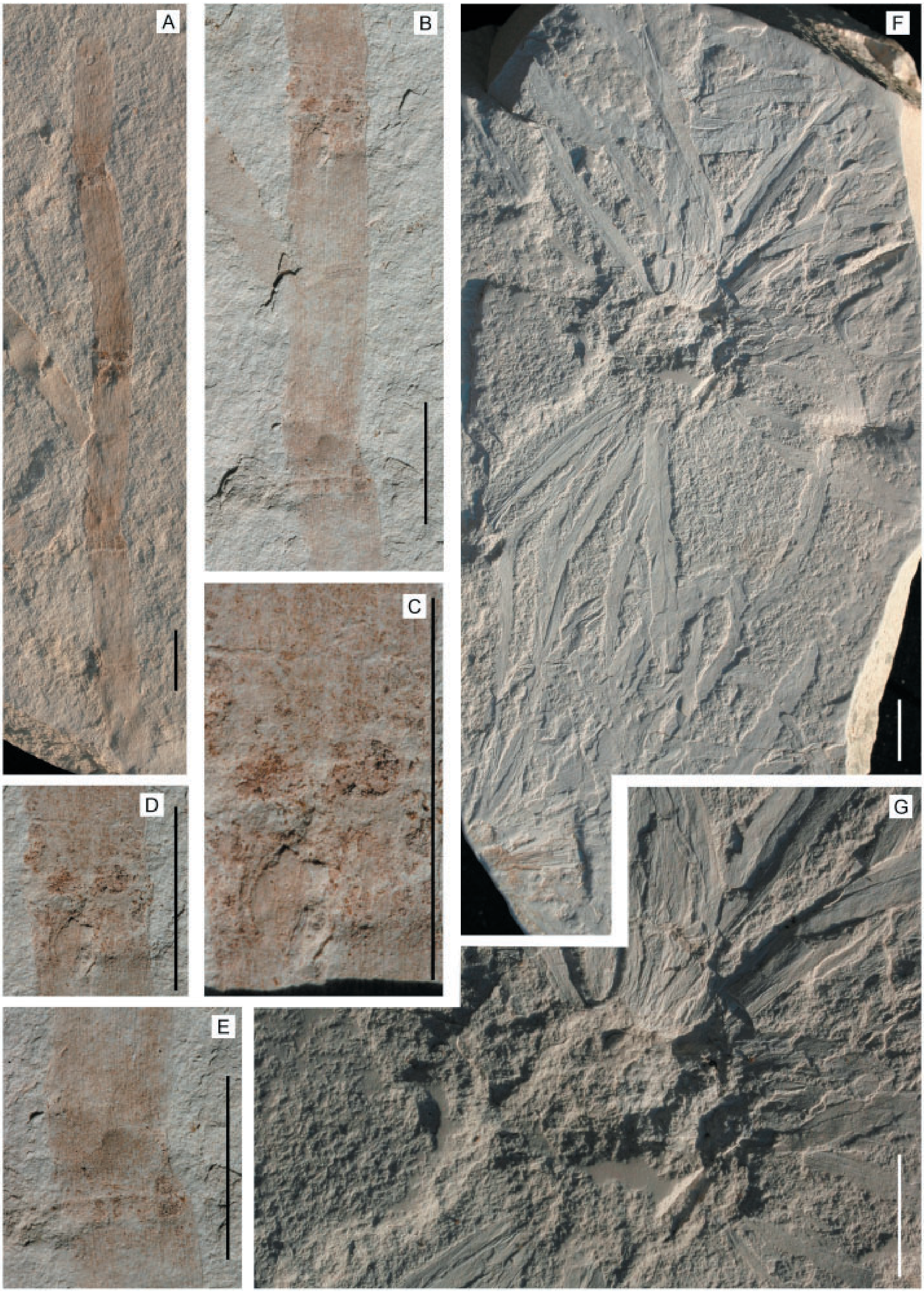

Figure 2. [A–E] *Equisetum* sp. indet. AMF 145067, [F, G] Leaf whorl Isoetaceae, AMF 145068, (scale bar = 10 mm).

Discussion.

Based on the gross form of AMF 145067 (Fig. 2A) this stem with nodal scars (Figs 2B–E) closely resembles the New Zealand Miocene *Equisetum* sp. described by Pole and McLoughlin (2017) but differs by the generally narrower stem with less branch scars at the node. The characters preserved are considered insufficient to warrant the erection of a new specific name. The only other Australian Cenozoic *Equisetum* was described recently by Rozefelds et al. (2019) from Makowata, Queensland. This consists of a short stem (ca 9 x 2.5 mm) with a slightly detached node, to which are attached, in a whorl, numerous leaves (24–30), joined at the base into a sheath and distally free. No nodes are evident on this stem but the large number of leaves clearly sets it apart from the low number of about five leaf or branch scars in the Chalk Mountain fossil. The Makowata fossil is rather unique in showing a whorl of leaves conjoined in a sheath with distal free leaves (not short teeth) similar to some genera occurring in the Triassic of Gondwana such as *Townroviamites* (Holmes 2001, Anderson and Anderson 2018) which have more numerous and much longer leaves.

