Plant macrofossils in Palaeoecology
BIO 352

INTRODUCTION TO PLANT MACROFOSSIL ANALYSIS

Lecture 1

Hilary Birks

- What is a plant macrofossil?

- How do we do plant macrofossil analysis?

  Obtaining samples (Where do we find macrofossils?)

  Site selection

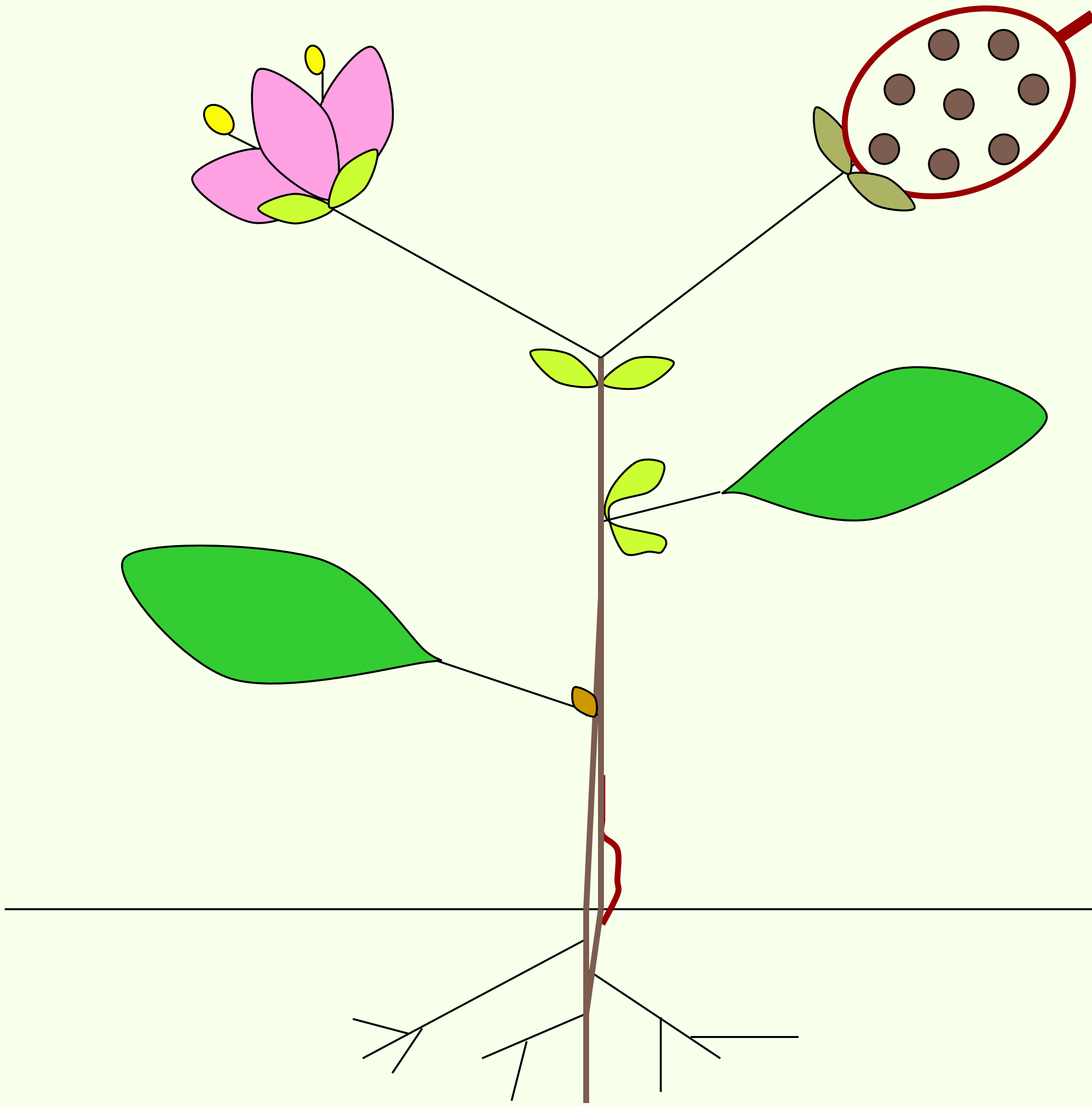
  Method

What is a Plant Macrofossil?

Any part of a plant preserved in sediments that does not require a high-powered microscope to see it and that can be manipulated by hand

(Contrast with pollen)

Parts of a plant that may be preserved



seeds

fruit

anthers

flower (petals)

calyx

bracts

inflorescence

stipules

bud

leaves

petiole

Bark - wood

stem

roots

1. Vegetative parts

Tree stumps and trunks = megafossils

Wood/charcoal (use wood anatomy to identify)

Leaves and needles (e.g. *Salix herbacea*, *Pinus*)

Buds and budscales (Tomlinson)

Stems, roots, nodes – peat (e.g. *Equisetum*, *Phragmites*)

