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Long term climate change and plant evolution in Australia

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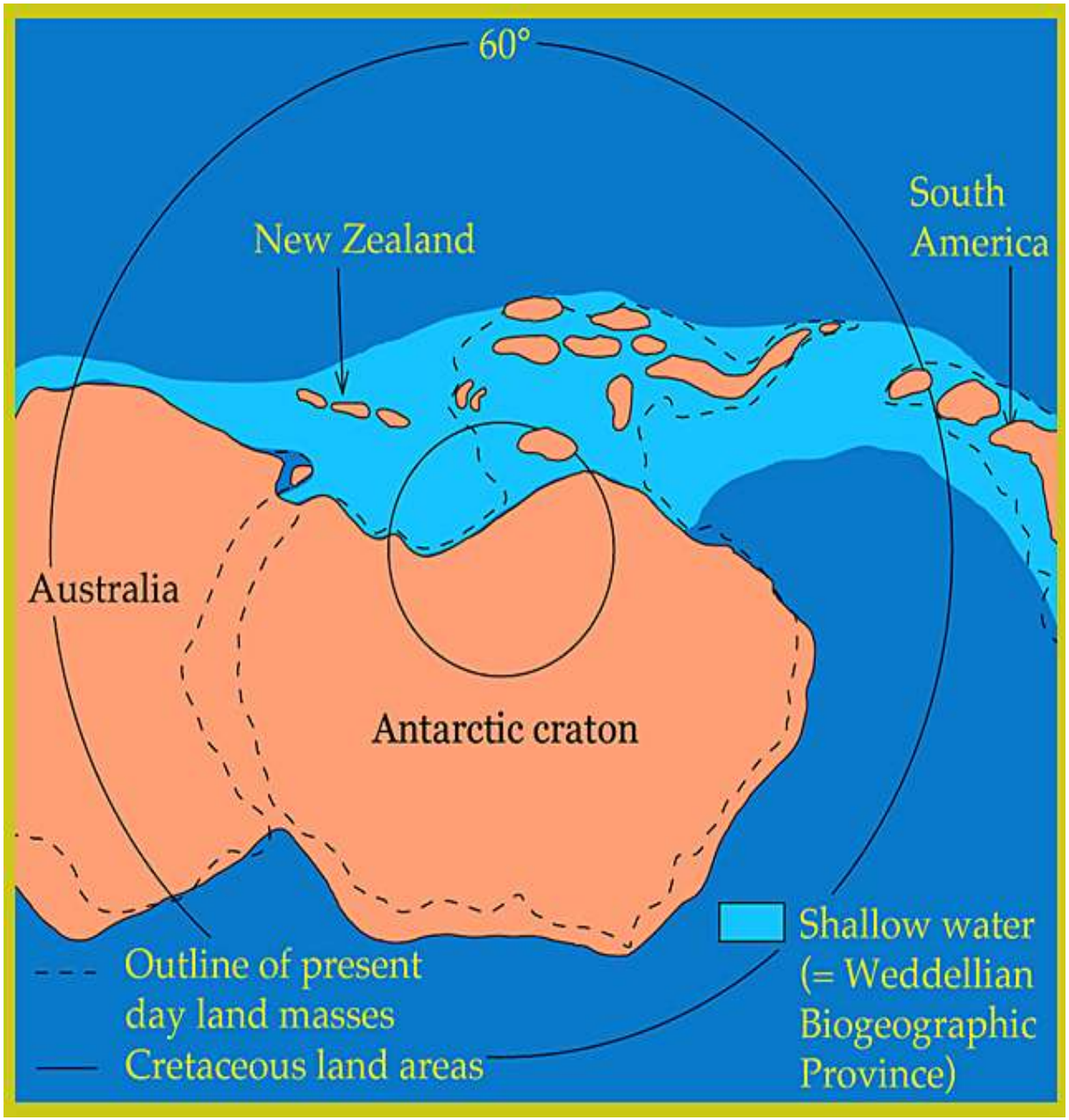
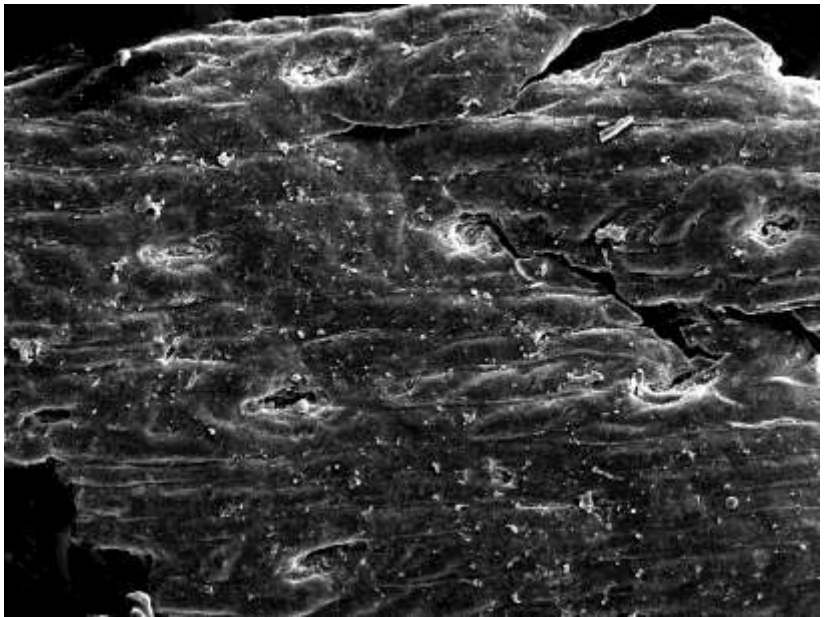
Weddellian Biogeographic Province

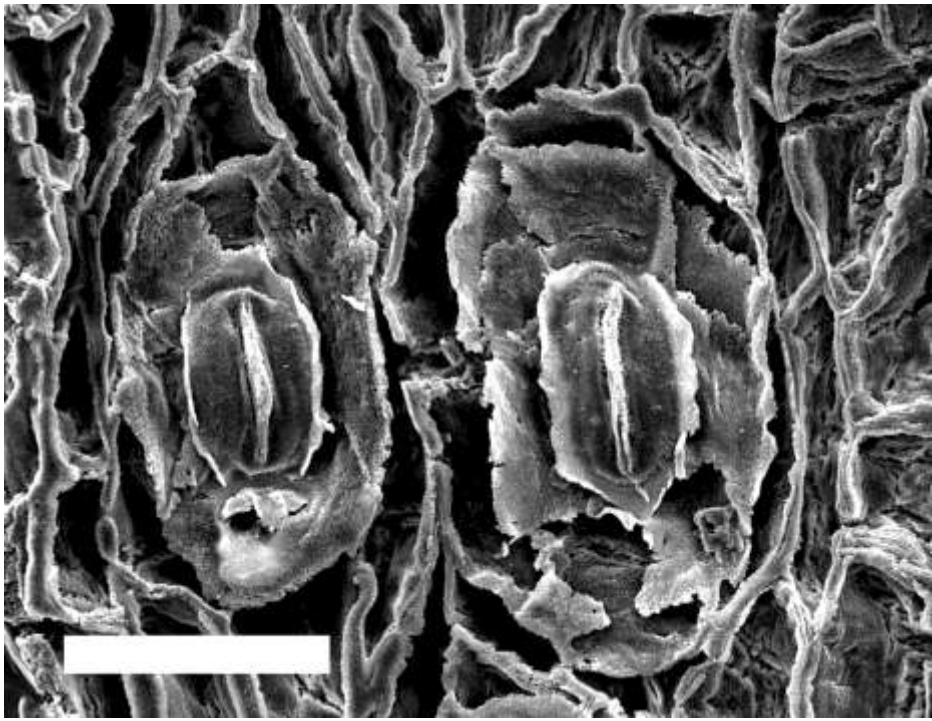


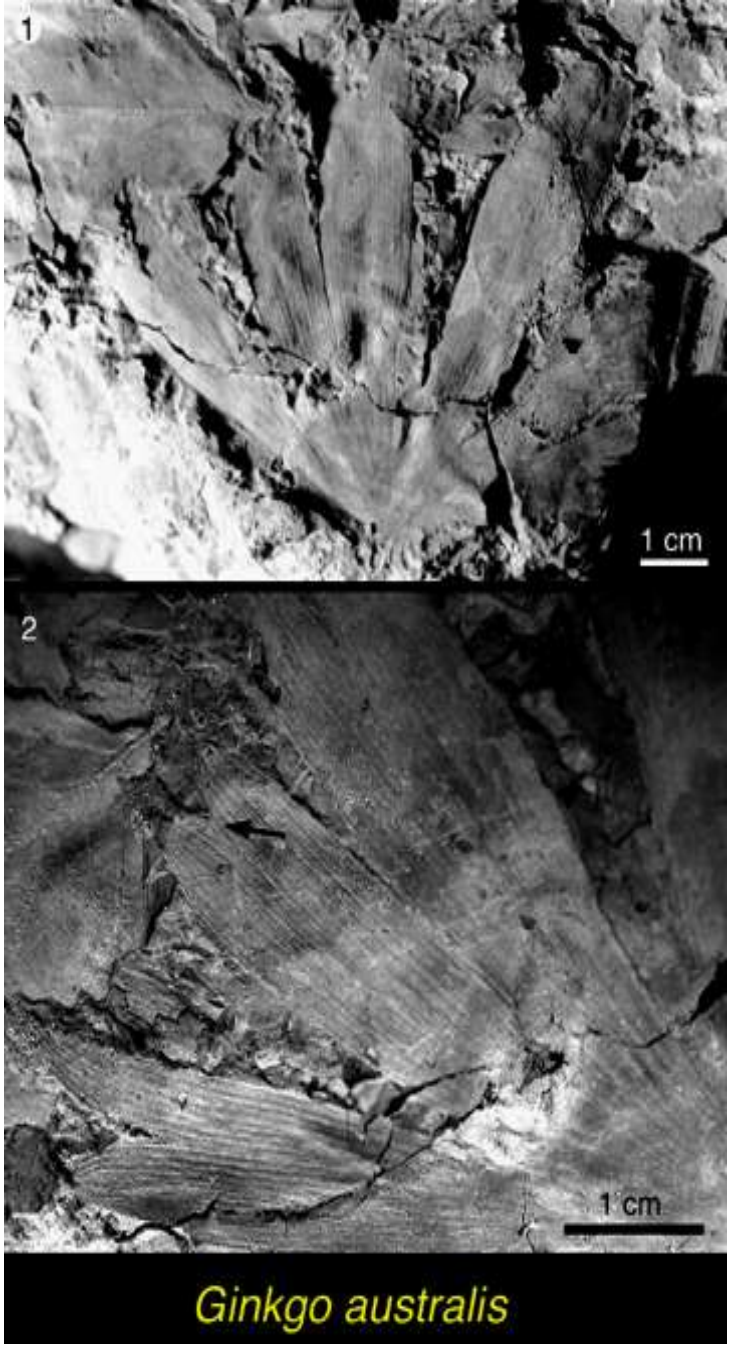
Many major Southern Hemisphere plant families evolved or diversified in the Late Cretaceous in the Weddellian Biogeographic Province, including Podocarpaceae, Nothofagaceae, Casuarinaceae and Proteaceae.

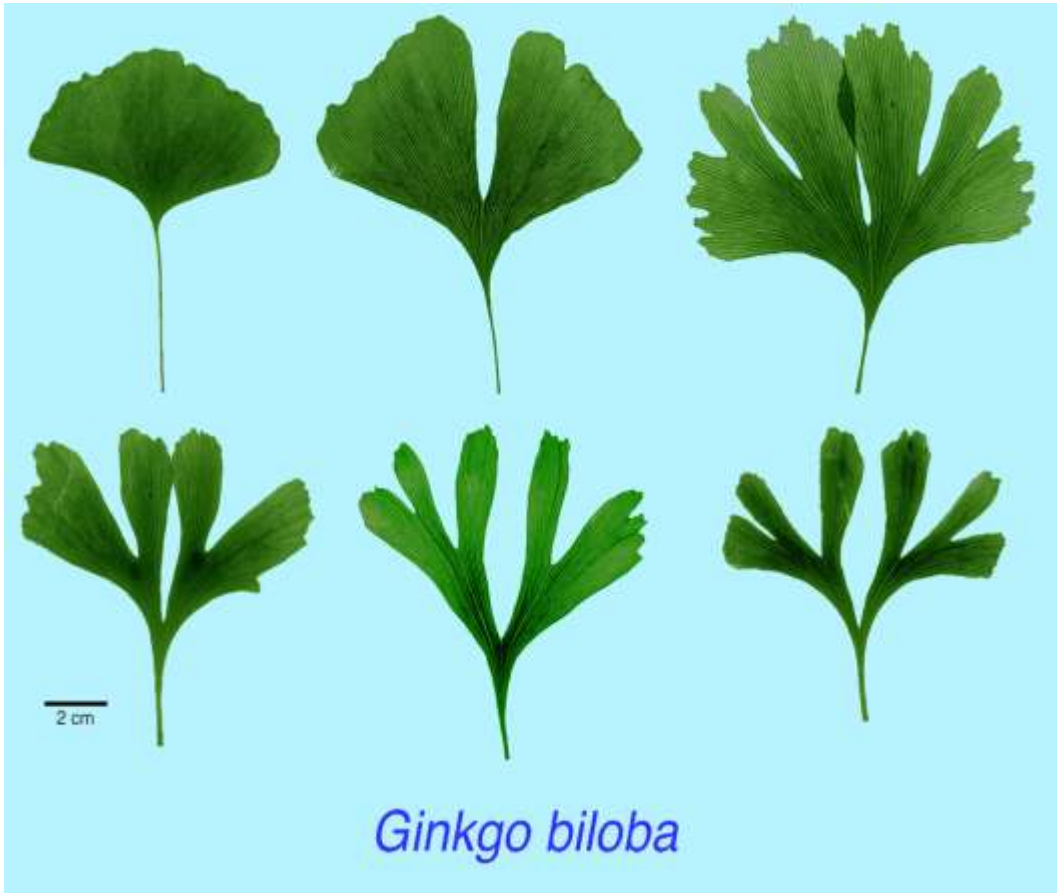
- Early in the Cenozoic, several very unusual taxa (from a modern perspective) continued to be common in the vegetation.
- These taxa appear to bear more resemblance to typical Cretaceous seed plants than to living taxa and they are represented by cycads, ginkgos, seed ferns and conifers.
- Few of this group seem to have survived the mid-Eocene (about 45 Ma)