The sphenophyte family Equisetaceae (which includes the genus *Equisetum* with about 15 extant species commonly known as horsetails) is an ancient group of plants first appearing in the Devonian Period *ca* 300 million years ago (Taylor et al. 2009). By the Carboniferous Period they had evolved into many diverse forms including tree-sized plants. In Gondwana during the Permian Period, sphenophytes formed an understory association with glossopterids that produced some of the World's greatest coal beds (Beeston 1991, McLoughlin 1993). Following the End-Permian extinction event many sphenophyte forms recovered and regained a cosmopolitan distribution (Taylor et al. 2009) and a great diversity in the Triassic of Gondwana (Anderson and Anderson 2018). They are well documented from the Australian and New Zealand Gondwana fossil plant collections (Rigby 1966, Gould 1968, Retallack 1980, Holmes 1982, 2000, 2001). However during Cretaceous time the sphenophytes declined in frequency and diversity throughout the World. *Equisetum,* the only surviving sphenophyte genus has an almost world-wide, natural distribution except for Australia and New Zealand where it was previously considered extinct by the Cenomanian (Cretaceous) with the last records being from the Winton Flora as reported by McLoughlin et al. (2010). However this view has been changed by Pole and McLoughlin (2017) who reported a Miocene (Cenozoic) *Equisetum* from two localities in central Otago, New Zealand and by Rozefelds et al. (2019) who described the first *Equisetum* from the late Eocene or early Oligocene, Makowata, Queensland, Australia. The fossil here described from the Chalk Mountain is significant in that it now extends the range for Australia into the Miocene. The cause of extinction of *Equisetum* from Australia and New Zealand remains obscure but Pole and McLoughlin (2017) suggest it may have been related to substantial environmental changes.

Given the age of the flora it could be argued that this fossil may be more closely compared to some angiosperm genus. However, it is most unlikely that this fossil belongs to *Casuarina* or *Allocasuarina* even though such plants have branchlets with whorls of leaves (tiny teeth) with regular articles (internodes) and bear a superficial resemblance to *Equisetum*. Their branchlets (stems) in all species are about 1 mm in diameter or less, (this fossil stem is 6 mm in diameter) the articles are very short about 10 mm (this fossil internode is from 25 mm up to 104 mm in length). Vegetative Casuarinaceae fossils are well known from the Paleocene of Australia (Scriven & Hill 1995) and the Miocene of New Zealand (Campbell & Holden 1984) and these show the typical tiny stems occurring in branchlets.

Order Lycopodiales

Family Isoetaceae

Leaf whorl, genus and species uncertain

Fig. 2F, G

Material.

AMF. 145068.

Description.

A diatomite block shows three whorls of linear leaves on one surface and on the reverse side a poorly preserved whorl surrounding a stem, possibly a continuation of the stem on the other surface bearing the large leaf whorl. The main leaf whorl shows about 16 linear leaves with parallel margins and faint parallel striations, to >40 mm in length and 4 mm in width surrounding a circular depression of a stem ca 12 mm in circumference. Point of attachment of leaves to the stem is not clearly preserved. The second whorl (lower left of main whorl) is smaller with narrower leaves and the third whorl (close to lower right of main whorl) is partially obscured.

Discussion.

The Chalk Mountain whorl of linear leaves resembles that of *Isoetes beestonii* (Retallack 1997

Fig. 6.3) a lycopod from the earliest Gondwana Triassic of Australia, previously known as *Cylomeia undulata* (White 1981c, 1986 figs 193, 201)

These differ from the Chalk Mountain whorls by the leaves emerging from a common area and the base of the leaves being flared to cordate (Retallack 1997, p. 502, fig. 7A). In the Chalk Mountain specimen the leaves appear to arise from different levels of the stem and in this aspect are more like the Triassic lycopod *Pleuromeia* or *Cyclostrobus* as described by Retallack (1997). Other records of *Isoetes* in Australia are from the Tertiary of Tasmania based on megaspores and leaves described as *I. reticulata* (Hill 1988) and from the Cretaceous of Victoria *I. bulbiformis* (Drinnan and Chambers 1986) is a corm with leaves.

The Chalk Mountain whorl of linear leaves also superficially resemble that of some equisetaleans from the Permian attributed by White (1986, fig. 181) to *Phyllotheca australis*. Similar whorls of linear leaves (*Zonulamites nymboidensis)* were described from the Australian Triassic by Holmes (2000). But the Chalk Mountain whorls of leaves show no evidence of being attached to the stem in a clear whorl or of conjoining at their base to form an encircling sheath around the stem as occurs in *Equisetum*.

Given the age of the flora it could be argued that this fossil may be more closely compared to some angiosperm genus. However, it is most unlikely that this fossil belongs to a plant with a superficial resemblance like *Galium aparine* (Rubiaceae). This has leaves in whorls that at first glance look similar to this Chalk Mountain fossil or like a Permian *Sphenophyllum* (Equisetaceae) but a prominent midrib and reticulate venation clearly set it apart.