Mosses (not liverworts) – identify as modern mosses

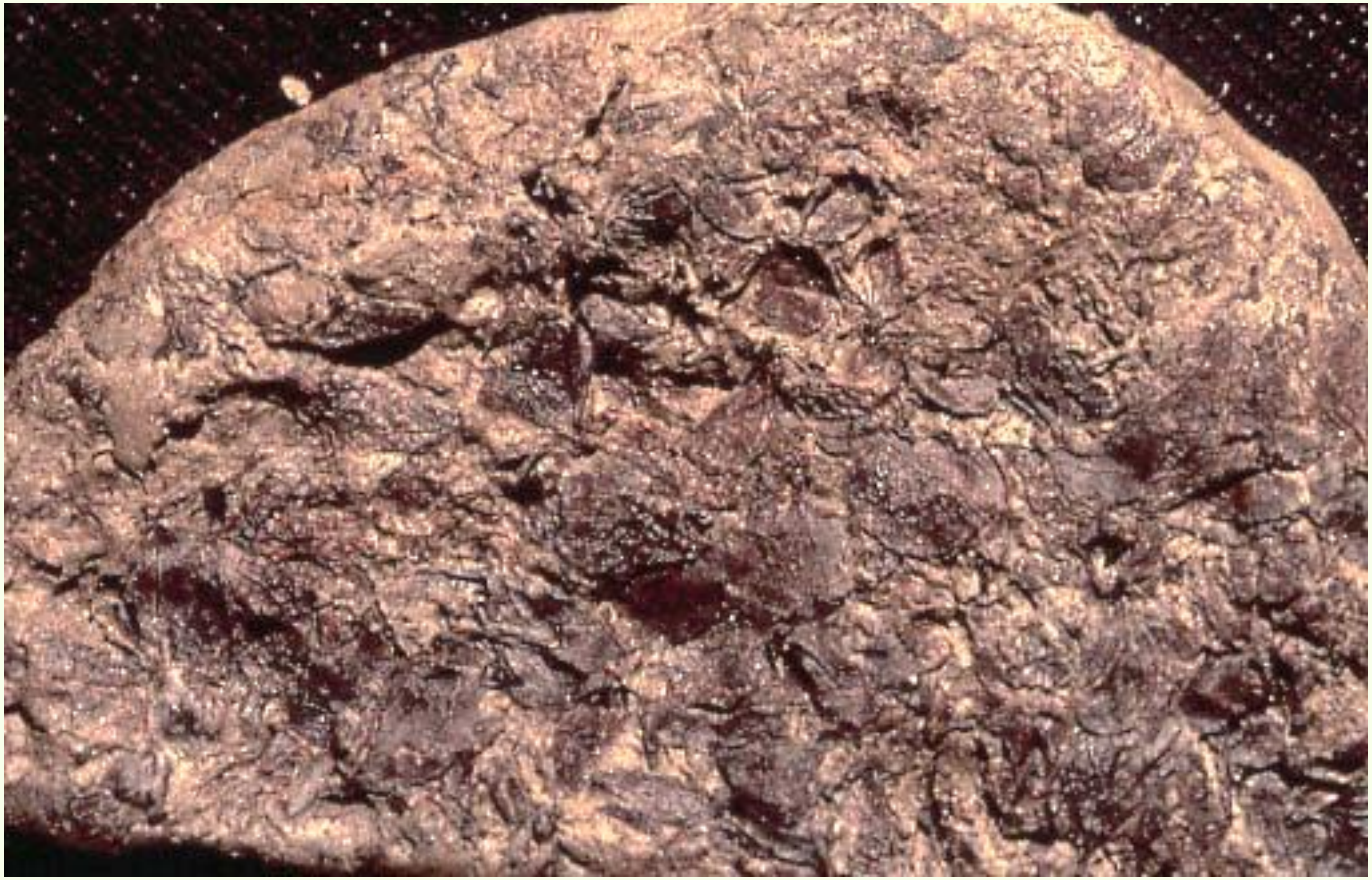
Megafossils

MacDonald 2007

Remains of Scots Pine, Rannoch Moor

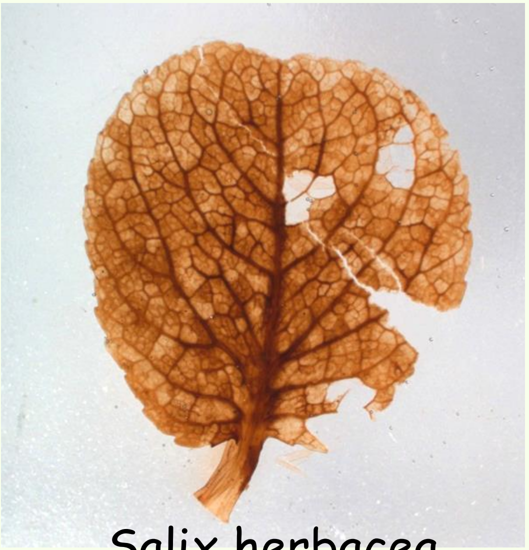
Pine stump, Lindås

Leaves



Salix herbacea leaf layer, Kråkenes

Salix leaves

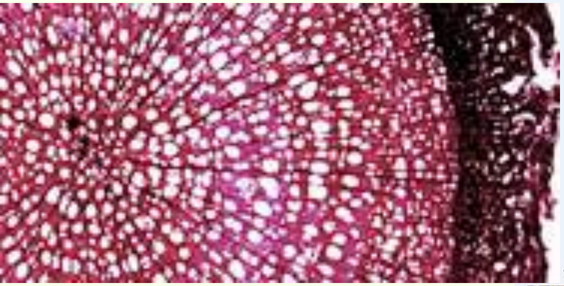


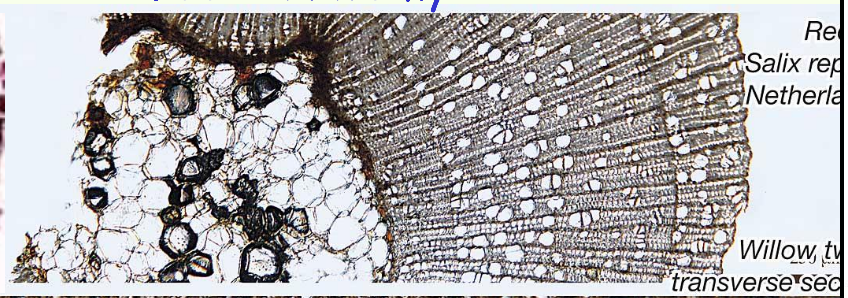
Salix herbacea

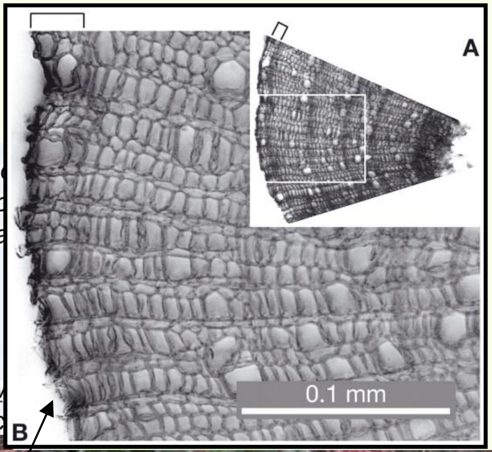
Salix polaris

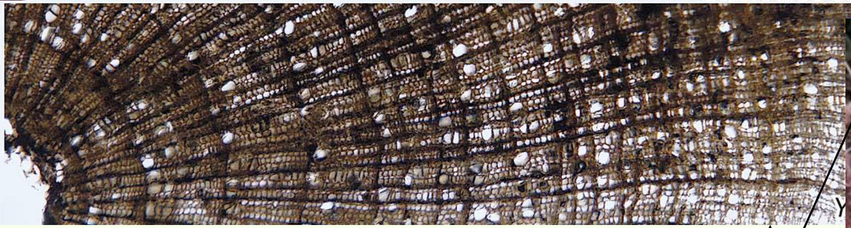
And other Salix species

Wood anatomy









Salix arctica

Peat

Vegetative remains, moss (e.g. Sphagnum, Cyperaceae, Ericaceae)

Chat Moss,

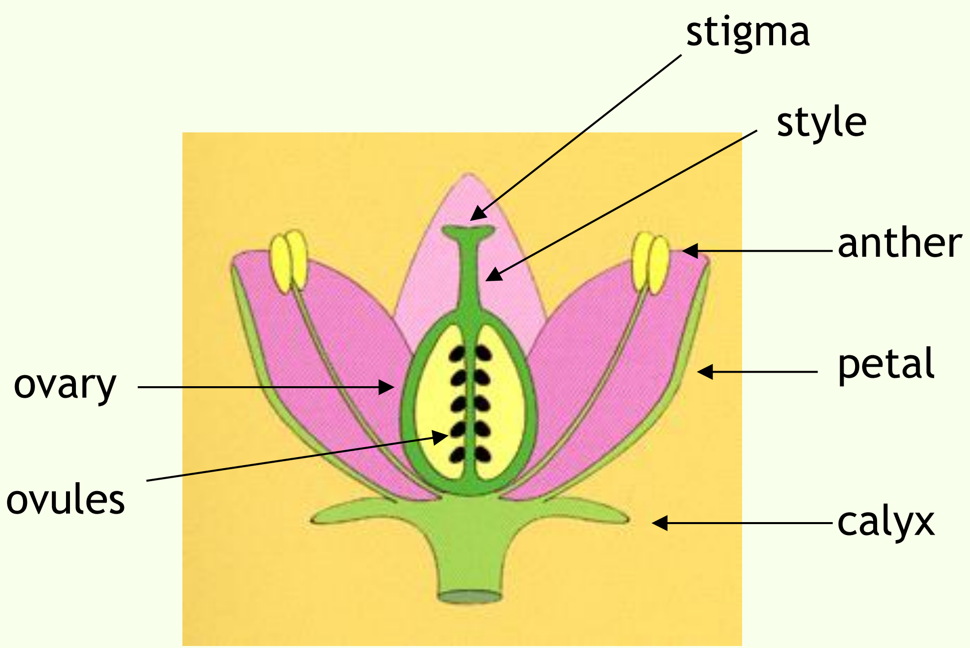
N. England

2. Reproductive parts (diaspores)

Seeds and fruits (angiosperms and gymnosperms)

Sporangia, megaspores, oospores, sclerotia etc. (lower plants)