Araucarioides over 20 cm long with broad attachment at base and acute apex









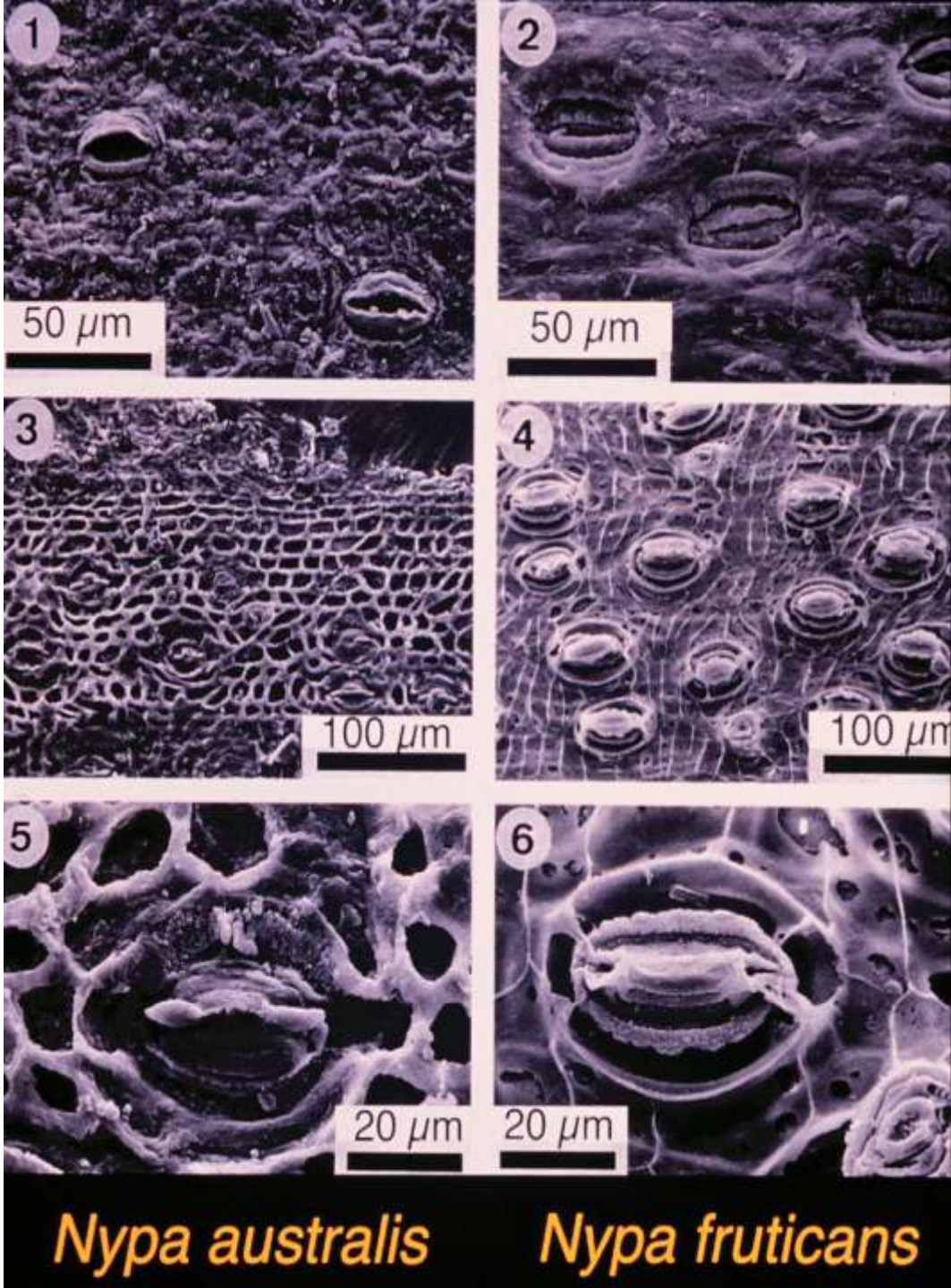
Tasmania was a refugium into the Eocene for *Ginkgo*

Pterostoma, an extinct genus of cycad bearing fronds with a clean abscission layer

Along with this largely extinct group of taxa is another group of taxa that today are found in tropical environments, both in extreme conditions and within rainforests.

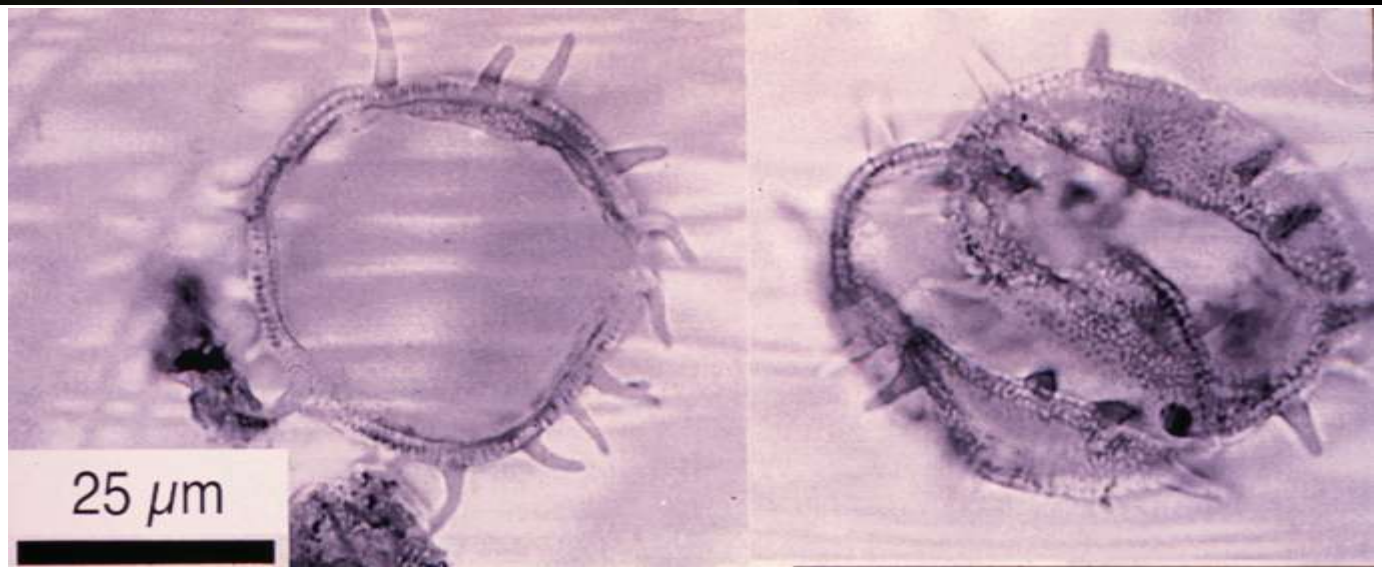
An extant *Nypa* mangrove swamp


2 cm


1
50 μm
2
50 μm
3
100 μm
4
100 μm
5
20 μm
6
20 μm
Nypa australis
Nypa fruticans

Nypa australis

Nypa fruticans



Unidentified leaf, Maslin Bay *Menispermaphyllum*, Nerriga

Both ~45 Ma, scales = 1cm

The conditions that allowed these taxa to occur at very high southern latitudes (adjacent to Antarctica) include:

- An extinct climate, including everwet conditions
- Extremely high atmospheric carbon dioxide levels
- High latitude photoperiods
- Possibly high natural disturbance regimes (in some cases)

- In most examples that we understand, very little evolution appears to have occurred since the Cretaceous. There has been significant extinction and range changes ("following" climates), but few examples of clear evolutionary change. Two examples we do know well will be outlined later.

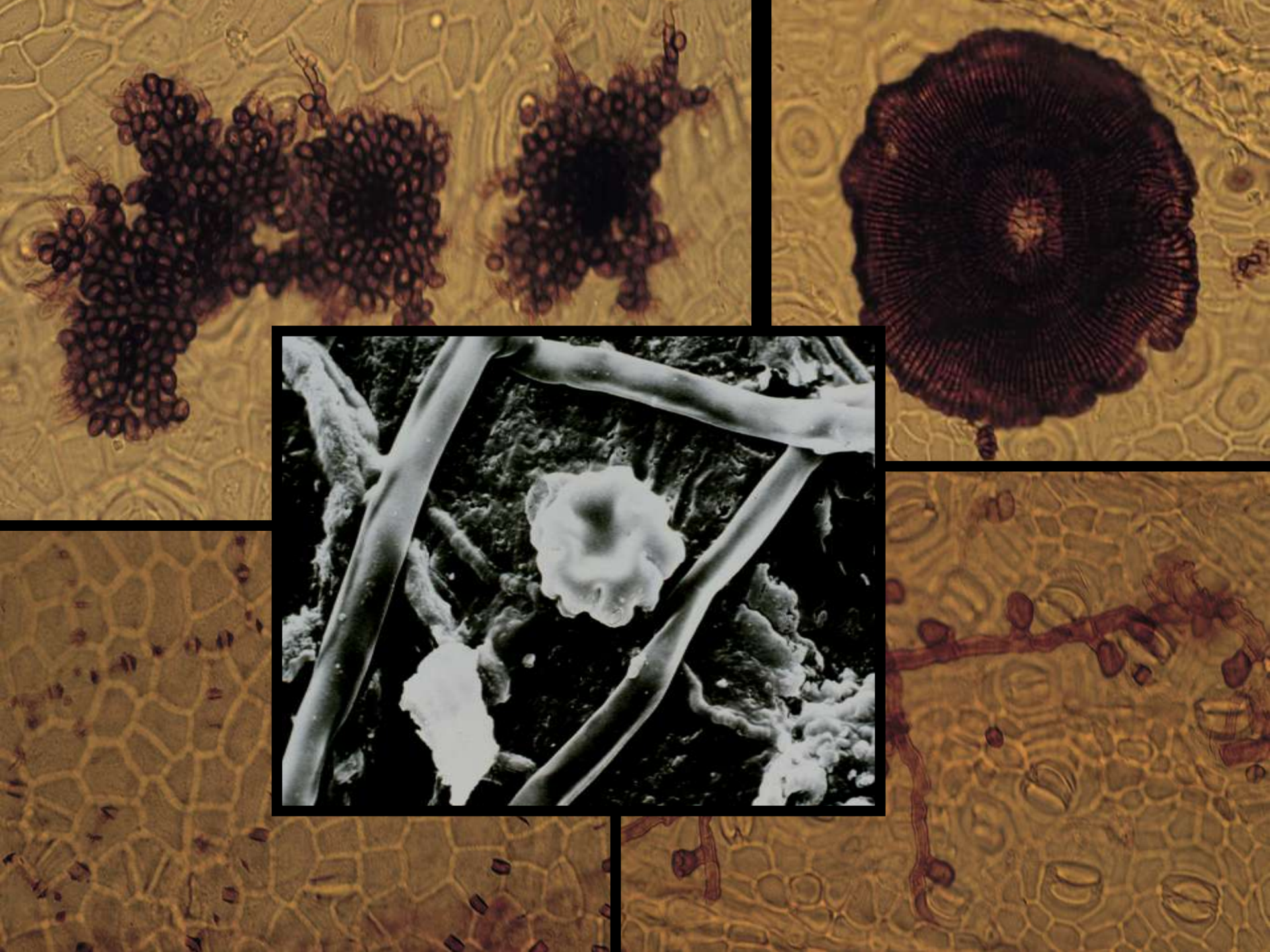
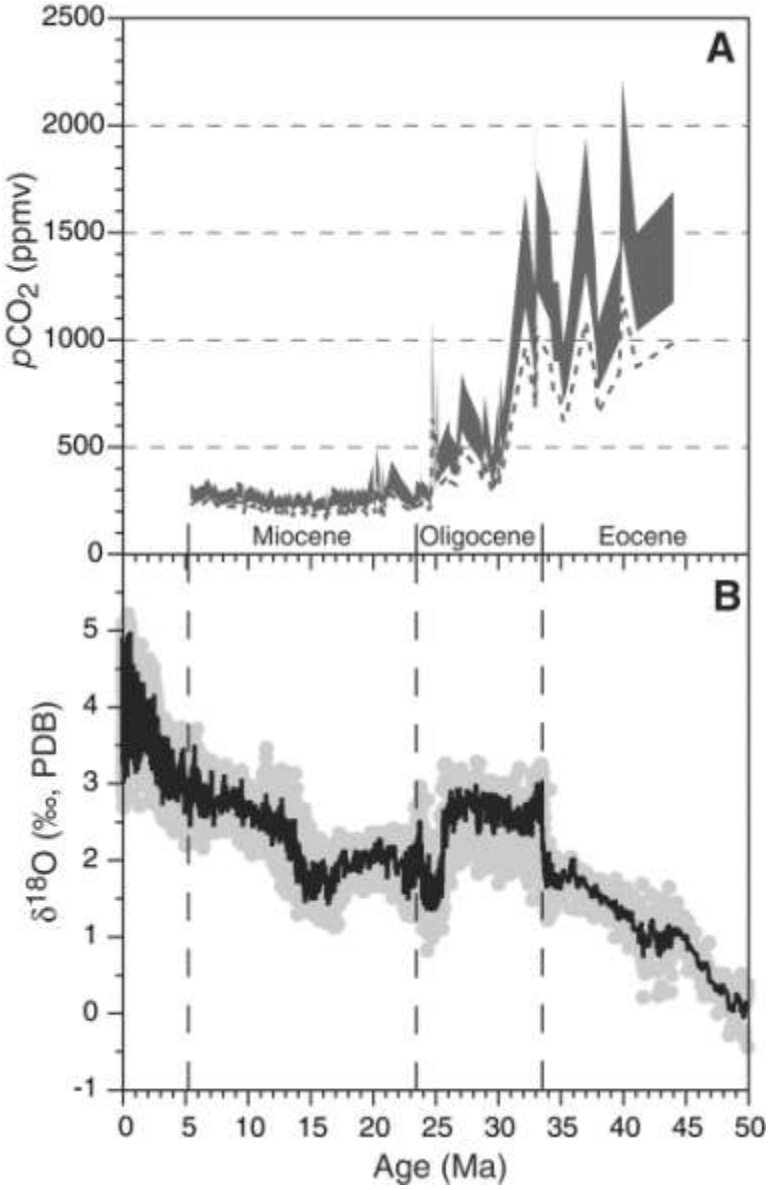


Fig. 3. (A) pCO2 estimates from M. Pagani et al., Science 309, 600-603 (2005)