The identity of these whorls remains uncertain but appear to be best placed in the Family Isoetaceae and possibly belong in a new genus. These leaf whorls are probably preserved *in situ* due to the stem continuing in 3D through the sediment and the presence of further whorls on the same slab. The extant genus of *Isoetes* (known as Quillworts) with some 192 species in the world (8 species in Australia) grow in or close to water and the leaves arise closely packed together from a central corm.

Order Pinales
Family Araucariaceae
Genus *Agathis*
Agathis sp. aff. *Agathis robusta* (More ex Mueller) Bailey
Figs 3C–E

Material

Based on two specimens, a terminal branch fragment AMF145071 and a single leaf AMF145070.

Description.

AMF145071 is a distal portion of a slender branch ca 25 mm in length as preserved, with four pairs of sub-opposite sessile elliptic leaves to 10 mm wide and 25 mm long, apices acute. Veins numerous, rising at base, fine, closely spaced and running ±ca parallel to the margin.

The second specimen, AMF145070 is a portion of a larger single leaf, with base and apex missing, estimated original length ca 6.5 mm, width 15 mm with fine closely spaced parallel venation.

Discussion.

A number of extant conifers have leaves with parallel veins and in the absence of reproductive structures or cuticles it is difficult to make a firm identification. In the Podocapaceae is *Nageia* with an extant distribution beyond Australia. Araucariaceae is a family restricted to three genera – *Araucaria, Agathis* and *Wollemia* which still grow in Eastern Australia. The first records of this ancient conifer family are from the Triassic Period (Taylor et al. 2009) while their greatest diversity and widest distribution was during the Jurassic Period (White 1981a, b, Anderson et al. 2007 pp 56–59, 135). They are also well known from Tertiary localities in south-eastern Australia (Bigwood and Hill 1985, Hill and Bigwood 1987, Hill et al. 2008).

Based on details of macro leaf form and venation, the Chalk Mountain fossils are placed in *Agathis* with a close affinity to *A. robusta* as illustrated in Harden et al. (2006). In the palynological study of diatomite and lignite from Chalk Mountain undertaken by Helene Martin (in Holmes et al. 1983) *Araucarites australis* Cookson, attributed to *Agathis* and *Araucaria* comprised 18.1% of the pollen in the lignite and 10.7% in the diatomite. *Agathis robusta* is today restricted to populations in rainforests of northern Queensland and south-eastern Queensland. These leaves also show some similarity to the Tertiary fossils of early Oligocene to early Miocene age named *Agathis tasmanica* known from macro and cuticular remains as described by Hill and Bigwood (1987) from Little Rapid River locality in Tasmania.

Genus ?*Agathis*, sp. indet.
Figures 3A, B.