Typical angiosperm flower

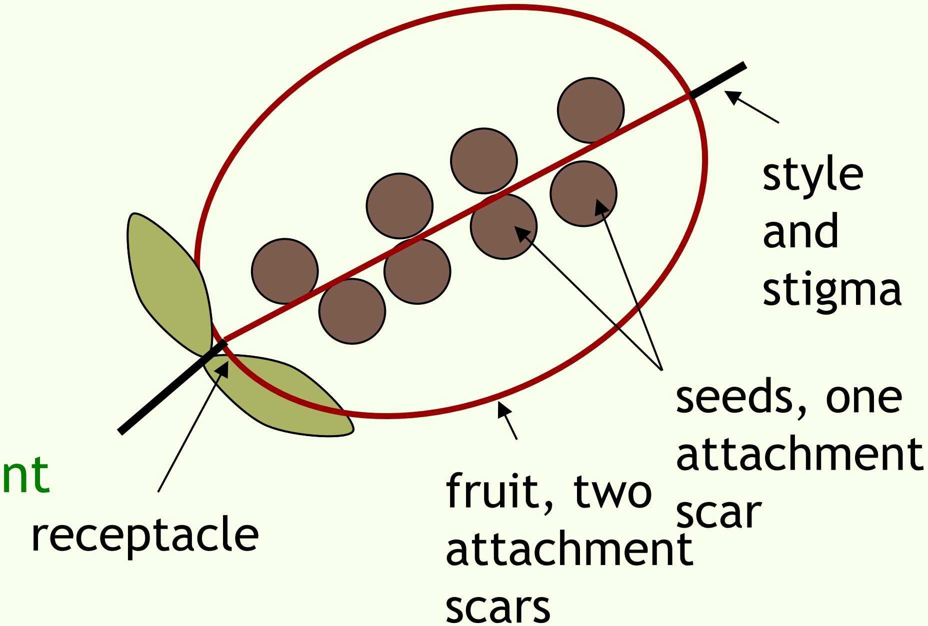


Spergularia rupicola

Seed

One scar, where attached to ovary wall (funiculus).

Can be single or together with many others in a fruit



Fruit

Two scars; attachment to plant
stigma/style

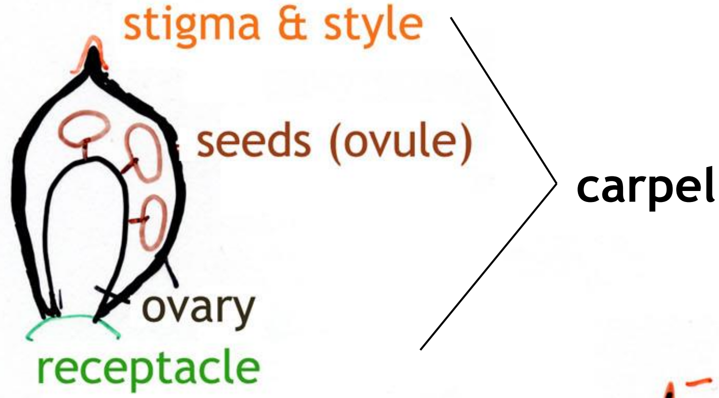
Can be one or many seeded

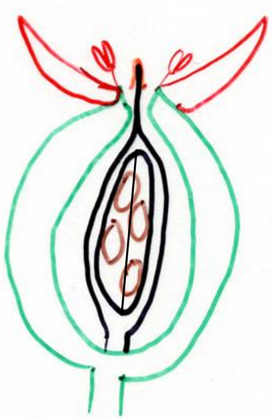
Ovary wall can be modified, as dry, succulent, woody, dehiscent, indehiscent. Different layers can have different structures in one fruit (e.g. plum).

Ovary can be enclosed in the receptacle (inferior fruit)

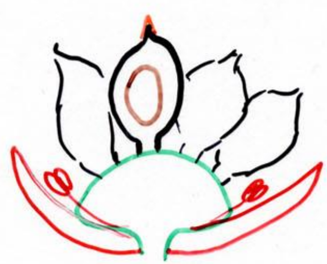
The arrangement and structure of seeds and fruits are very important in taxonomy.

The general structure of seeds and fruits follows plant families closely.





Inferior fruit
e.g. apple



Ranunculus (buttercup)
(single seeded achene)
Asteraceae

Fabaceae (pea, bean)
1 carpel

Adaptations to Dispersal

Wind: wings, plumes, parachutes, very small ‘balloon’ seeds

Water: floating; woody, spongy, reticulum (holds air bubbles), hairs

Animal: External; hooks, burrs, screw mechanisms, ants, mammals, birds

Internal; succulent – eaten, seed deposited; either spat out or eaten and deposited in faeces

Small dry seeds may be shaken out of dry capsules, e.g. by wind or animal or rain contact

No apparent mechanism

Wind dispersal - wings

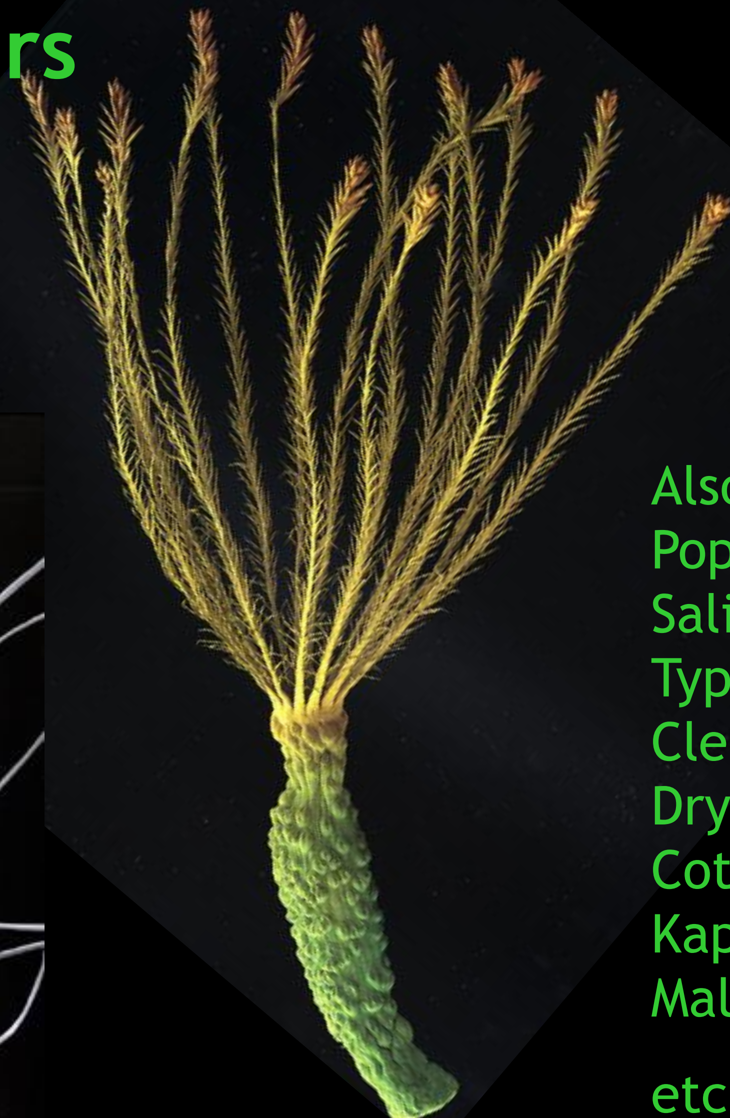
Acer

Also:
Betula,
Pinus,
Tilia,
Ulmus,
Fraxinus,
etc.
- in many families

Spergularia media - Caryophyllaceae

Wind dispersal - hairs

Hairs on seed - Epilobium



Also: Populus, Salix, Typha, Clematis, Dryas, Cotton and Kapok in Malvaceae,

etc.