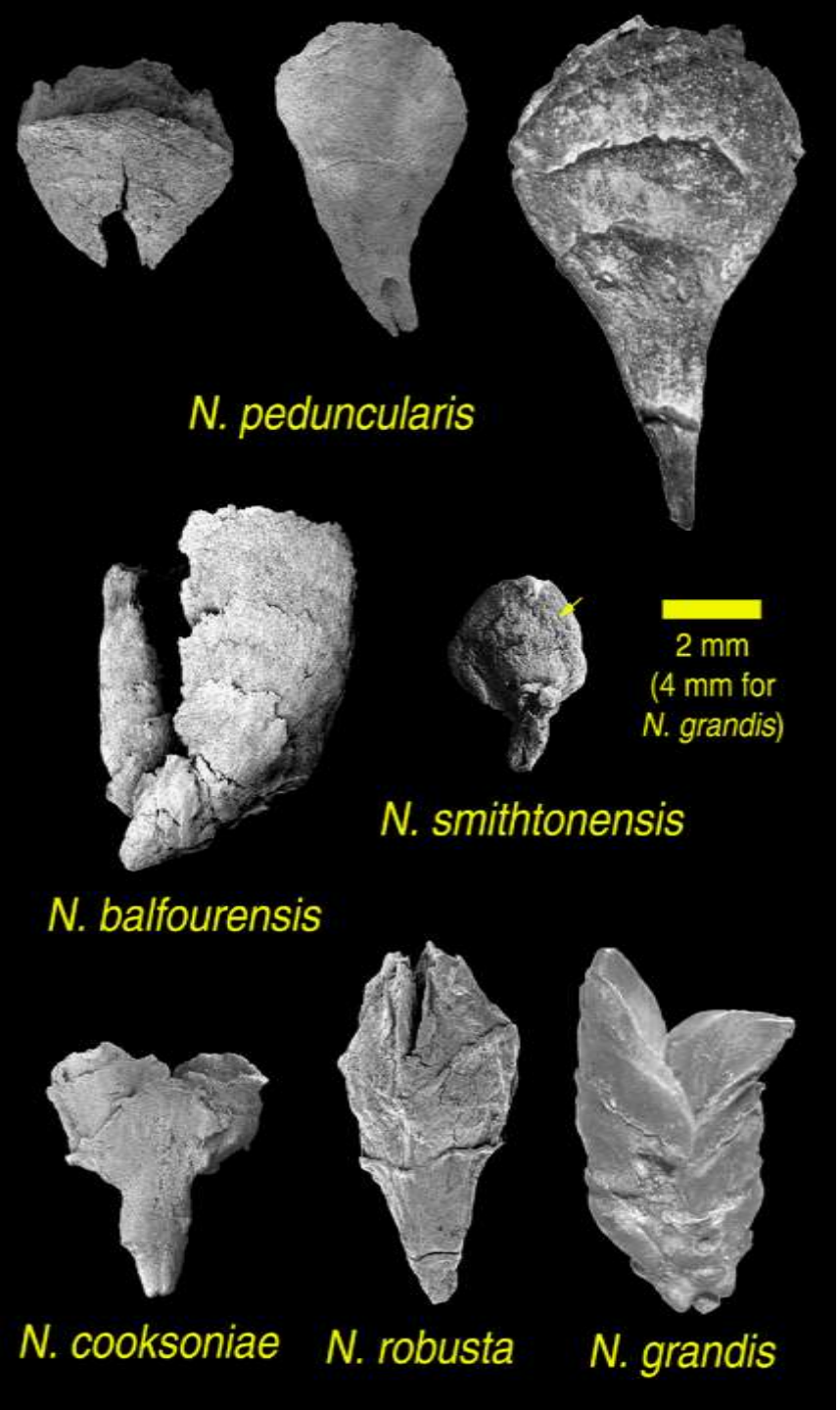
From this time onwards, until Australia separated from Antarctica, many other rainforest elements dominated southern Australian vegetation.

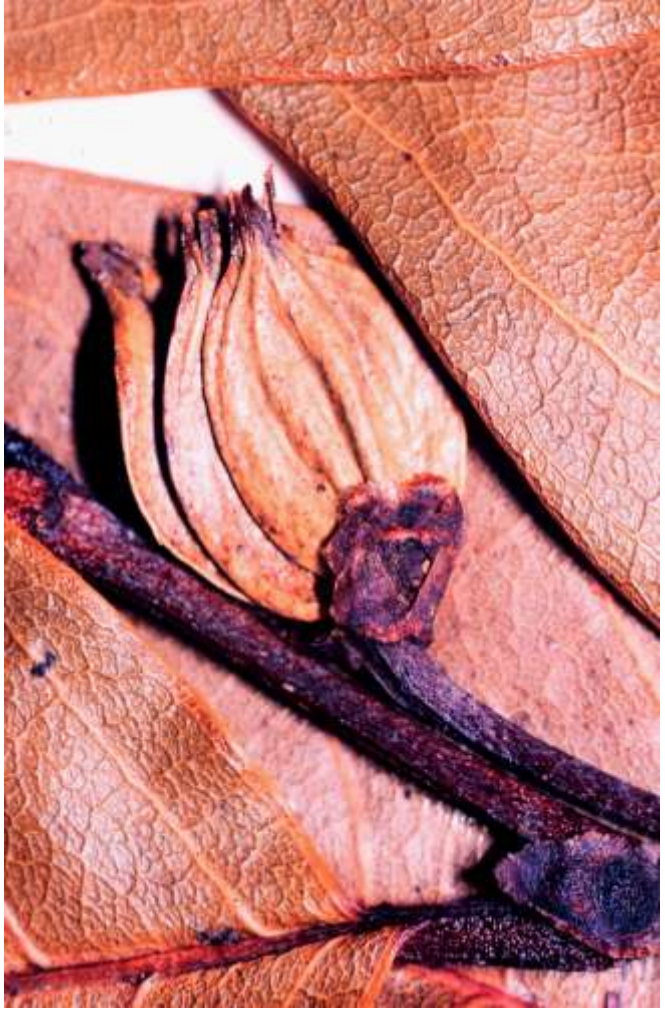
Most of the nearest living relatives of these fossils occur today from northeast Australia northwards into the tropics.

Following the separation of Australia from Antarctica, about 35 Ma, the vegetation of southern Australia remained mostly rainforest, but took on a less mesothermal aspect.

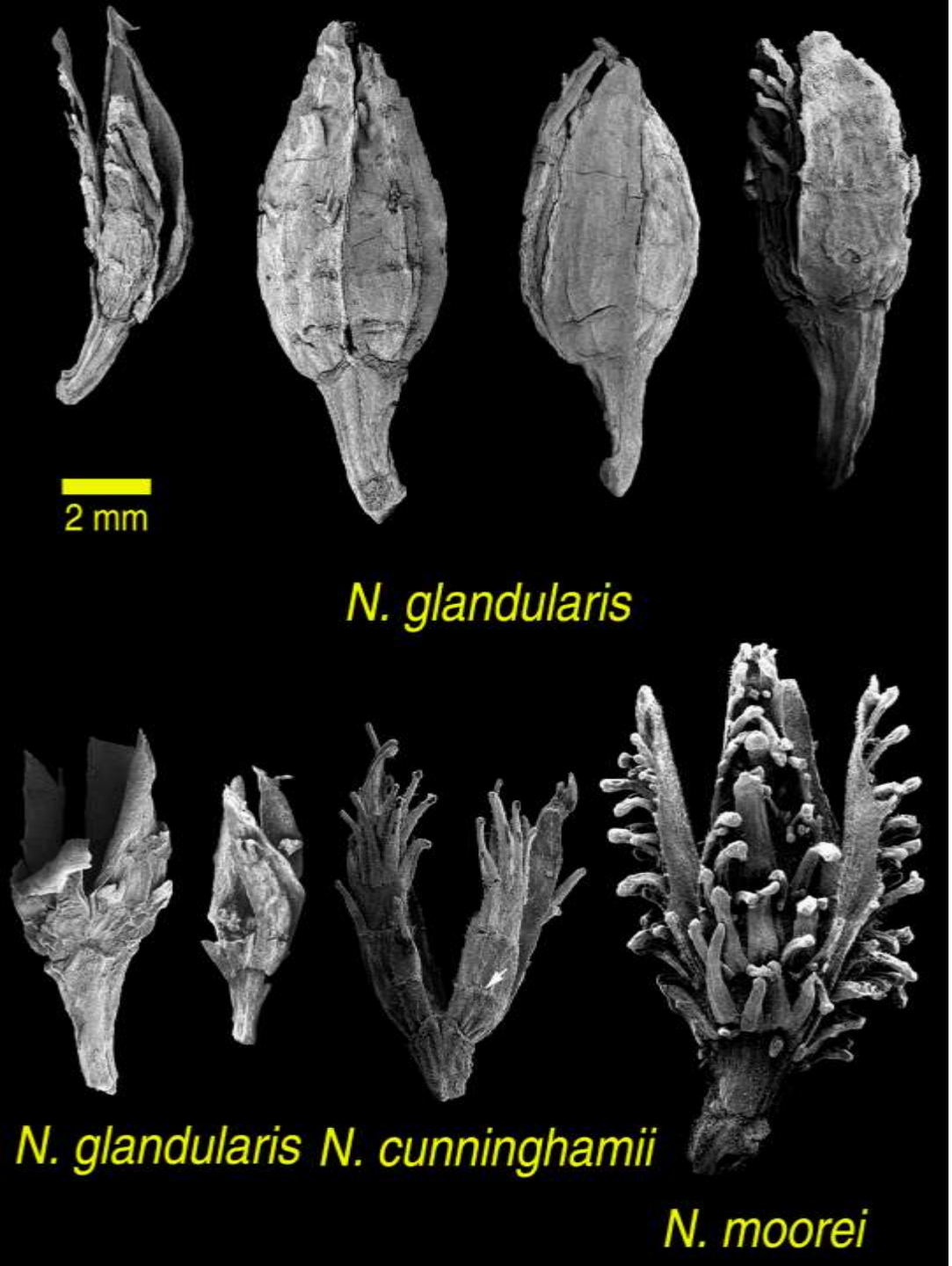
Rainfall remained high, at least initially, and temperature extremes must have been compressed.

Species diversity was very high and some taxa attained extreme diversity.





Cupules of fossil and living *Nothofagus* subgenus *Brassospora*



Cupules of fossil and living *Nothofagus* subgenus *Lophozonia*

Leaf and cupule fossils of *Nothofagus* subgenus *Nothofagus* from the Early Oligocene of Tasmania

Angiosperms are common and diverse and include leaves, wood, flowers, fruits and seeds. Most have not yet been described, like these leaves above of Lauraceae (left), Cunoniaceae? (middle) and Elaeocarpaceae? (right)

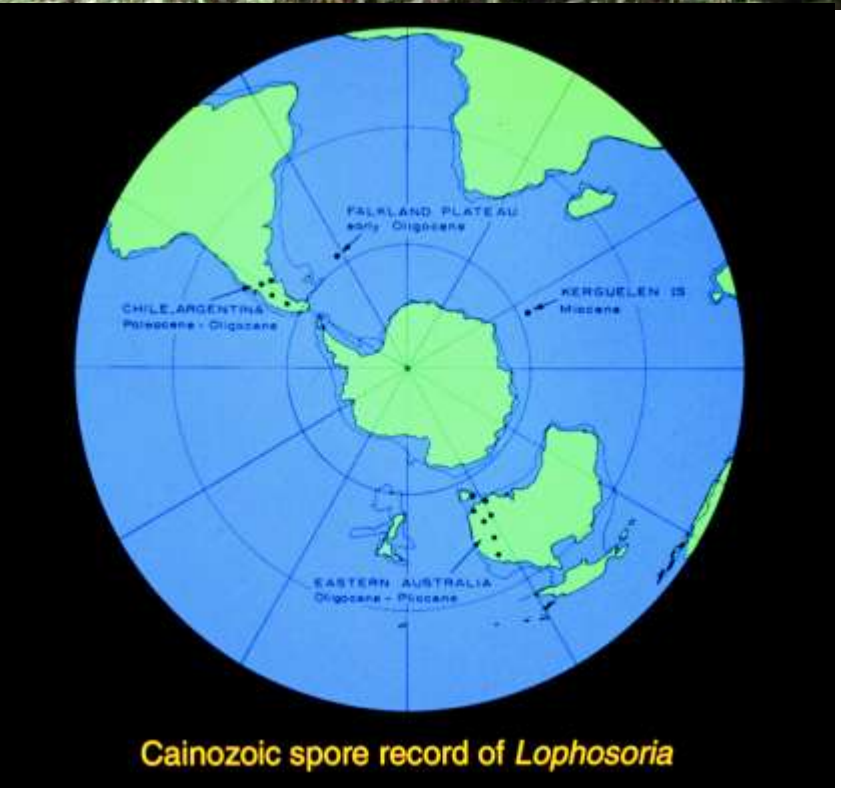
The extinction of some taxa from Australia during the last 35 million years can be very difficult to explain.

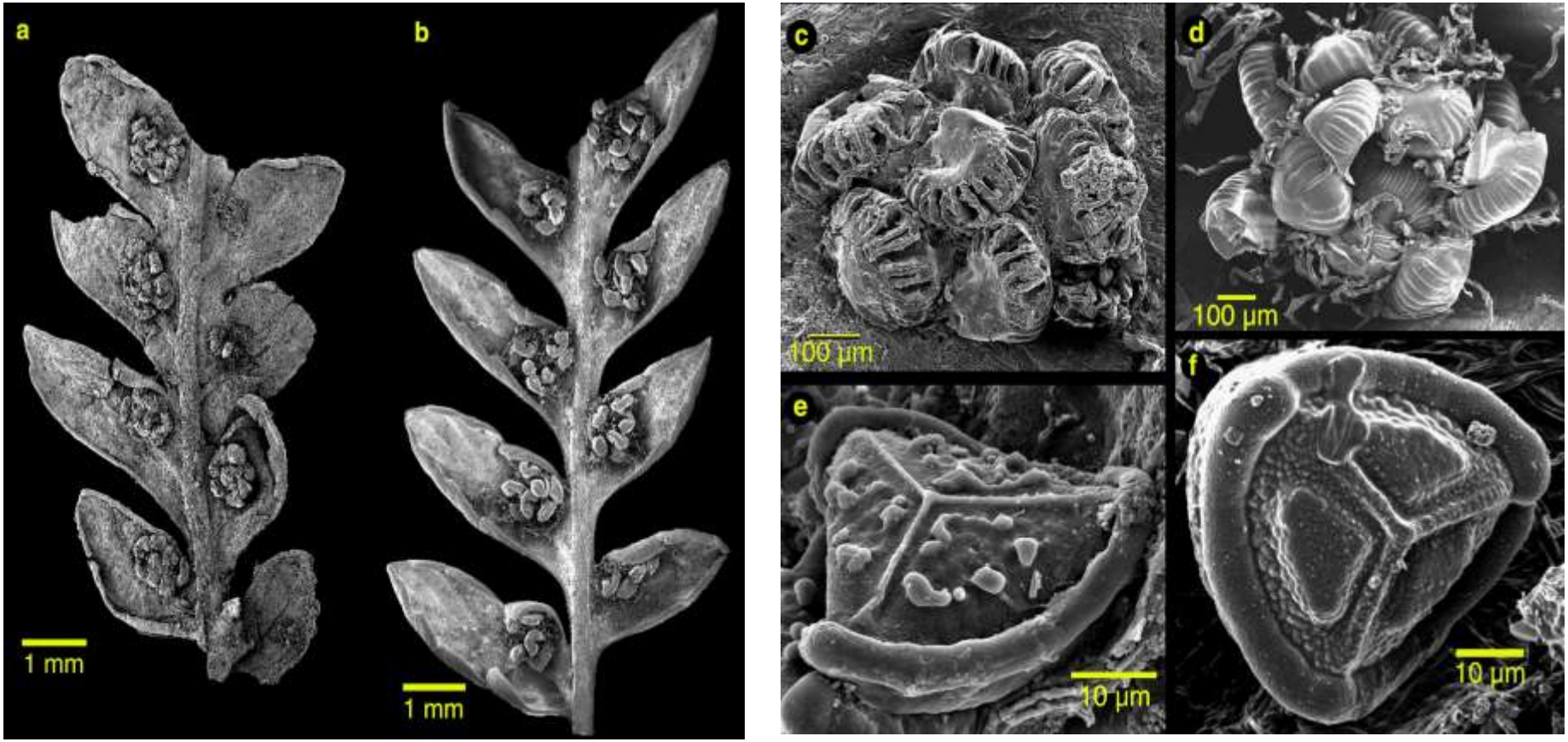
A good example is *Lophosoria quadripinnata*, an extant fern that is common in disturbed environments throughout South America.