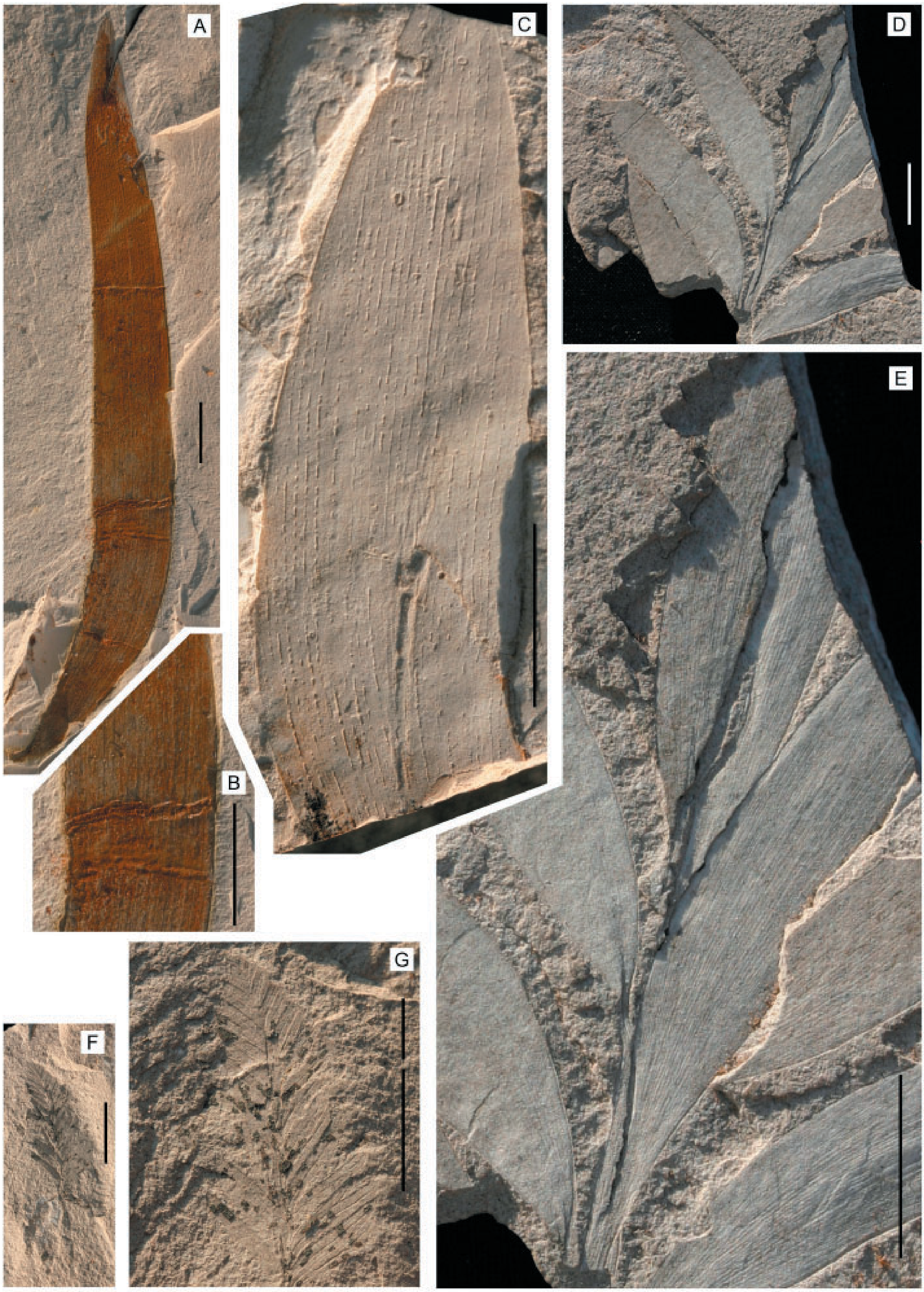

Figure 3. [A, B] ?*Agathis* species indet. AMF 145069; [C–E] *Agathis* sp. aff. *A. robusta*, [C] AMF 145070, [D,E] 145071 [F, G] Foliar conifer-like twig, AMF 145072, (scale bar = 10 mm).

Material

AMF145069.

Description

Leaf elongate elliptic, length 130 mm, central portion with parallel margins 13 mm wide, with ca 20 faint longitudinal ribs or striations; tapering proximally and distally; transverse scars across the stem at 25, 50 and 85 mm from the assumed base.

Discussion

Superficially this specimen resembles an *Equisetum* stem but differs by the proximal and distal tapering and appears more leaf-like. Branch or leaf scars on these apparent nodal scars are not evident. These irregular transverse scars (Fig. 3B) may be insect tunnels or physical damage during preservation. In form and the fine parallel venation this leaf falls within the extreme limits of *Agathis robusta* (Harden et al. 2006) but differs in the greater length from the Chalk Mountain leaves referred to that species above. It can also be compared to the much larger Tertiary leaf described by Bigwood and Hill (1985) as *Araucarioides linearis* which is based on an incomplete leaf, base and tip unknown, 160 mm length (as preserved) and to 15 mm wide. As cuticles are not preserved on the Chalk Mountain fossils no further comparisons can be made with the latter species or others based largely on cuticular differences as described by Hill and Bigwood (1987) and Hill et al. (2008).

This leaf may also be compared with extant Cycadales leaflets (Hill and Osborne 2002) as it has an elongated linear form with fine parallel venation. Most Australian genera *Cycas*, *Lepidozamia*, *Macrozamia* have very long leaflets with a length/width ratio far greater than the Chalk Mountain leaf. However, the leaflets of *Bowenia* come closer being 70–150 mm long and 15–40 mm broad with the margins smooth and occasionally toothed. *B. spectabilis* is unusual for a cycad in bearing bipinnate leaves and its present distribution is restricted to the tropical coastal ranges of north-eastern Queensland. *Macrozamia heteromera* occurs in the Warrumbungle region growing in dry sclerophyll woodlands and the extremely long linear leaflets are usually forked one to three times.

Family and Genus uncertain
Foliar conifer-like twig
Figures 3F, G

Material

AMF145069.

Description

A terminal portion of a foliar twig, 22 mm long as preserved, with ca 24 linear-oblong sessile leaves 1 mm in width and 8 mm long, decreasing distally in length towards the apex. Each leaf with a distinct central vein, secondary veins absent.

Discussion

This foliar twig and leaf form is found in many extant conifer families and we restrict our comparison to two Australian possibilities. It resembles that of *Podocarpus lawrencei,* an extant conifer growing as a tall shrub or tree in Victorian Eminundra rainforest and in heathlands in northern Victoria and southern NSW (Harden et al. 2006). It is also comparable to a larger fossil twig named *P. cupressinoides* from the Eocene of Penrose NSW (White 1986, fig. 365). In gross morphology the twig is also similar in form to some extant angiosperms in the family Epacridaceae.

Angiosperm Families (listed alphabetically)

Family Cunoniaceae
Genus *Ceratopetalum* Sm.
Ceratopetalum priscum Holmes and Holmes, 1992
Fig. 4A

Material

Holotype MMF25501, paratypes AMF 3975, (illustrated in White 1990, p. 197), AMF78245 (c.p. AMF78246), all from Chalk Mountain Formation.