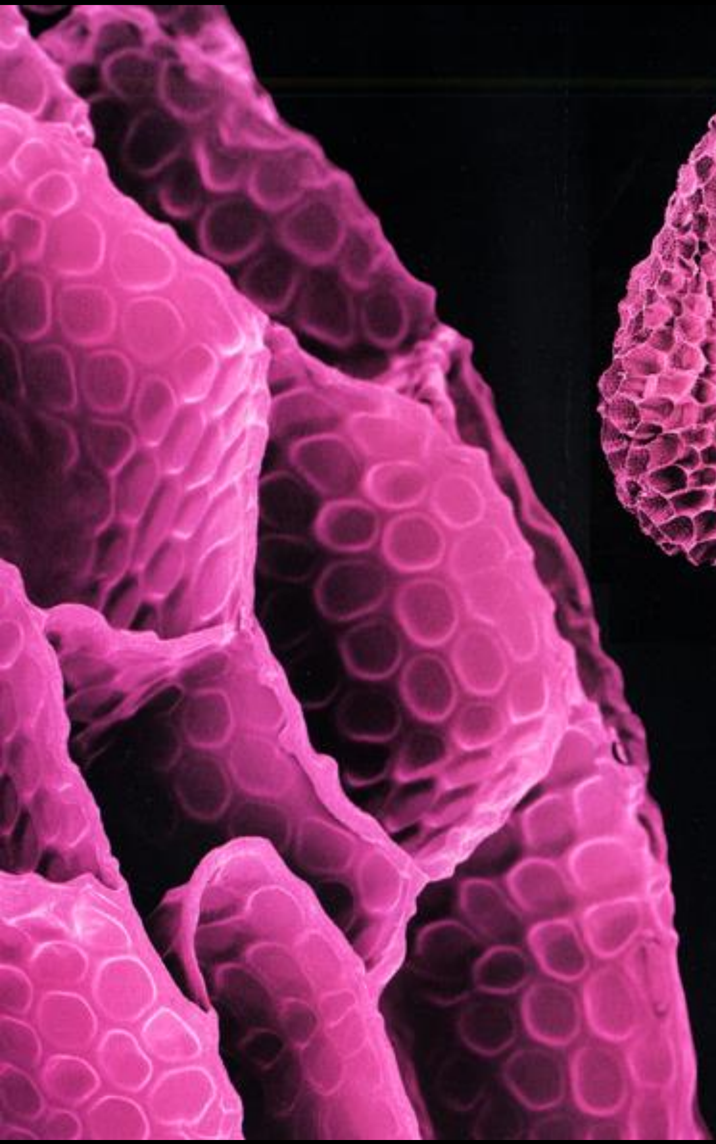
Hairs on fruit (pappus) – many Asteraceae

Wind dispersal – balloon seeds, very small

Orthocarpus luteus - Orobanchaceae

Narthecium ossifragum - Liliaceae

Balloon seeds – dust seeds



Network with increased surface area
and thus wind resistance

Many families:
Orchidaceae,
Orobanchaceae,
Pyrolaceae, Gentianaceae,
Ericaceae, Saxifragaceae,
Liliaceae, Lentibulariaceae,
Parnassiaceae,
Scrophulariaceae etc.

Drosera
natalensis -
Droseraceae

Digitalis purpurea - Scroph

Water dispersal - float

Float:

Fibrous/spongy e.g. coconuts

Corky – e.g Alnus

Hairs – e.g. Salix, Typha

Reticulum or spiny – e.g. many balloon seeds

Hydrophobic surface – e.g. Darlingtonia, Nymphoides

Air in fruits

Rain splash dispersal e.g. Caltha, Lamiaceae

Sea travellers, drift fruits

Lodoicea – double coconut – Seychelles – fibrous mesocarp (removed here); (actually does not float) coconuts; mangroves

Sea beans or nickernuts

Animal dispersal – external

hooks on seeds or fruits

Hackelia – Boraginaceae

Galium aparine, Bidens, Arctium, etc.

Acaena - Rosaceae

Animal dispersal - external

- Ant dispersal (Myrmecophory).
Many seeds have oily arils (elaiosomes) e.g. Viola, Ulex, some cacti, Moehringia, Euphorbia, Polygala, Chelidonium, Centaurea, Borago. ---
- Sugary seed coat: Cyclamen
- Mammals and birds (storage; eaten; hooked)

Animal dispersal - internal - eaten
Succulent fruits and seeds

Seeds: pomegranate

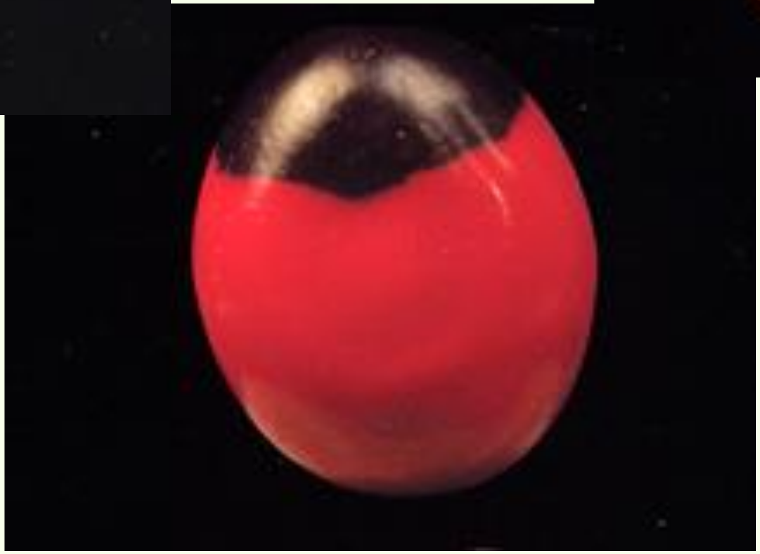
Fruits: berries: Vaccinium, Viscum, etc.;
single fruits clumped: Rubus

Receptacle: strawberry, apple etc.