This fern was present in Australia until relatively recently.

What caused its extinction here, while it remained a thriving, disturbance-based species in South America?


Lophosoria quadripinnata
extant distribution


FALKLAND PLATEAU
early Oligocene
KERGUELEN IS
Miocene
CHILE-ARGENTINA
Paleocene - Oligocene
EASTERN AUSTRALIA
Oligocene - Miocene
Cainozoic spore record of Lophosoria



Lophosoria quadripinnata from Balfour (left) and extant (right).

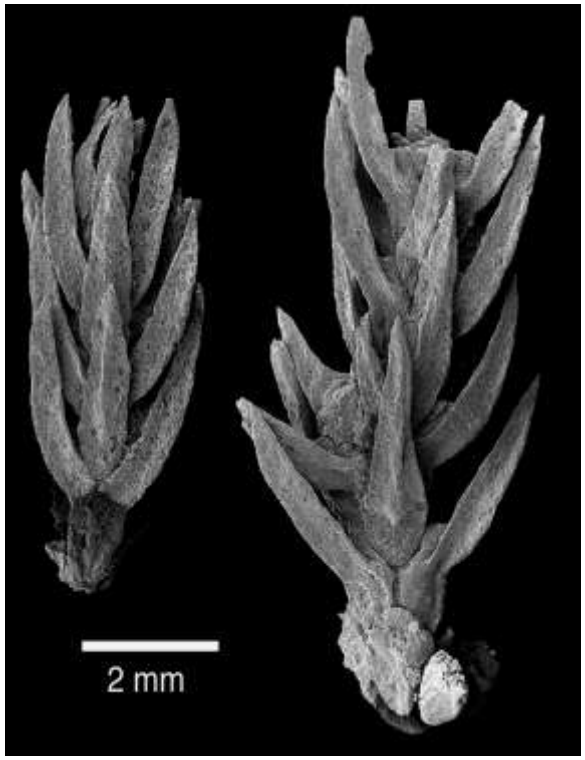
Conifers represent a special case in the Australian fossil record:

- They reached remarkable diversity at about the time Australia separated from Antarctica
- Many of them evolved to survive as small trees or shrubs in the understorey of dense and diverse rainforests
- The extinction of many conifers in Australia appears to be directly linked to a drying climate

Site	Age	Total
Buckland	Early Eocene	8 (5)
Regatta Point	Early Eocene	11 (7)
Hasties	mid-Late Eocene	12 (8)
Loch Aber	mid-Late Eocene	6 (6)
Cethana	Early Oligocene	16 (10)
Lea River	Early Oligocene	11 (8)
Little Rapid River	Early Oligocene	26 (14)
Monpeelyata	L Oligo-E Miocene	7 (5)
Pioneer	L Oligo-E Miocene	14 (11)
Regatta Point Upper	Early Pleistocene	7 (7)

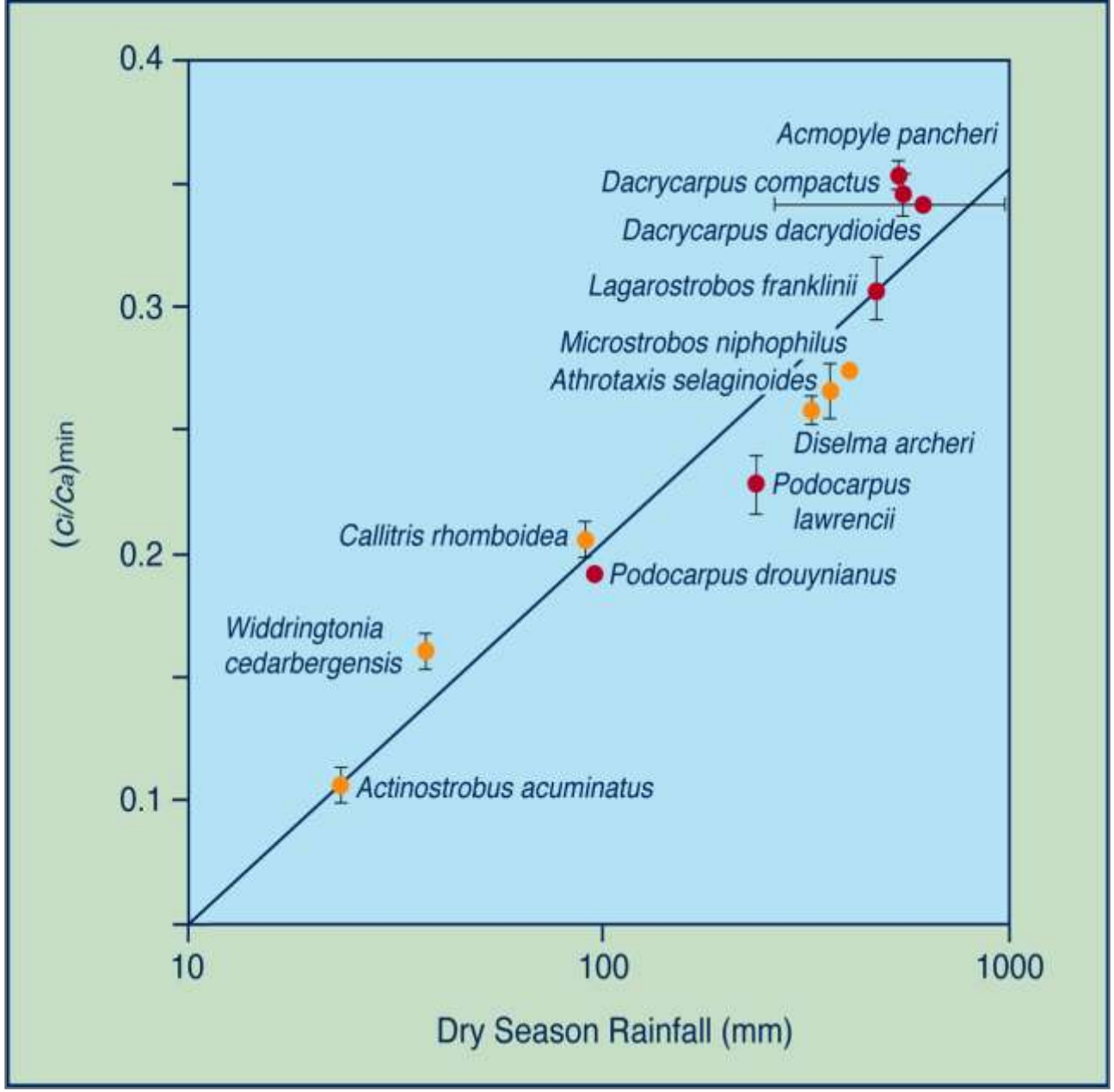
Conifer fossils in Tasmanian localities. The total is the number of species identified, with the number of genera in brackets.

Some very tall conifers (e.g. some Araucariaceae, some Cupressaceae) must have been forest emergents, as they are today. *Fitzroya cupressoides,* an enormous forest tree in southern South America today, and once common in southeastern Australia



Fitzroya acutifolius from the Early Oligocene of Tasmania

Increasing Water Use Efficiency ->



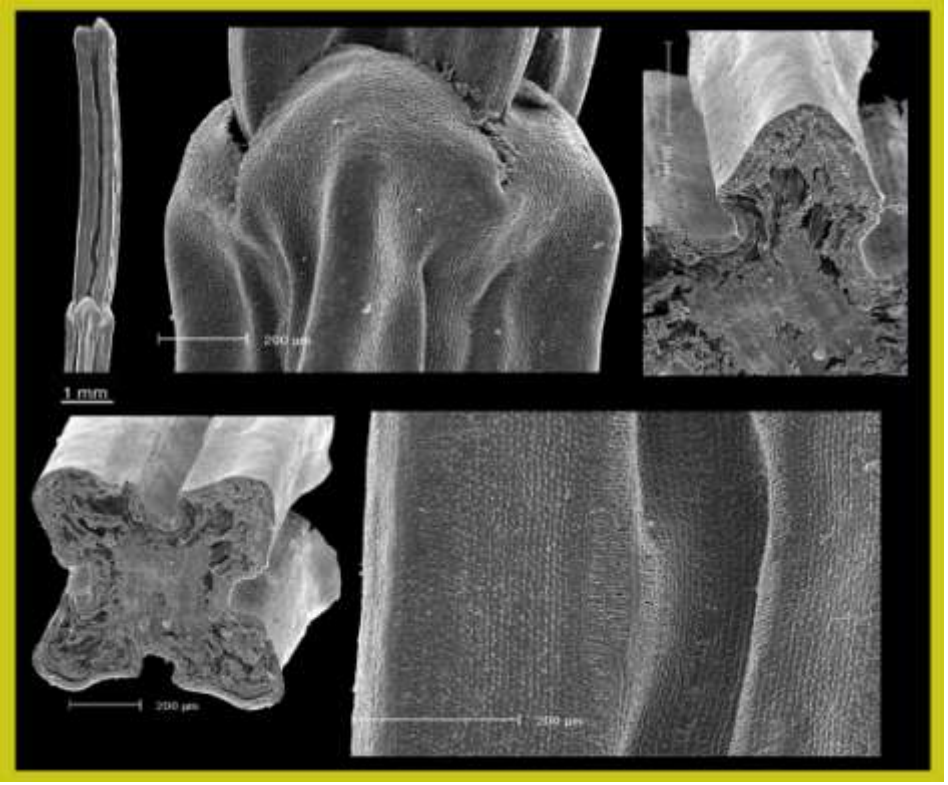
Increasing Dry Season Rainfall ->

There are two good examples of evolution in response to climate change that we know reasonably well from the fossil record:

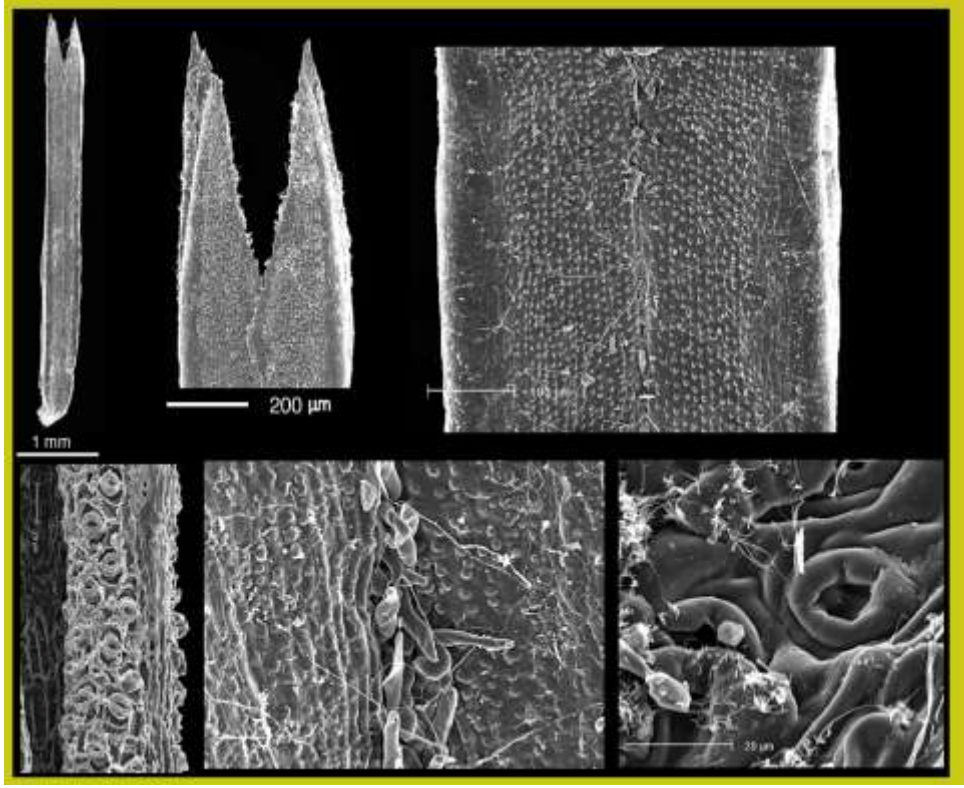
1. The generic diversification of Casuarinaceae, and

2. The evolution of arid-adapted *Callitris*

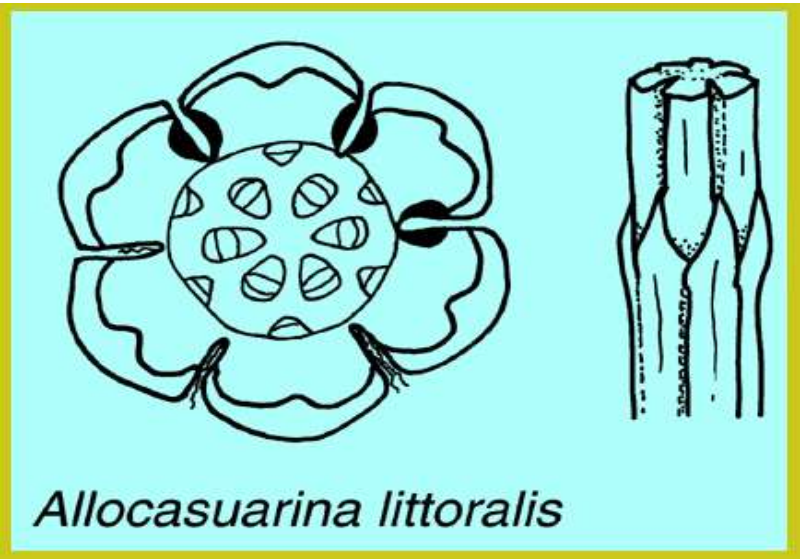
Both examples are incomplete and open to more than one interpretation. That given here is the one we consider most likely.