Description

Flower-fruit with five narrow-oblong sepals; apices obtuse, bases not contracted, petals, if present, with a single vein trifurcating distally.

Discussion

The three detached flower-fruits of *Ceratopetalum priscum* from the Chalk Mountain locality are preserved as limonite or colourless impressions (Holmes and Holmes 1992, White 1990, p. 197). They are differentiated from other fossil and extant *Ceratopetalum* species by the sepal bases not being contracted and the petals with a single vein trifurcating distally (Barnes and Hill 1999). In *Ceratopetalum* the sepals of the flower grow larger after fertilisation and remain attached as part of the dehisced fruit.

A more widespread distribution of this extant genus during the Cenozoic is indicated by Holmes and Holmes (1992) who also describe *C. wilkinsonii* from near Emmaville, New South Wales from Late Eocene to Early Oligocene and Barnes and Hill (1999) who listed occurrences placed in *Ceratopetalum* from the

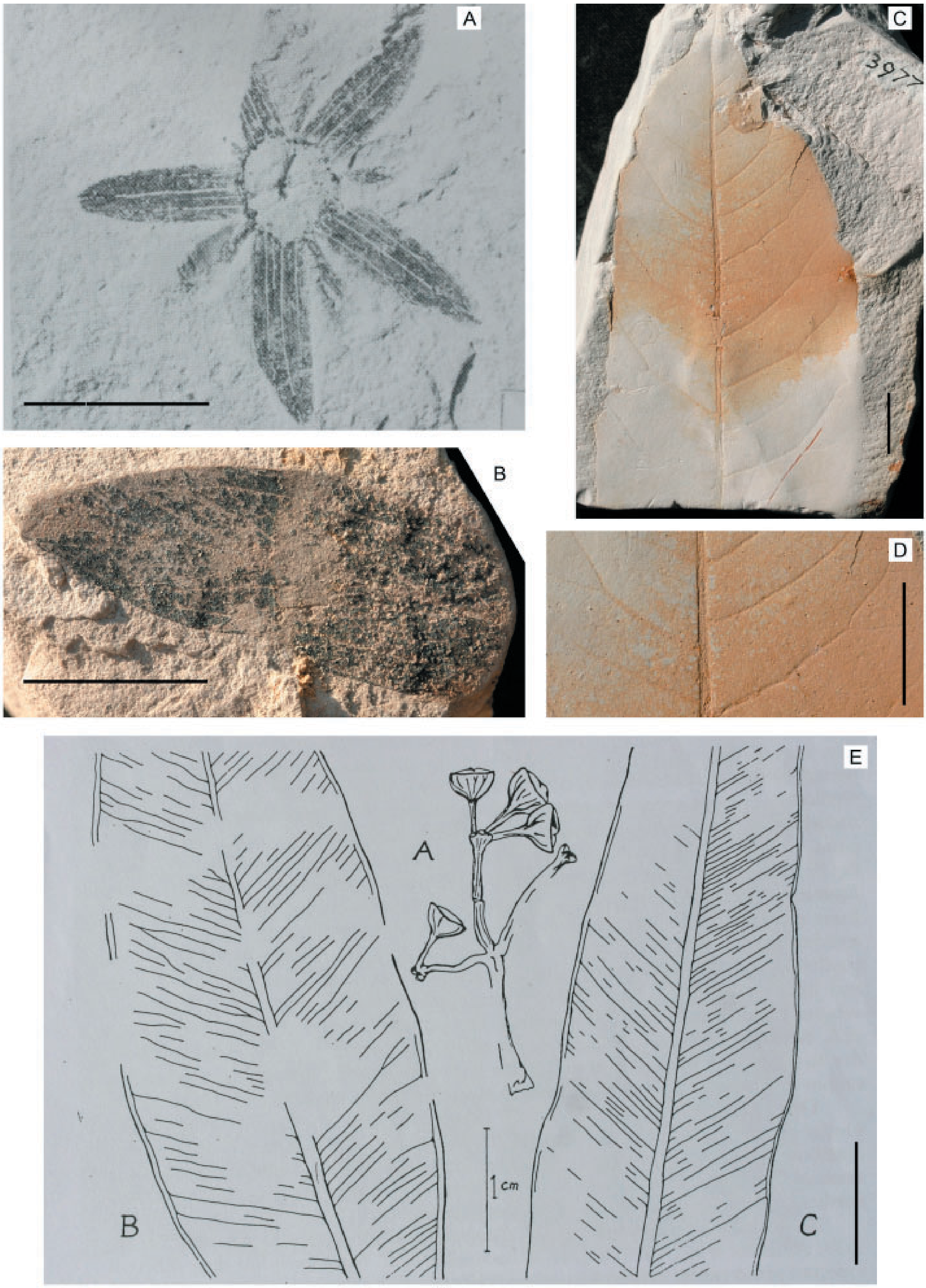

Figure 4. [A] *Ceratopetalum priscum* from Holmes and Holmes (1992, Fig. 1) MMF25501. [B] ?Myrtaceae leaf form [C] AMF 145073. [C, D] ?Moraceae leaf form [D] AMF 145074. [E] from Holmes et al. (1983, Fig.1). [E](A) *Eucalyptus bugaldiensis* AMF61713. [E](B) *Eucalyptus* leaf form A, AMF61721, [E](C) *Eucalyptus* leaf form B, AMF61724, (scale bar = 10 mm).