Aril: Taxus, Podocarpus

Animal dispersal - birds

Strelitzia reginae
Strelitziaceae,
South Africa

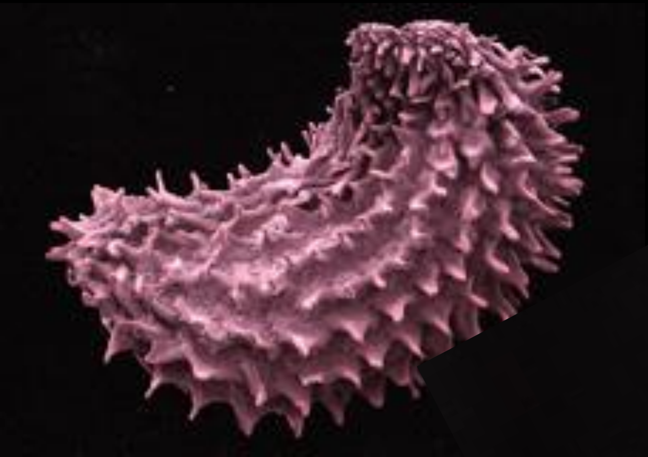


Abrus precatorius
Fabaceae, tropics

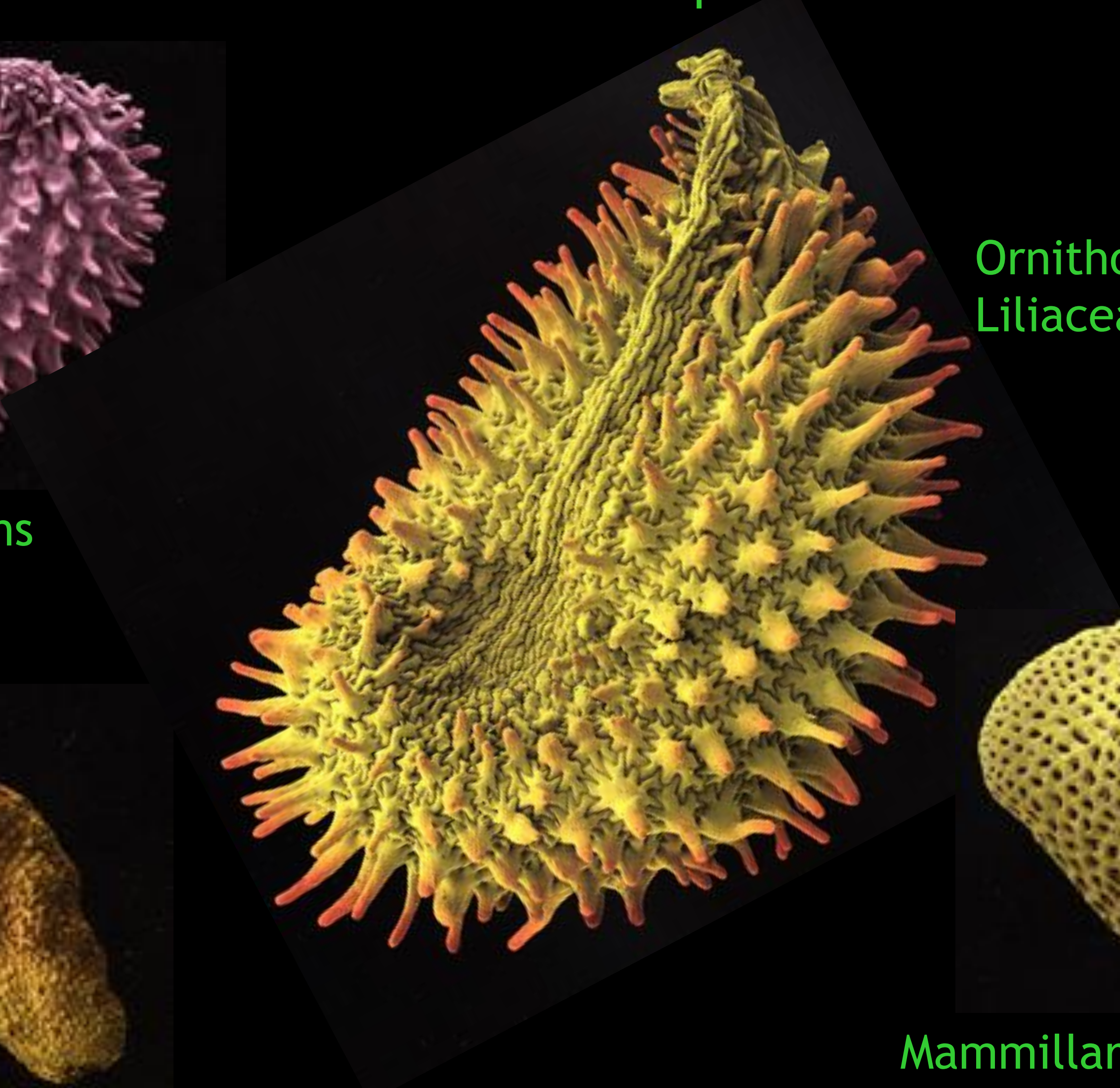
Acacia cyclops
Fabaceae,
Australia

No special adaptation to dispersal

Often have fantastic cell patterns – function unknown

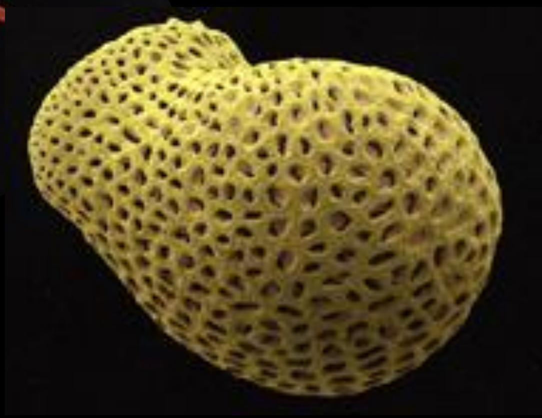


Heuchera rubescens
Saxifragaceae



Ornithogalum dubium
Liliaceae

Hermannia muricata
Malvaceae



Mammillaria theresae
Cactaceae

Size range (usually between 1 and 10 mm)

Orchid (minute) – acorn – *Trapa* – avocado - mango – coconut (double coconut is largest (30 kg) – takes 5-7 years to mature)

Germination

Immediate: e.g. *Primula*, *Pulsatilla*, *Cyclamen*, some aquatics

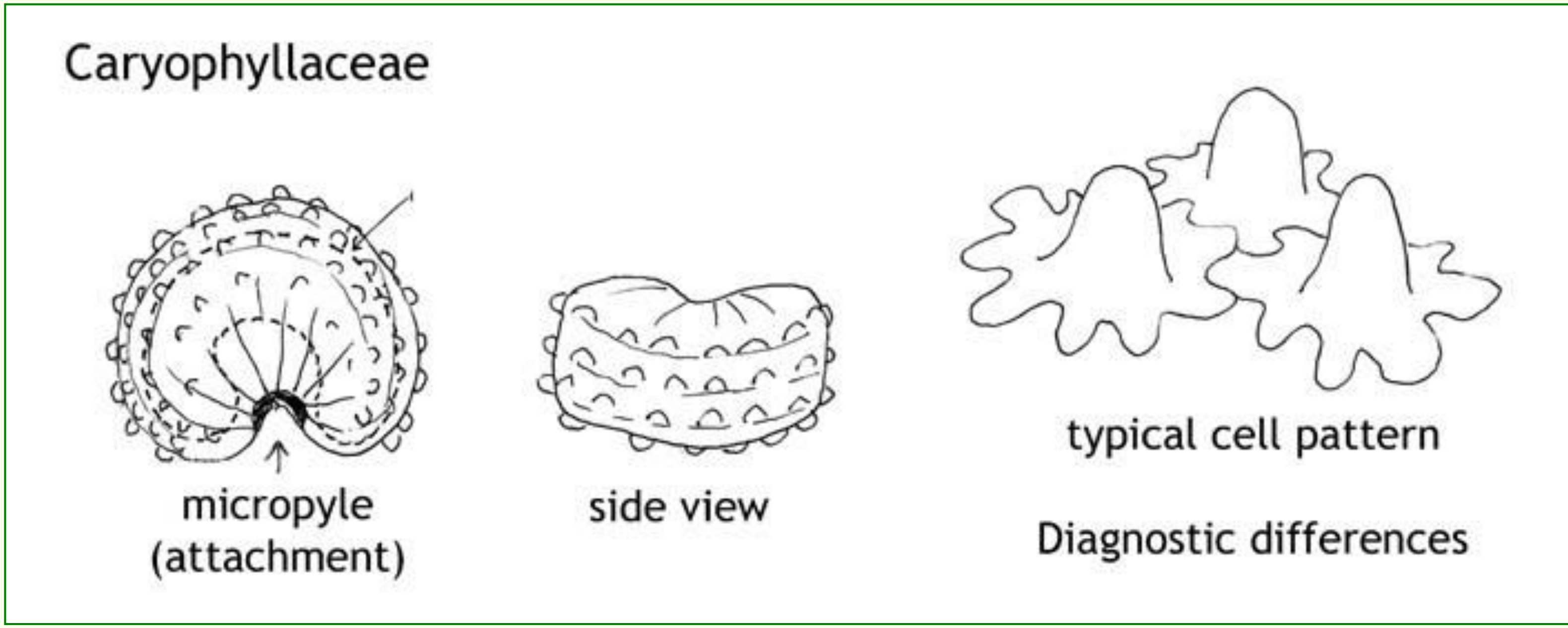
Dormancy: Adaptation to overwintering

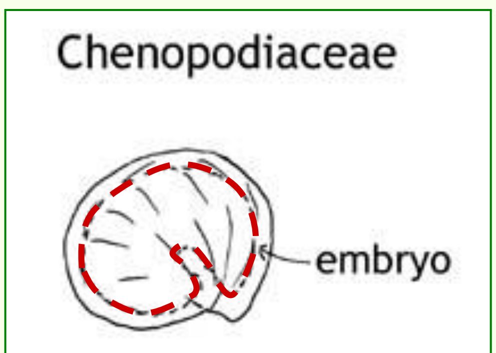
Long dormancy: seed bank

A fossil seed is a failed seed; not germinated

To be preserved, must be abundantly produced, preservable, able to reach deposition environment, (i.e. dry or anaerobic conditions that inhibit decay)