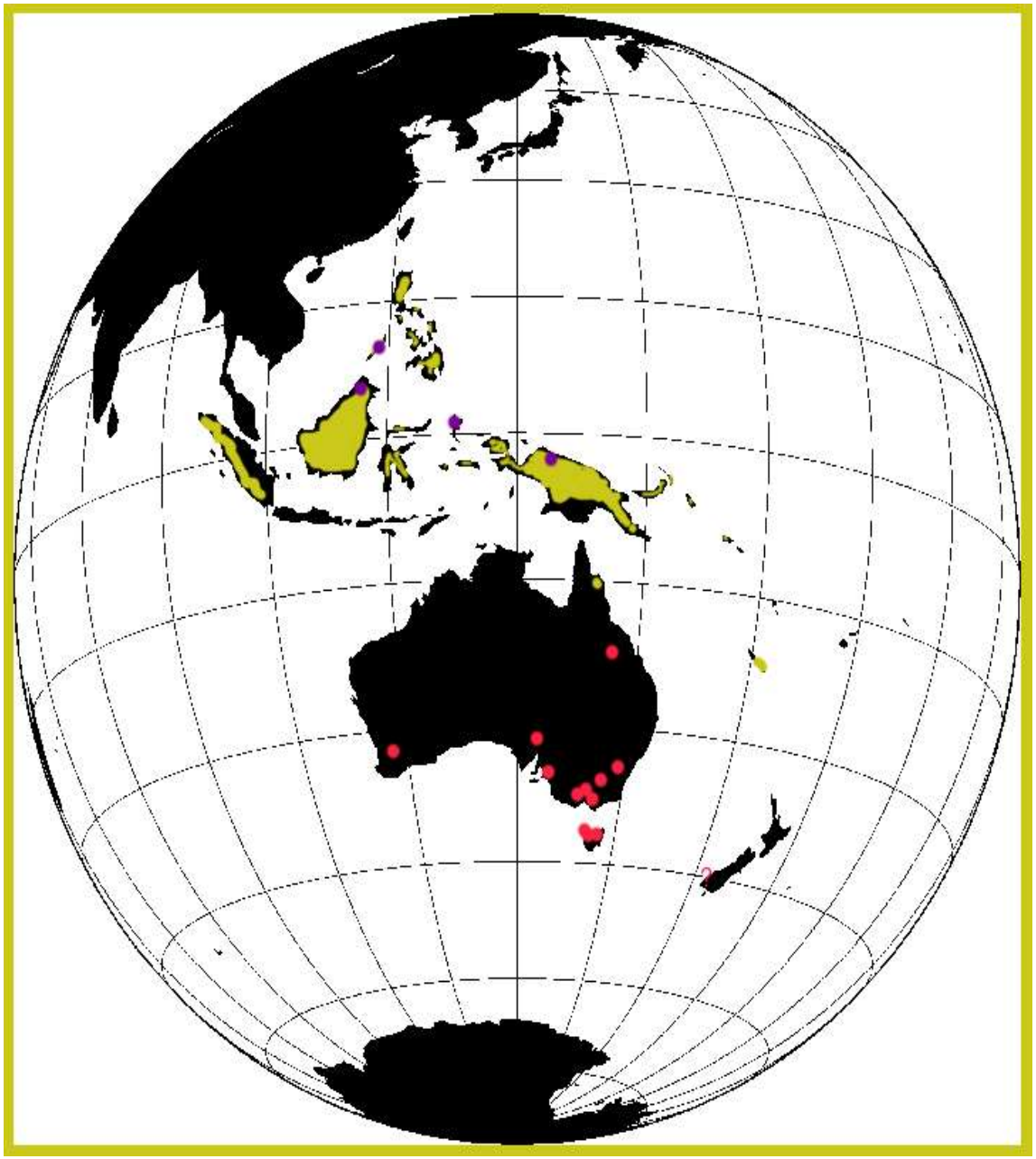
Gymnostoma



Ceuthostoma



There are three basic morphologies of foliage within Casuarinaceae, with *Allocasuarina* and *Casuarina* the same.



Gymnostoma distribution

Present

Past (including Patagonia)

Ceuthostoma Distribution

Present

Past distribution unknown

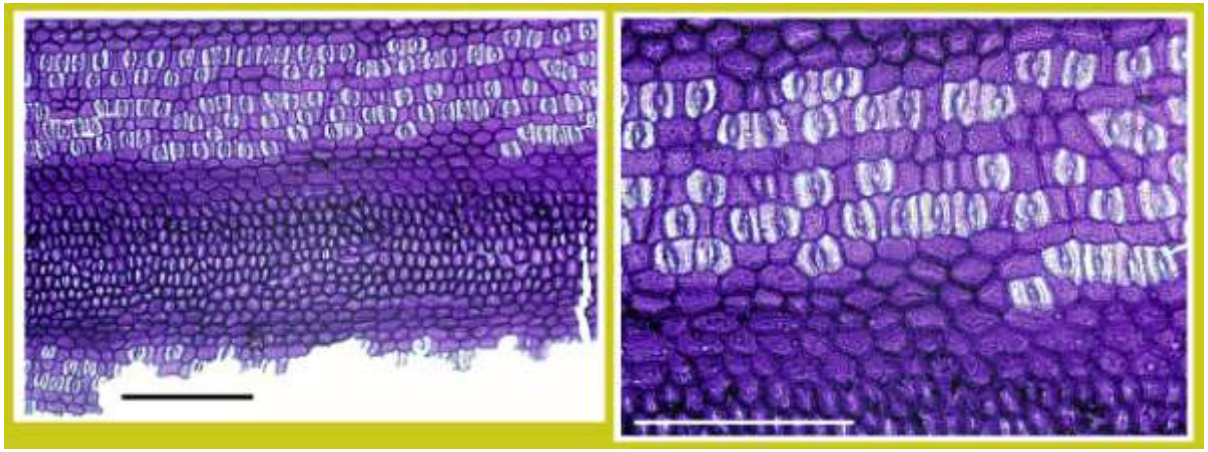
Gymnostoma - Nelly Creek, Northern South Australia (~45 Ma)

4 leaves, teeth

exposed stomata in rows at furrow edge

stomata in 8 rows

no trichomes



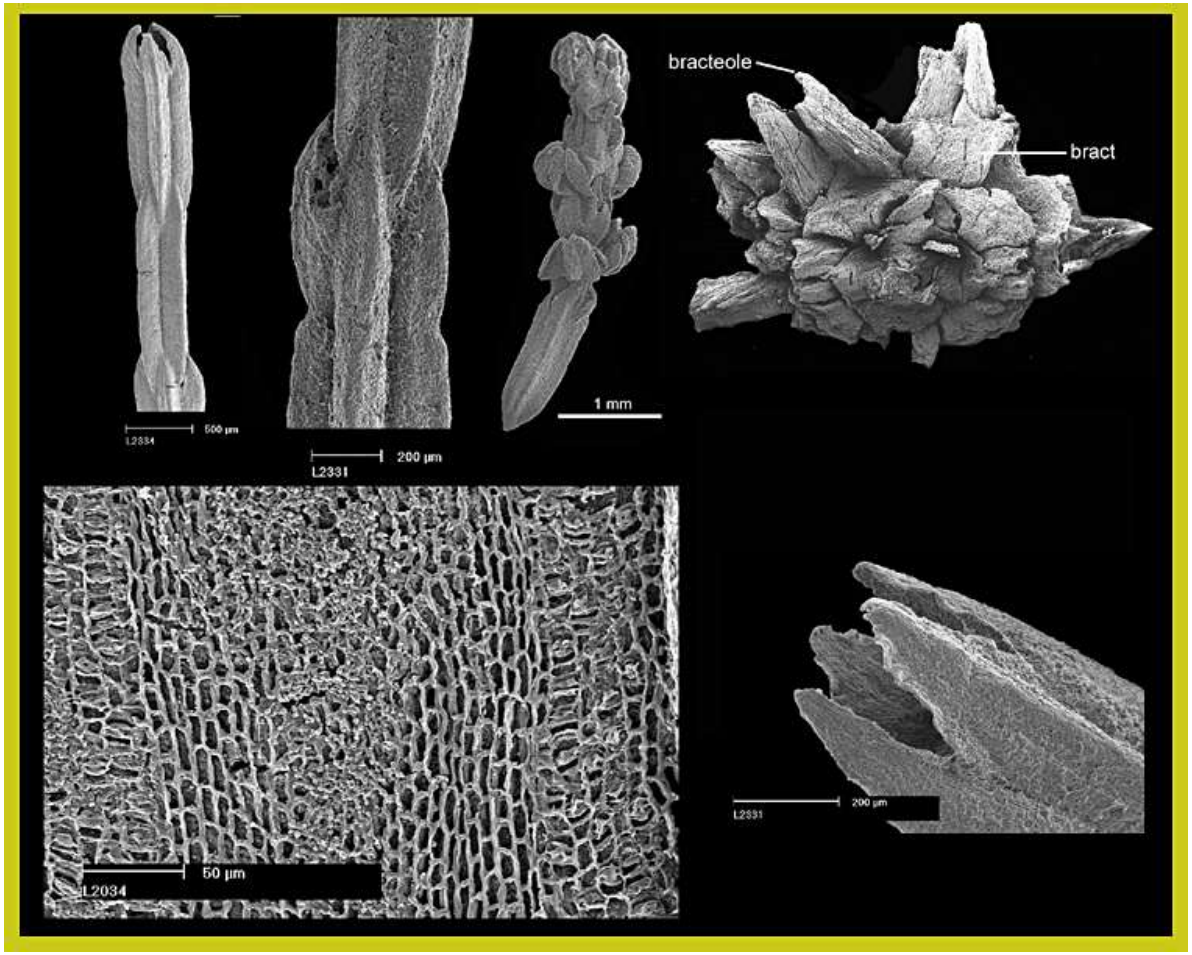
Gymnostoma - Little Rapid River, NW Tasmania (~ 30 Ma)

4 leaves, teeth

open grooves

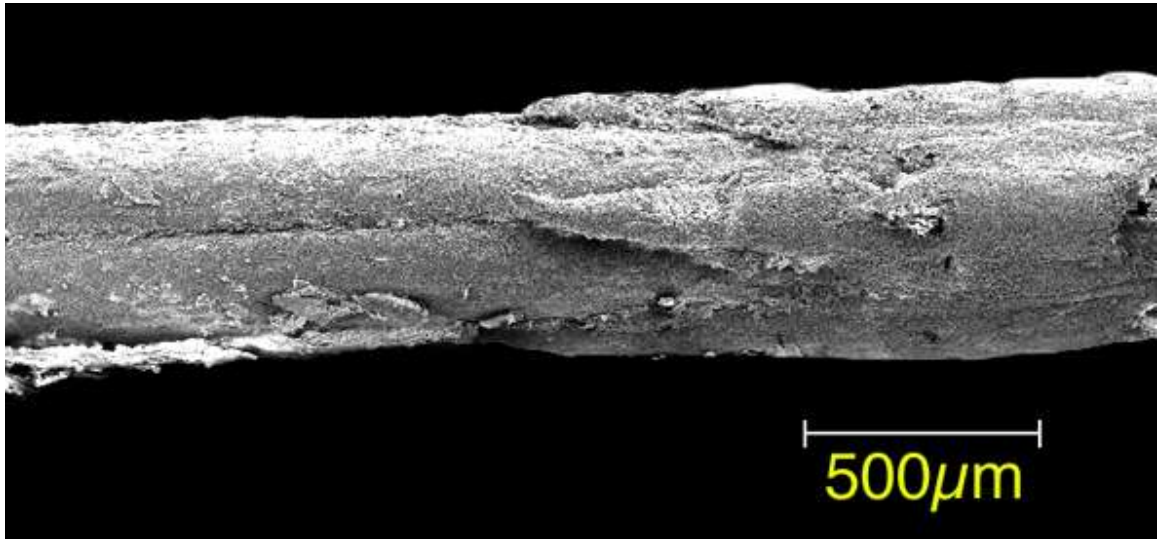
stomata in 8 bands

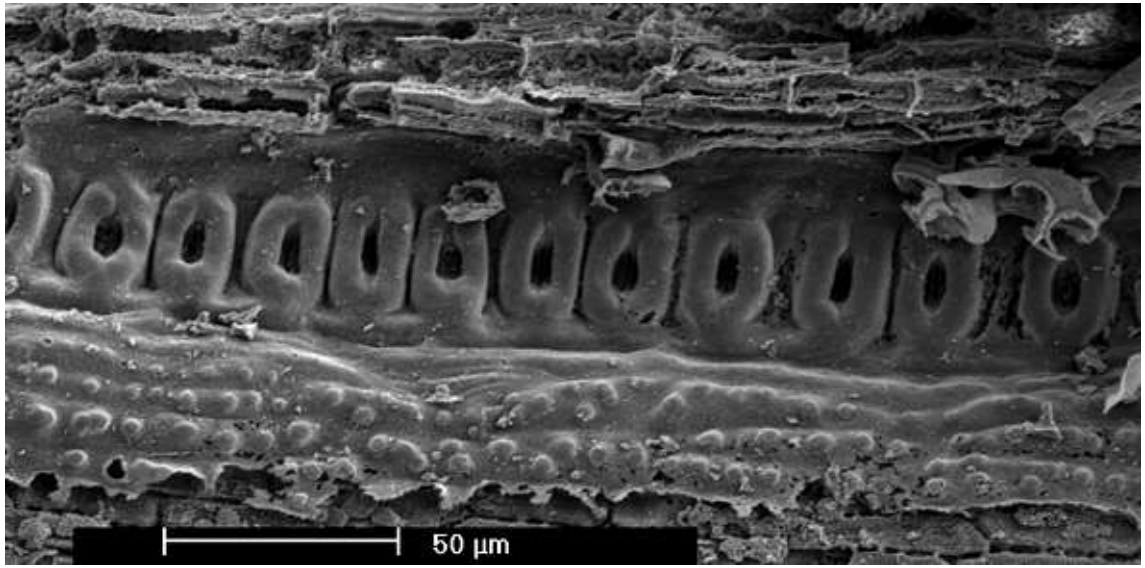
'cone' with broad bracts



(Guerin & Hill 2003)

Casuarina or *Allocasuarina*? Riversleigh, NE Qld (~25 Ma?)