Middle Eocene Beds of Maslin Bay, South Australia.

The oldest known radially symmetrical five winged fossil fruits with unique characters supporting their inclusion in *Ceratopetalum* are from the Early Eocene of Patagonia, Argentina (Gandolfo and Hermsen 2017). Because the affinities, provenance and age of those fossils is so well established, their new fossil species *C. edgardoromeroi* Gandolfo and Hermsen, is an excellent candidate for use as a calibration point in divergence dating studies of the family Cunoniaceae. It represents the only record of *Ceratopetalum* outside Australasia and further corroborates the biogeographic connection between the Argentina Laguna del Hunco flora and ancient and modern floras of the Australasian region. Jud and Gondalfo (2018) suggest that although Australasia is currently the centre of diversity of the family, the Argentinian findings suggest that west Gondwana had an important role in their diversification. According to Barnes et al. (2001) a Cretaceous origin of Cunoniaceae is possible, and may account for its widespread distribution on Southern Hemisphere landmasses.

Family ?Moraceae
Genus and Species uncertain.
Leaf Form D
Figures 4C, D

Material.
AMF145074.

Description.
Upper portion of a broad ovate leaf 40 mm wide and 85 mm long, as preserved. Apex bluntly pointed. Distinct narrow midvein terminating at apex. Secondary lateral veins irregularly alternate, departing from midrib at ca 60°, decurving across lamina to reach margin at ca 30°, occasionally forking at 2/3 distance to margin.

Discussion
As the leaf base and tertiary venation are not preserved to allow certain identification, this specimen is listed as Leaf Form D. From the features that are present it appears to be of rainforest origin and in particular details of the leaf it resembles some extant native *Ficus* species (Harden et al. 2006). Note that the *Ficus rubiginosa,* Rusty Fig, still grows in the Warrumbungle region (Mackay 2017).

Family Myrtaceae
Genus *Eucalyptus*

Eucalyptus bugaldiensis Holmes and Holmes, 1983
Fig. 4E(A) from Holmes et al.1983

Material.
AMF61713–61720.

Description.
Based on three umbellasters attached at a common point to a stem, each umbellaster is composed of seven or fewer fruit. Fruit hemispherical with the external surface ornamented by 7–10 longitudinal ribs. The rim is flat and exerted valves form a low triangular projection 0.5 mm above the rim.

Discussion.
This material was described in detail by Holmes et al. (1983) and illustrated in colour by White (1990 pp 58, 59). Due to lack of cuticle and attached or closely associated foliage it is difficult to compare these fertile organs with extant *Eucalyptus* species. In gross morphology there is a similarity with the extant Coolabah tree, *Eucalypus microtheca* (subgenus *Symphyomyrtus* section *adnataris*) a widespread species often growing on ground subject to flooding. Christophel (1989) considered the Chalk Mountain leaf and fruit impressions as definitely eucalyptoid as was also noted by Hill et al. (2016).

Eucalyptus sp. Leaf Form A.
Fig.4 E(B) from Holmes et al. 1983

Material.
AMF61721–3

Description.
Leaf lamina lanceolate to narrow falcate, asymmetrical about lamina base; secondary veins ca 1 mm apart, parallel and running at 50° to 60° to the intramarginal vein which runs close and parallel to the leaf margin. Tertiary veins form an irregular network of about 4 rows between the secondary veins.

Discussion.
The venation pattern of Leaf Form A resembles that of various eucalypt species now placed in *Corymbia* and *Angophora* and *Eucalyptus trachyphloia,* a bloodwood growing in the sandy soils of the nearby Pilliga region. See Holmes et al. (1983) for further discussion on the venation pattern and classification.

Eucalyptus sp. Leaf Form B
Fig. 4E(C) from Holmes et al. 1983

Material.

AMF61724–5, MMF15284.

Description.

Leaf lanceolate, slightly falcate, base asymmetrical, secondary veins sub-parallel, spaced irregularly and running a slightly undulate course to the intra-marginal vein.

Discussion.

Eucalyptus Leaf Form B differs from *Eucalyptus* Leaf Form A by the wider spacing and irregular course of the secondary veins. In form and venation Leaf Form B is similar to the leaves of extant *Eucalyptus raveretiana,* Black Ironbark, that grows along inland watercourses, river flats and open woodland (Halford 1997). See Holmes et al. (1983) for further discussion on the venation pattern and for a colour illustration of the attached leaves White (1990 p. 197).