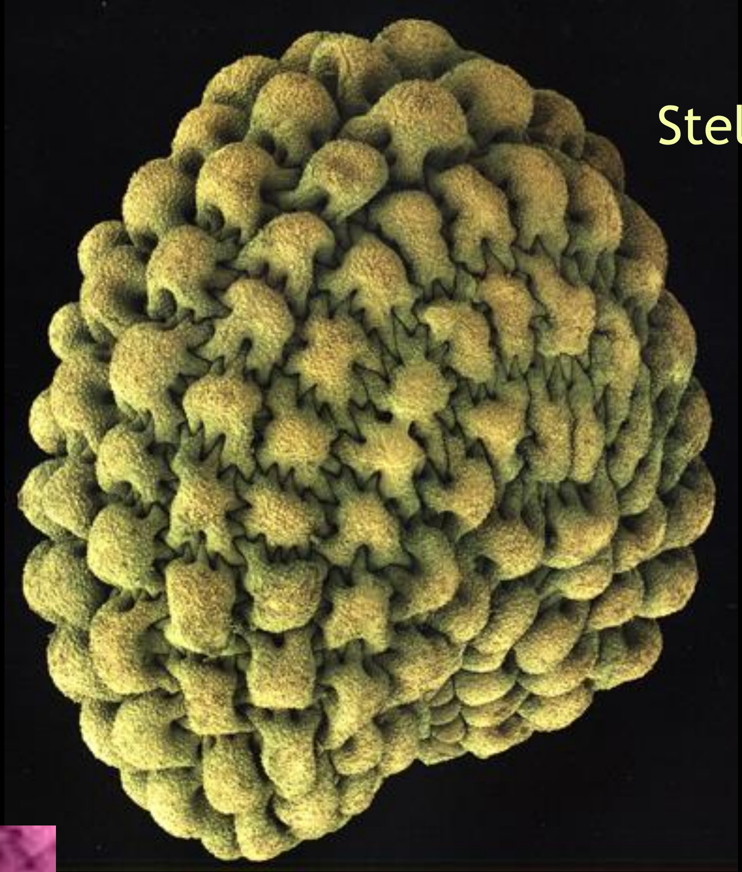
Types of seeds Curved Embryo



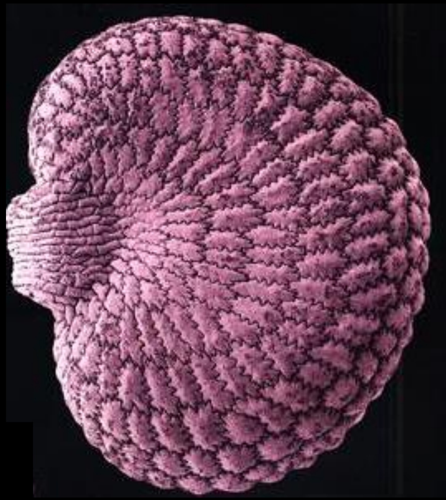


Like Caryophyllaceae, but smooth and shiny, with ill-defined cell pattern. Size and shape much more important.

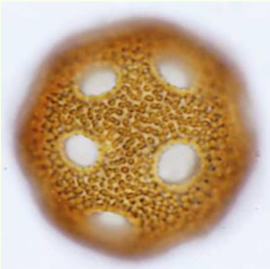
Caryophyllaceae



Stellaria pungens

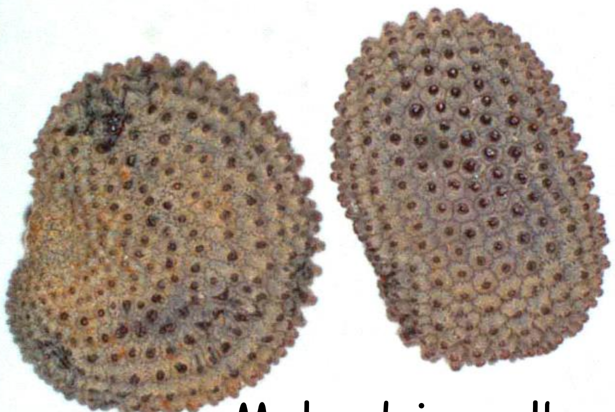


Caryophyllaceae



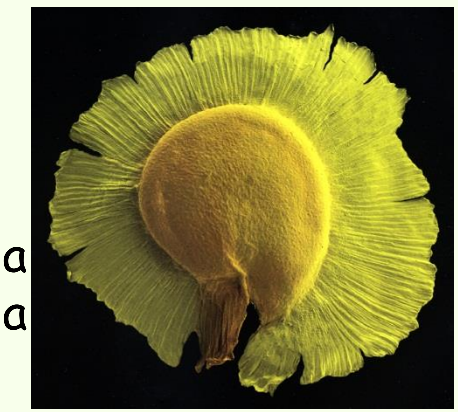
Silene acaulis

Lychnis flos-cuculi



Melandrium album

Sagina intermedia

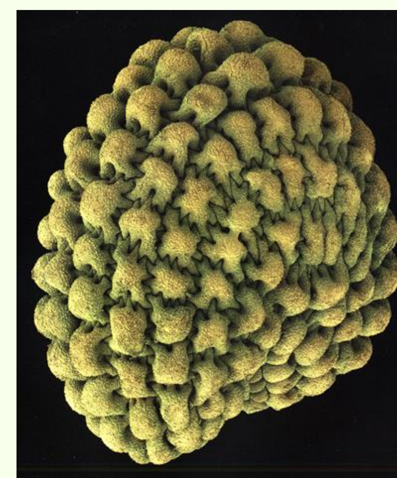


Spergularia media

And more ….

Cerastium,
Arenaria,
Minuartia,
Gypsophila,
Scleranthus
etc.