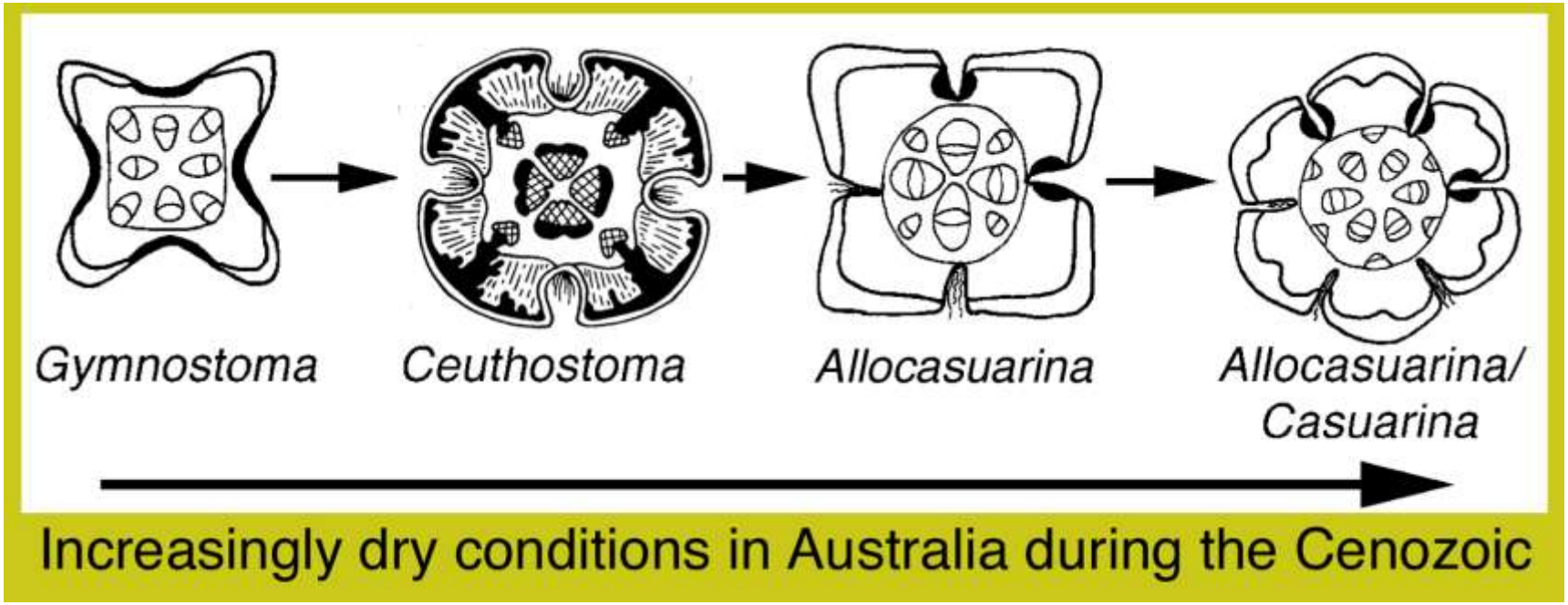
5 leaves, teeth

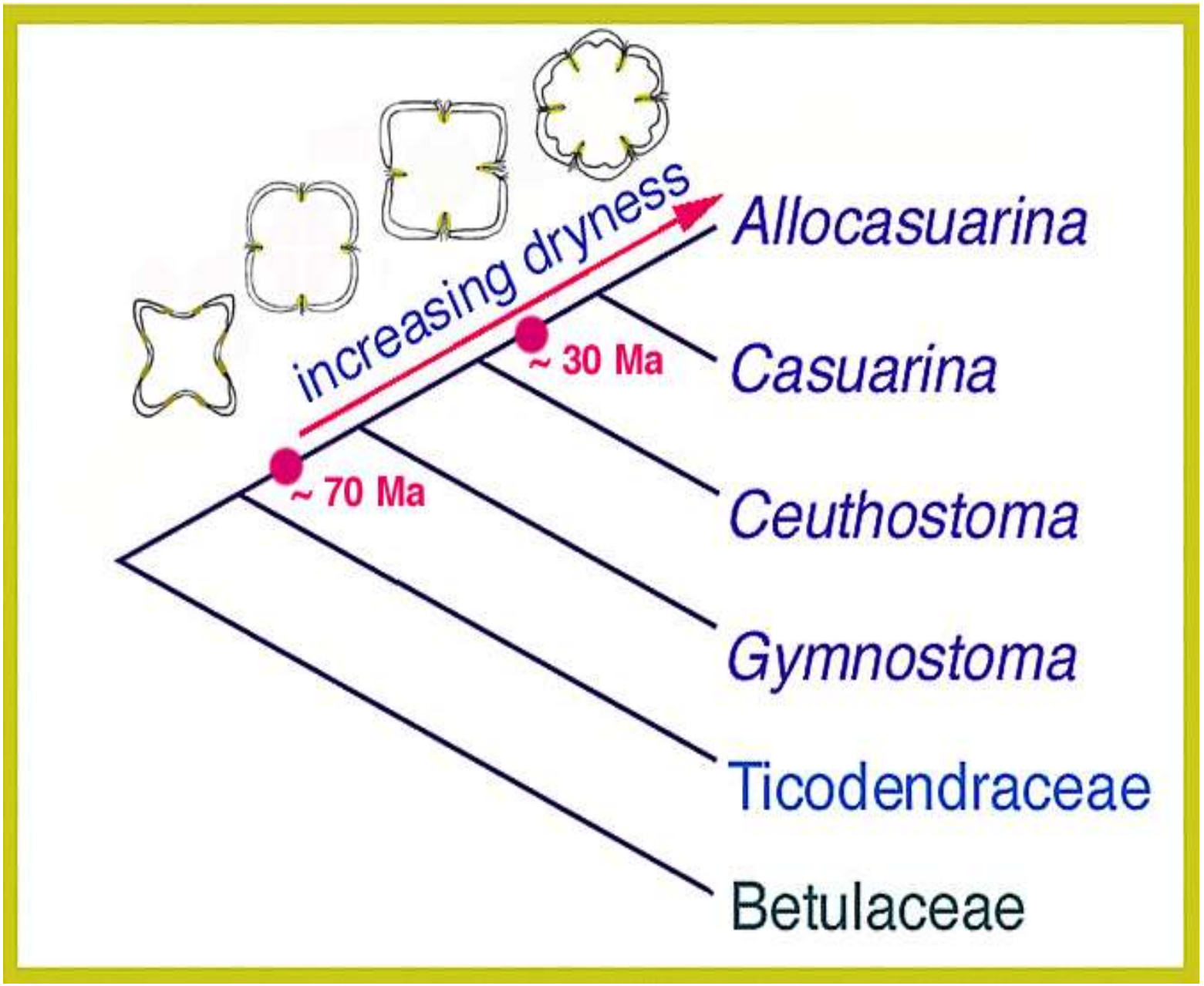
stomata encrypted
and without waxy plugs

(Guerin & Hill 2006)

For the Casuarinaceae, highly reduced leaves in whorls of 4, exposed stomata, and stomata with waxy plugs appears to be the ancestral condition.

Gymnostoma evolved in response to low nutrients (scleromorphy) and then:

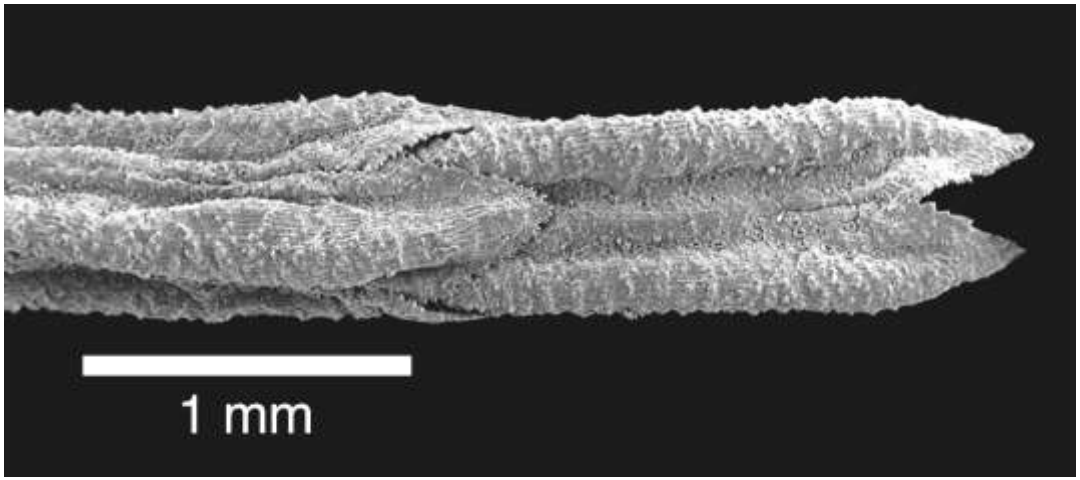


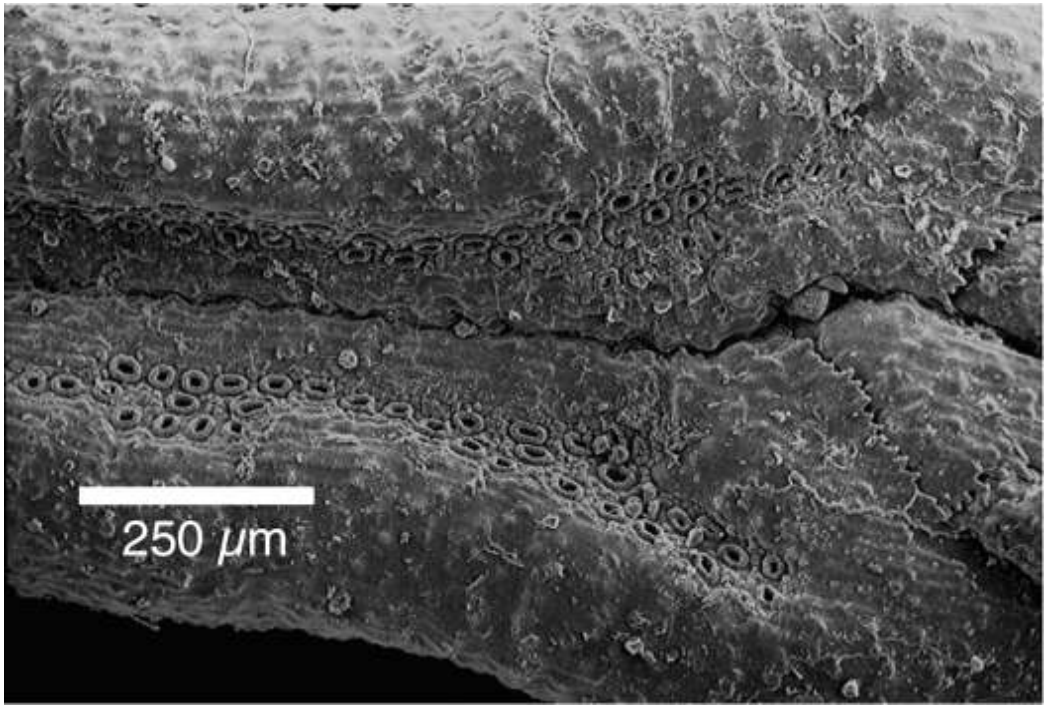

increasing dryness
~ 30 Ma
~ 70 Ma
Allocasuarina
Casuarina
Ceuthostoma
Gymnostoma
Ticodendraceae
Betulaceae

Callitris and *Allocasuarina*, North Stradbroke Island, Queensland

Callitris - general characteristics

Leaves
- in whorls of three
- fused at the base

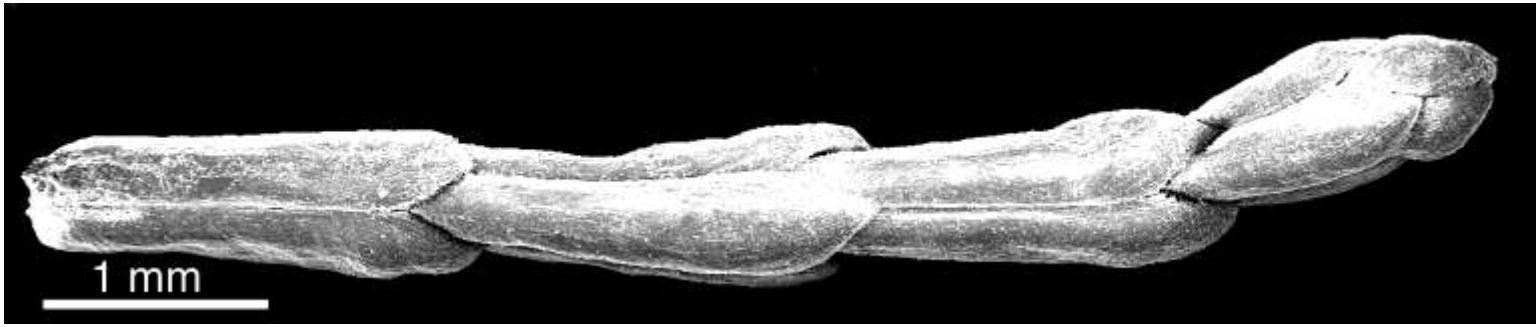




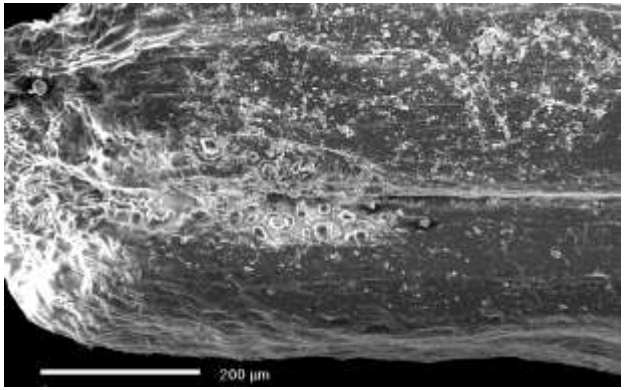
Stomata
- exposed
- in rows
- with Florin rings

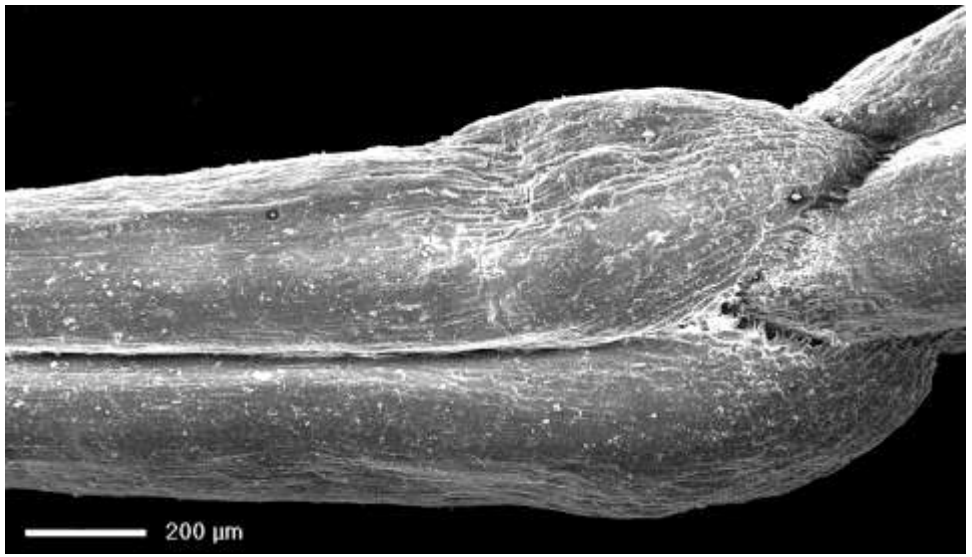
Callitris verrucosa

widespread species, inland dunes and semi arid deserts



- no exposed stomata
- frilled leaf margin

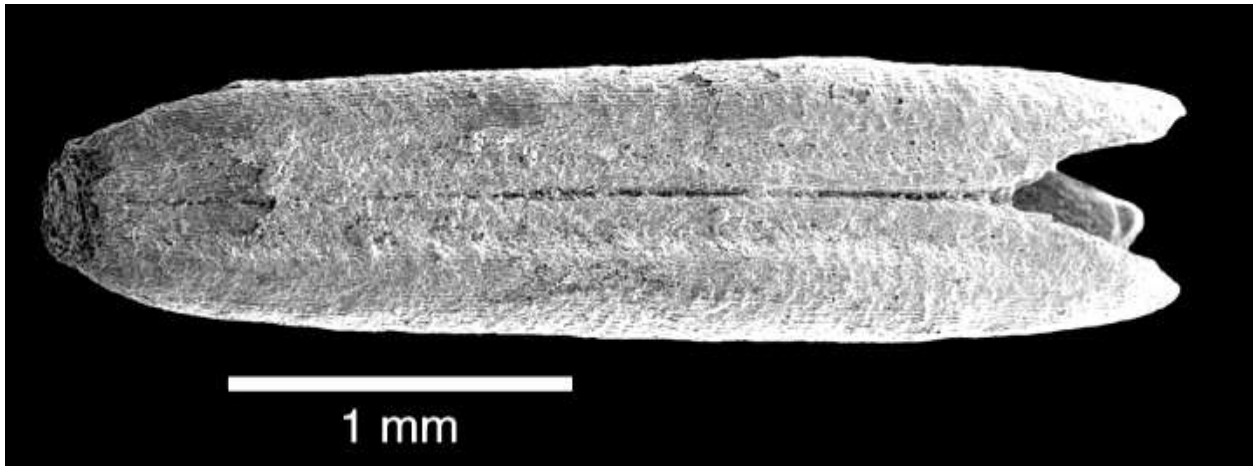


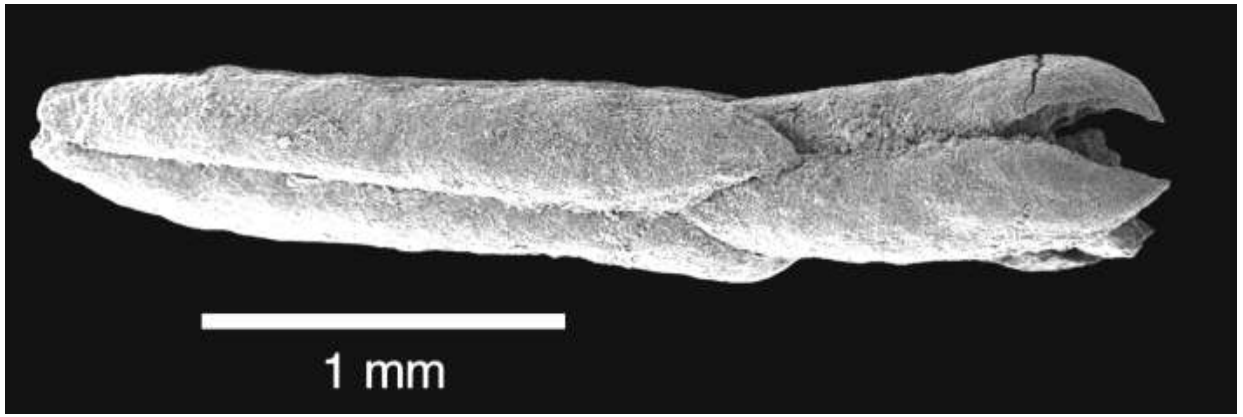


Callitris strahanensis - Regatta Point, Tasmania (~ 700 ka)