Lange (1980) commented on the absence of eucalypt cuticles from mid-Tertiary floras around the margin of the Australian Plate that were dominated by rainforest. The presence of eucalypt fruit and leaves in the Chalk Mountain flora indicates that the warming and drying of the region was occurring in the Warrumbungle region by the mid Miocene and resulted in the introduction of a sclerophyll flora into a previous rainforest dominated environment.

The earliest *Eucalyptus* fossils were described by Gandolfo et al. (2011) from the Eocene Laguna del Hunco palaeoflora of Patagonia, Argentina and from New Zealand by Pole (1993) indicating the genus may have occurred around the Southern Hemisphere at that time which suggests that the rich extant Australian population of eucalypts may be a relic from an Early Cenozoic time. The cause of extinction of *Eucalyptus* from South America (Hermsen et al. 2012) and New Zealand remains obscure (Hill et al. 2016).

Family ?Myrtaceae
Genus and Species uncertain
Leaf Form C
Figure 4B

Material.

AMF145073.

Description

A small ovate-elliptic leaf, apex rounded-acute: base missing: length as preserved 25 mm, total length probably ca 35 mm, width 10 mm: tri-veined, outer veins running parallel 1mm in from leaf margin. Lateral veins widely spaced, leaving midvein at ca 20° and running almost straight to outer vein.

Discussion.

This small leaf fragment is distinguished by its three veins and the pattern of the lateral veins at an acute angle. The extant rainforest genus *Rhodamnia* has similar three veins from the base but the lateral veins are closely spaced and run at an obtuse angle >45^{o} towards the leaf margin (Floyd 1989, Harden et al. 2006). The three main veins are somewhat similar to those in the much smaller sepals of *Ceratopetallum* (Figure 4A) but the lateral veins differ by being at an acute angle.

Family Urticaceae
Genus *Dendrocnide*
Dendrocnide sp. A aff. *D. excelsa*
Figs 5 A–D

Material.

AMF145075, 145076 and counterpart 145077, 154078.

Description.

Based on the macro features of two closely similar ovate leaves, almost complete but with base missing, to 80 mm wide. Margin slightly undulate, entire to slightly toothed. Midvein to 2 mm in width, decreasing gradually to leaf apex. Secondary veins prominent, leaving midrib as opposite pairs closer to base, sub-opposite to alternate distally as angle of attachment decreases from ca 80° to ca 40° upwards; decurving slightly but close to margin curving upwards to run parallel to leaf margin; rarely forking. Tertiary veins joining secondary veins at right angles 2–3 mm apart. Quaternary veins form an irregular network of very fine lines between the tertiary veins.

Discussion.

The venation pattern of the fossil leaves is identical to that in the mature foliage of extant *Dendrocnide excelsa* (Fig. 5E) and *D. moroides* trees (Floyd 1989, Harden et al. 2006). In Australia these two species have very similar leaves with *D. excelsa* having a cordate base while *D. moroides* is a peltate leaf with the base truncate to cordate. None of the fossil leaves have their base preserved and their identity is thus uncertain. *D. excelsa* is commonly known as the Giant Stinging Tree and has numerous silica spines on the leaf surface. When touched by humans the spines enter the skin causing severe and prolonged pain. The silica spines are not evident on the fossils. The Giant Stinging Tree is a pioneer species in eastern Australian rainforests following openings of the canopy as a result of severe storms. The young trees show vigorous growth with very large juvenile