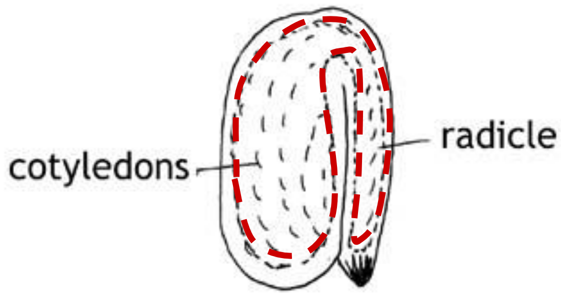
Silene maritima



Stellaria pungens

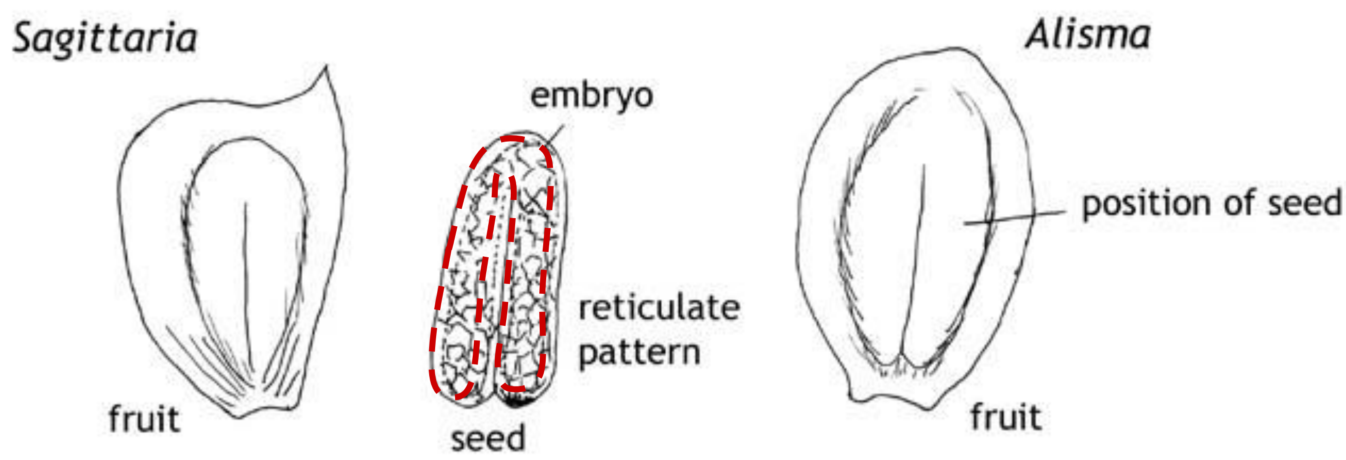
Cruciferae (Brassicaceae)

Elongated shape. Differentiated on size and shape. Some have distinctive cell pattern, e.g. *Rorippa*.



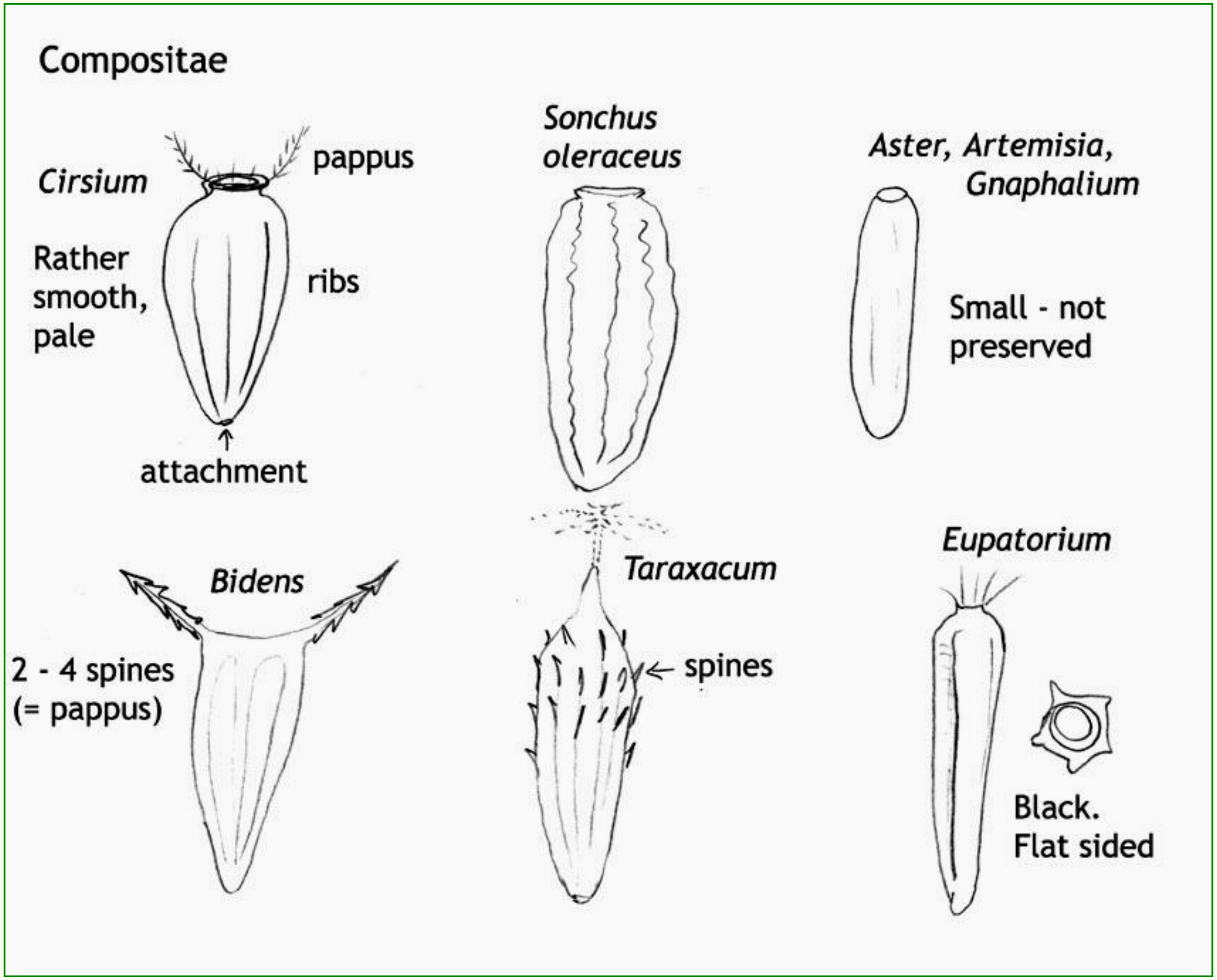
Sometimes find parts of the fruits, e.g. *Draba*

Alismataceae



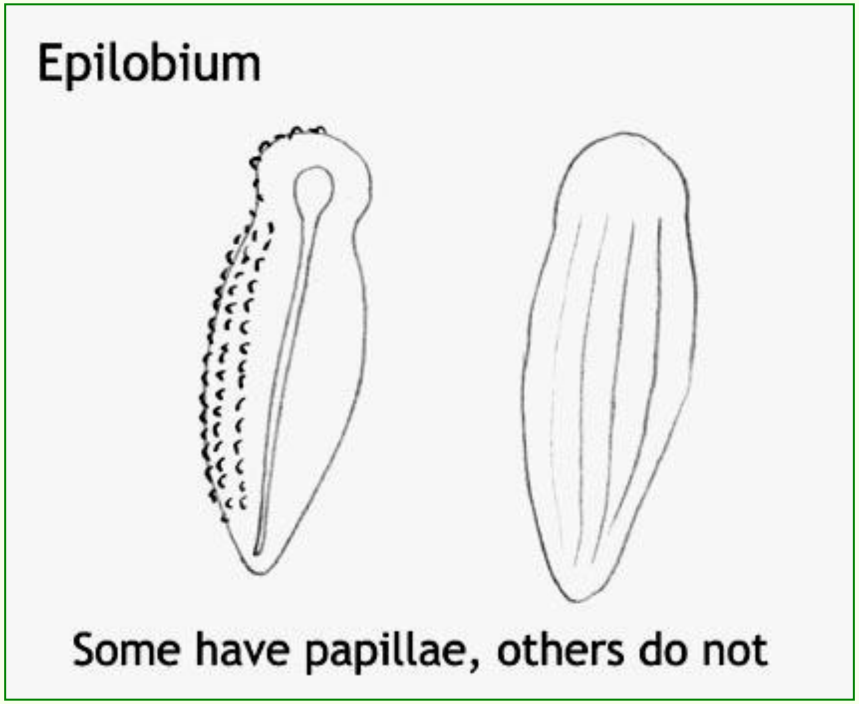
Compositae (Asteraceae)

Large family. Wide variation. Same basic design – one-seeded fruits in an inflorescence. Pappus is modified flower parts.