Callitris

Stony Creek - western uplands, Victoria ~ 2.6-1.7 Ma

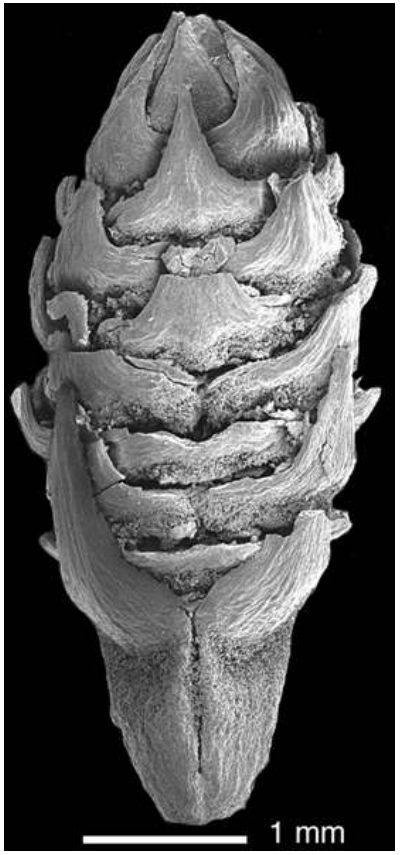


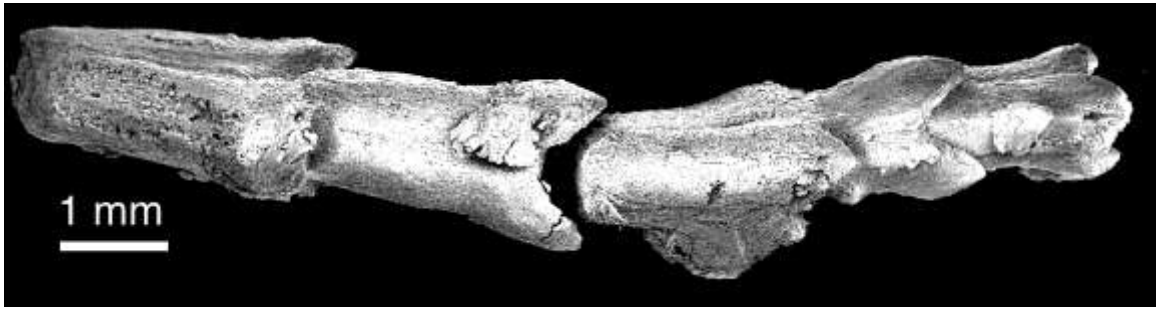


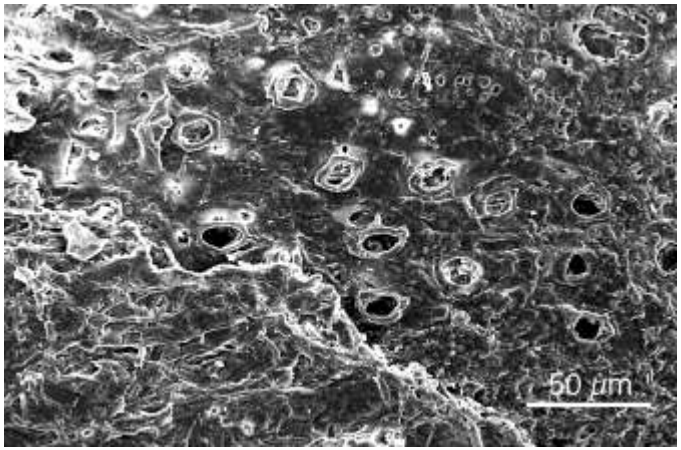
leaves

- whorls of three
- fused

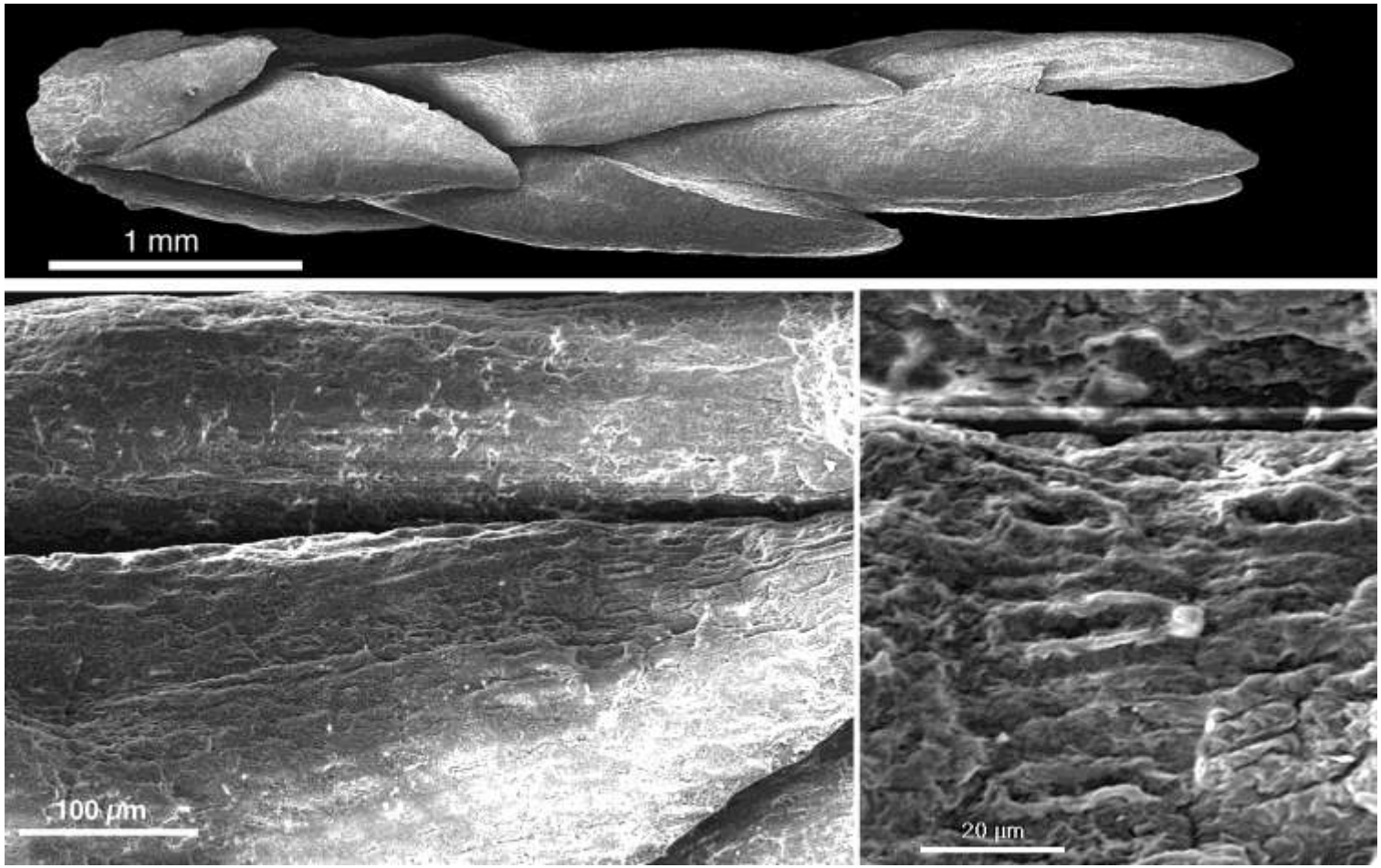
Callitris - Latrobe Valley, Victoria





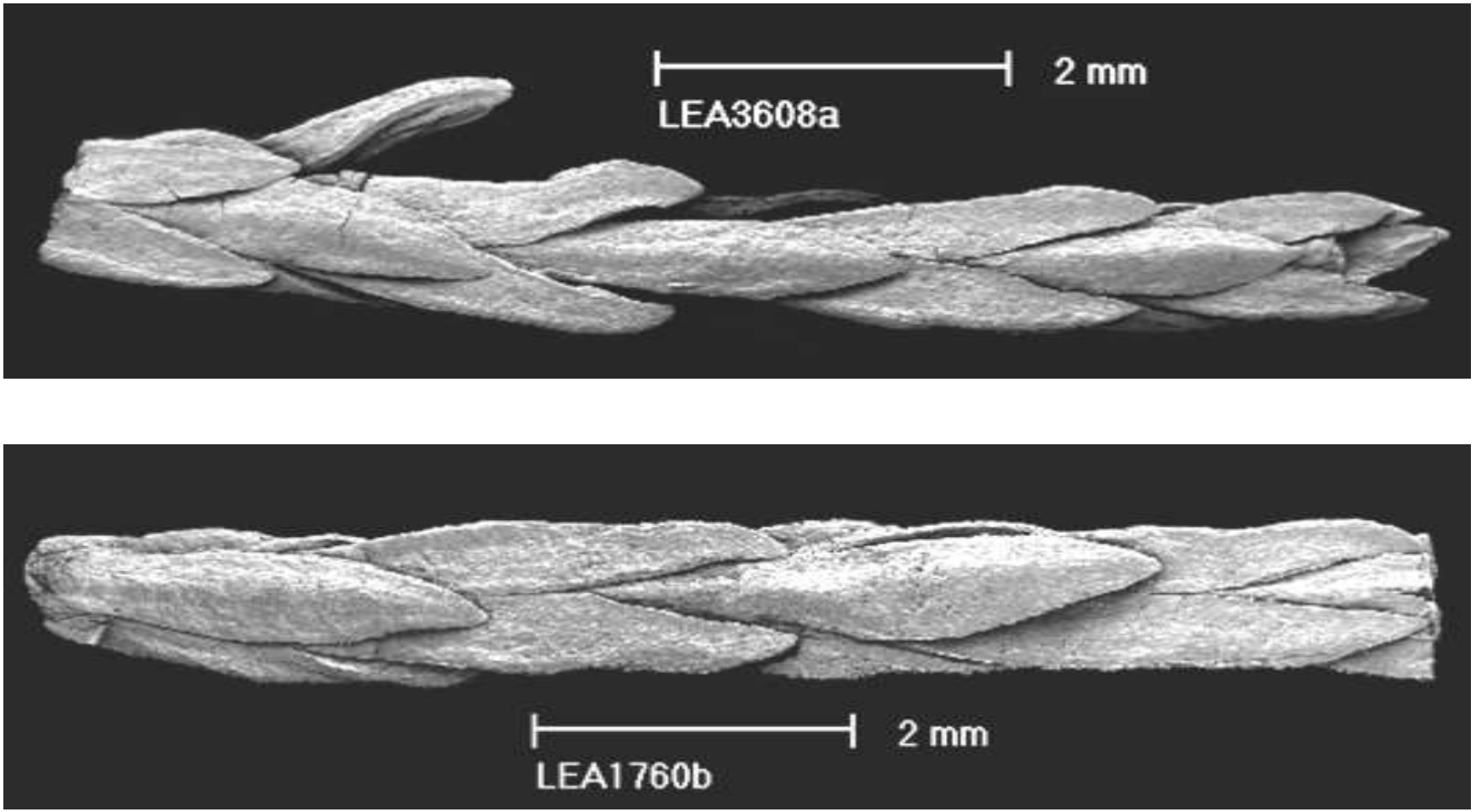


Callitris ? Lea River, Tasmania (~ 33 Ma)



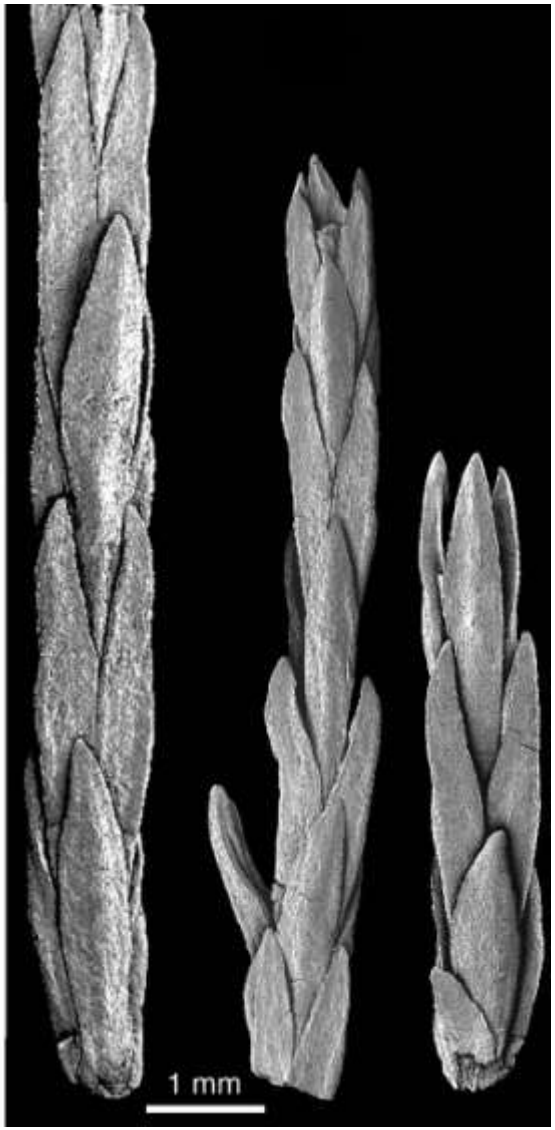
Leaves in whorls of three, but only slightly fused at the base
Stomata in rows, and with Florin rings