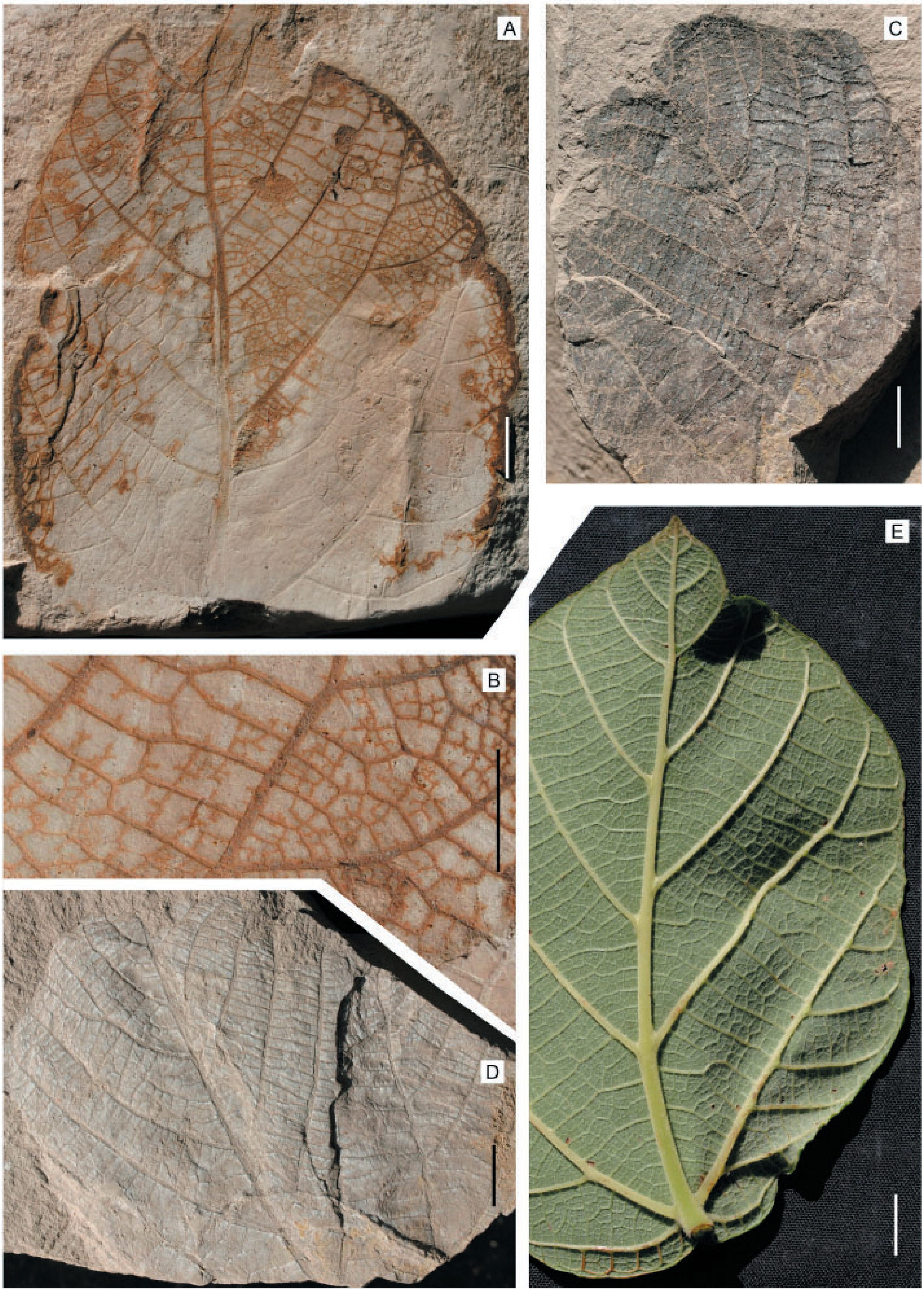

Figure 5. [A–D] *Dendrocnide* sp. A aff. *D. excelsa*. [A, B] AMF 145075. [C] AMF 145076. [D] AMF 145077 (counter part of 145076). [E] *D. excelsa* extant leaf from Dorrigo Rainforest, (scale bar = 10 mm).

leaves that are frequently eaten by insects. On older trees the leaves reduce in size identical to the fossils described above. Extant mature trees may reach 44 m in height and to 6.4 m in diameter at breast height (see www.nationalregisterofbigtrees).

Fossil pollen attributed to the Urticaceae family has been recorded from the Upper Oligocene and Miocene deposits in Australia (Martin 1994). There are no previous macrofossil records of *Dendrocnide* from Australia which makes these leaves from the Chalk Mountains very significant. The world macrofossil record of Urticaceae is scattered and largely based on fossil achenes from the Late Cretaceous of Central Europe (Friis et al. 2010).

An additional fragmentary leaf (AMF154078 not illustrated) shows generally similar venation to the two illustrated specimens but with two unusual secondary veins.

RECONSTRUCTING THE CHALK MOUNTAIN FLORA

In reconstructing a flora based on limited preserved remains, one must accept that the fossil material may have been transported from varying distances and from diverse vegetation types. The macrofossil remains described above and the palynological records of Martin (in Holmes et al. 1983) of swamp, riverside, rainforest and sclerophyll type vegetation preserved in the Chalk Mountain diatomite indicates a variety of sources. Greenwood (1994) noted that fossil leaf accumulations constitute a biased but often detailed record of the parent vegetation. In the Chalk Mountain Formation, except for a thin basal lignite horizon (Fig. 1) the pure diatomite of the lake deposit clearly demonstrates that there were no incoming streams depositing sediments in the caldera (White 1994). The fossil plant material was therefore deposited mainly by gravity or carried from a distance by wind storms. There is some evidence of *in situ* preservation based on the whorls of leaves assigned to the ?Isoetaceae which possibly grew around the lake margin. The occurrence of *Equisetum* also indicates a moist possible swamp environment. The presence of eucalypt material with rainforest remains does not necessarily reflect a common rainforest origin. The eucalypts were probably from a sclerophyll forest adapted for growth on the sandy soils derived from the adjacent and underlying Jurassic Pilliga Sandstone beds and the rainforest species from sheltered and moist gully situations.

The low *Nothofagus* pollen content and the high myrtaceous content including *Eucalyptus* fruit and leaves (Martin in Holmes et al. 1983) indicates that the Warrumbungle region vegetation was responding to a warming and drying climate as the Australian plate moved northwards during the Middle Miocene (Wilford and Brown 1994). This resulted in the introduction of a sclerophyll flora possibly due to an increasing fire frequency that altered the previous rainforest dominated vegetation (Hill et al. 2016, Kershaw et al. 1994).

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