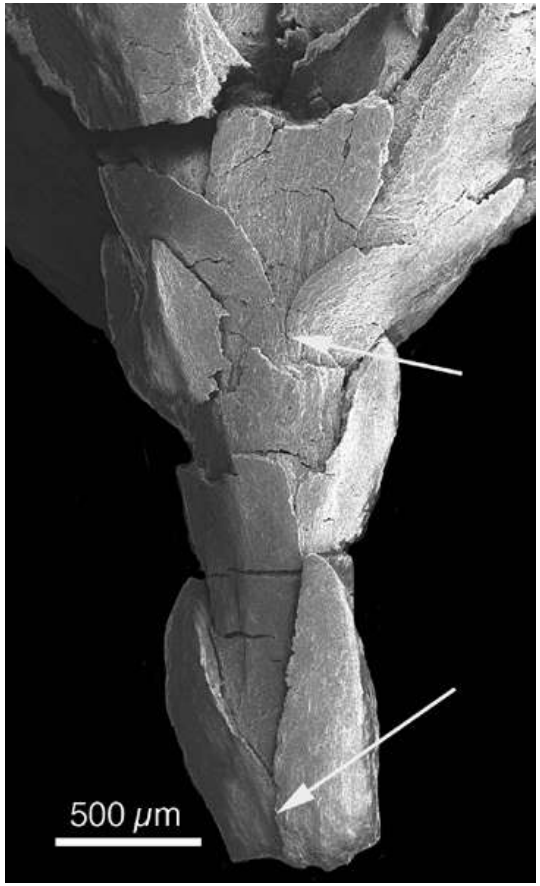
Foliage from the same taxon, with variously fused leaves



Other taxa at this site include *Libocedrus* (Cupressaceae), *Nothofagus* (rainforest trees)

Lea River - ovulate cone and foliage comparison

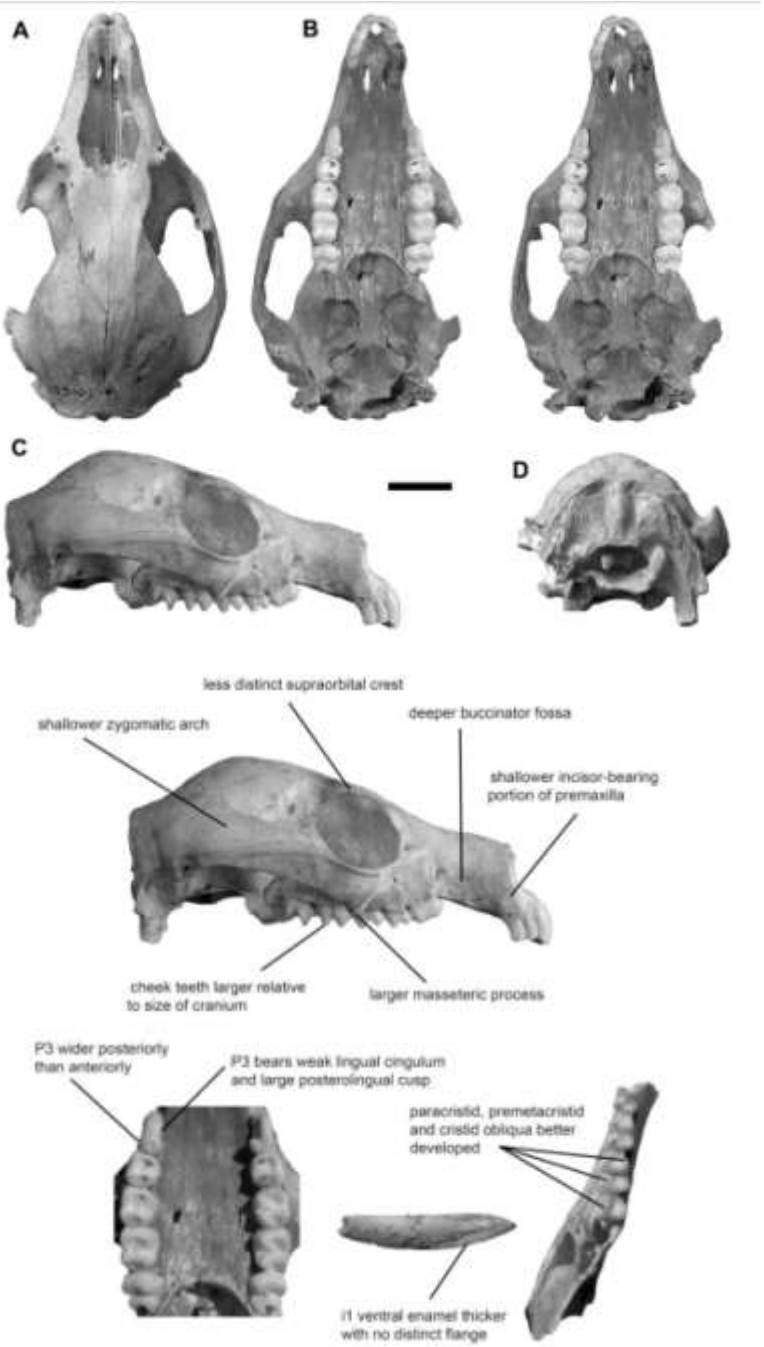


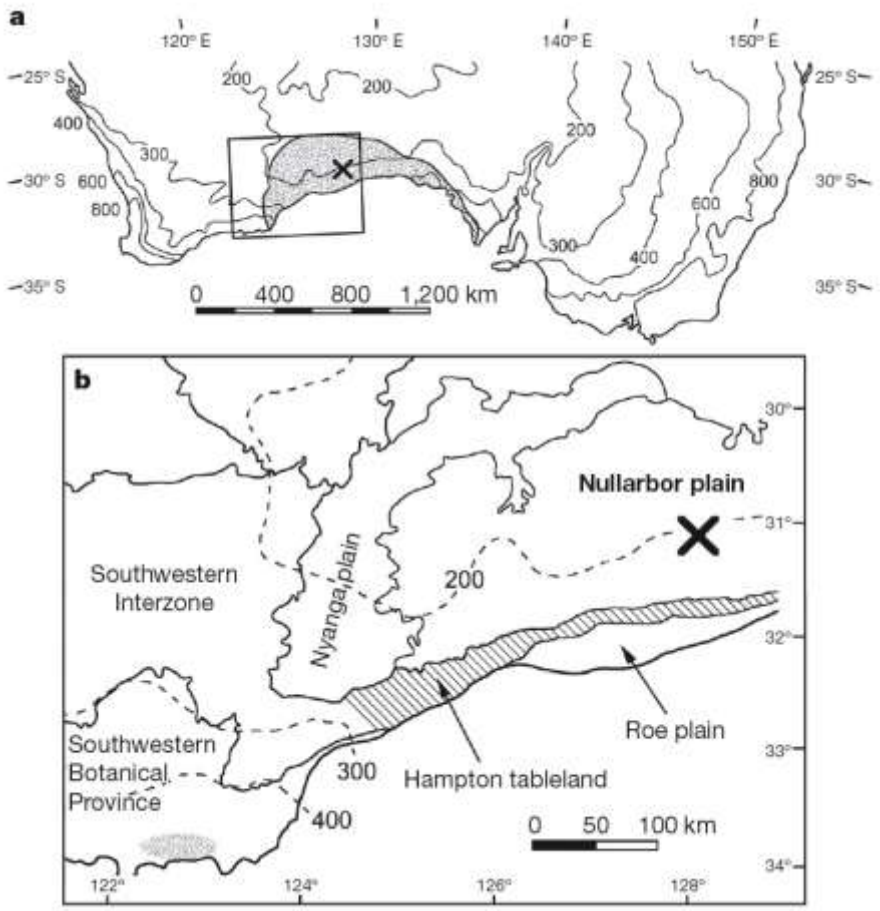


Some leaf fusion

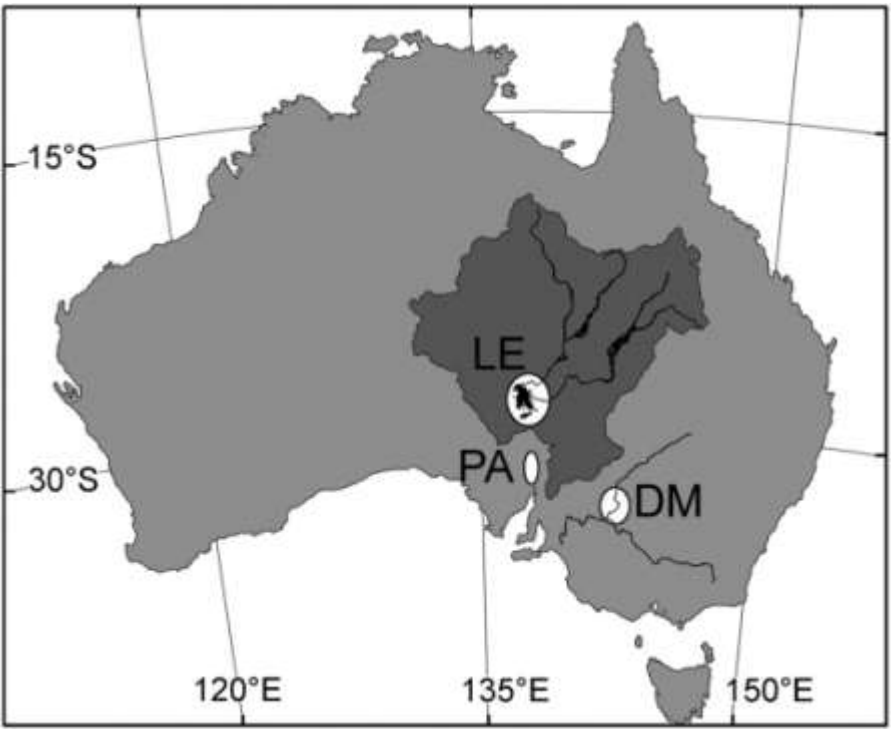
The most probable conclusion is that *Callitris* had a rainforest origin and was exapted to aridity, possibly by evolving as a riparian conifer.

Rainforest *Callitris* was in place no later than ~35 Ma, extant *Callitris* was in place no later than ~17 Ma.

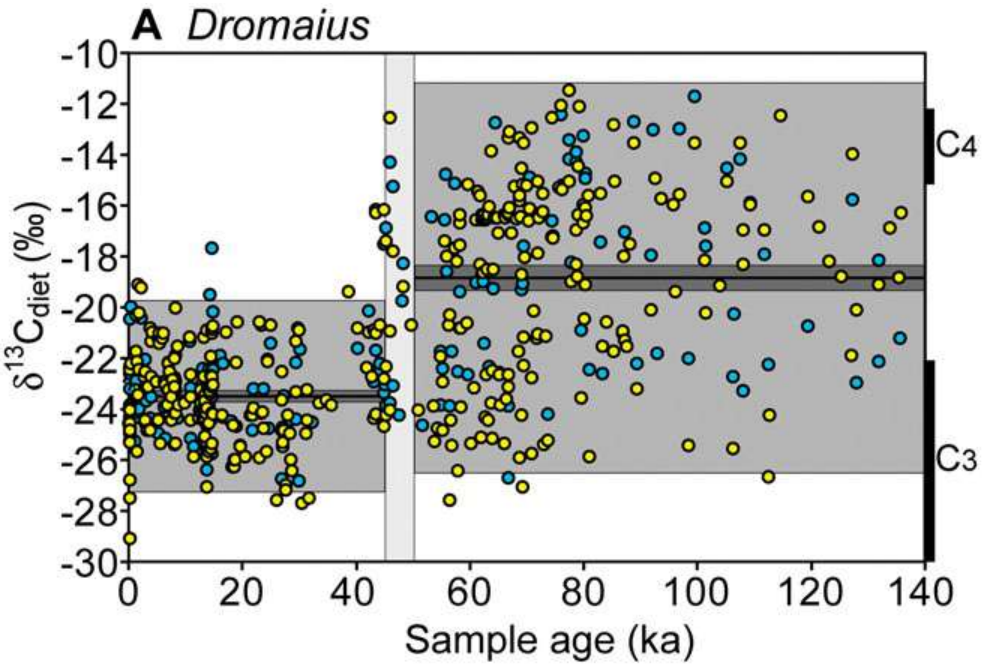


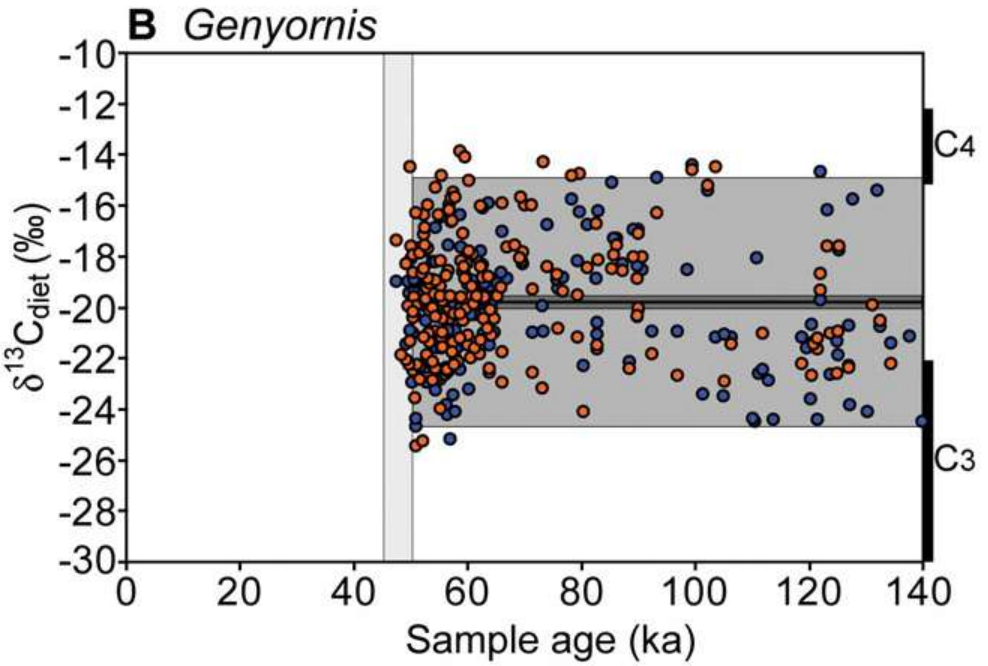


Two tree kangaroo species from the Nullarbor Plain (~700ka)



Emu and *Genyornis* egg shell data from ~140ka onwards





"A 140,000-year record of dietary $\partial^{13}C$ documents a permanent reduction in food sources available to the Australian emu, beginning about the time of human colonization; a change replicated at three widely separated sites and in the marsupial wombat. We speculate that human firing of landscapes rapidly converted a drought-adapted mosaic of trees, shrubs and nutritious grasslands to the modern fire-adapted desert scrub. Animals that could adapt survived; those that could not became extinct."

Miller *et al.* 2005. Science **309**, p. 287.

Megalania prisca approaches a nest of *Genyornis newtoni*