Epilobium

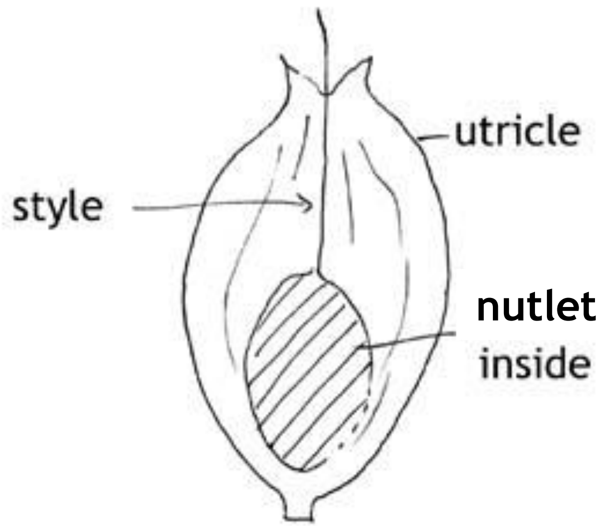
Berggren (1974)



Wind-dispersed - parachute of hairs on the seed; also good for water dispersal – many are marsh plants

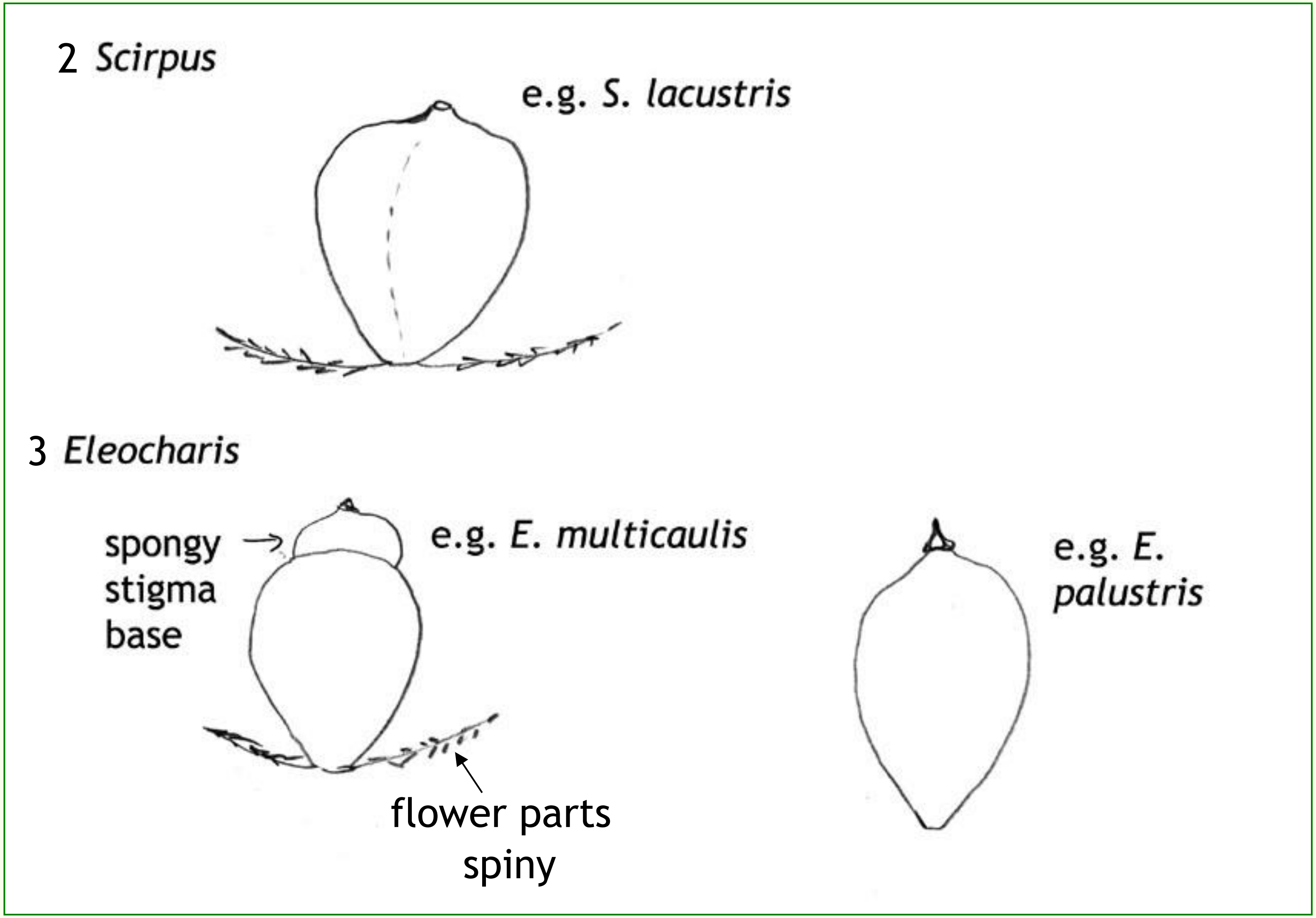
Cyperaceae

Seed type corresponds to divisions within the family.
e.g. Berggren (1964), Nilsson & Hjelmqvist (1967)



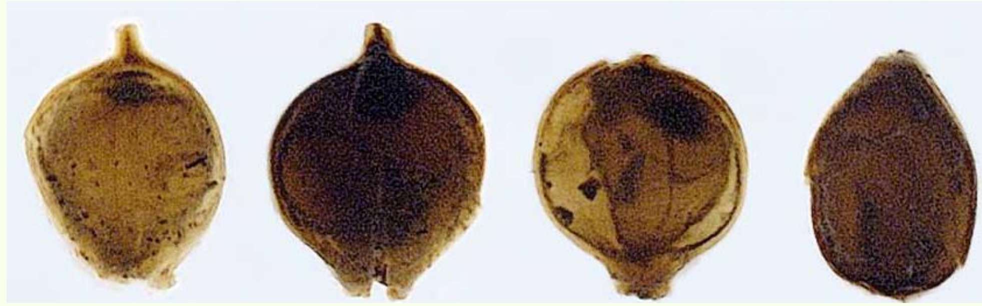
Utricle (flower) not often preserved. Can be loose or tight, sometimes with a distinctive vein pattern. That of *C. lasiocarpa* is hairy.

More Cyperaceae – flower parts modified to spines



Others: Cladium, Rhynchospora, Eriophorum, Trichophorum, Kobresia, Blysmus

Cyperaceae



Carex spp.

Kobresia myosuroides

Cladium mariscus

Cyperus spp

Eleocharis palustris

E. uniglumis

Eriophorum vaginatum

Trichophorum cespitosum

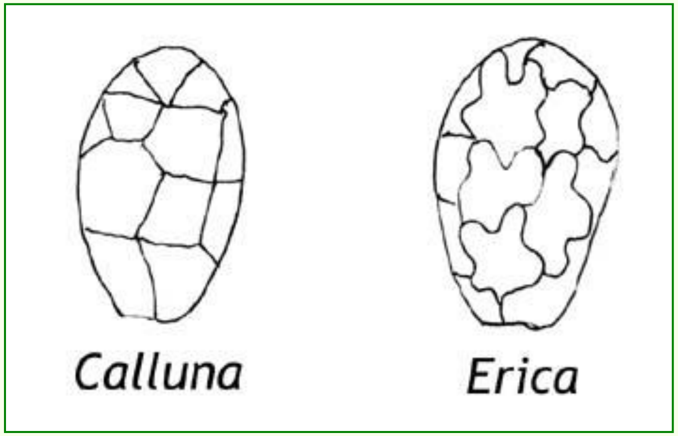
Scirpus lacustris

and more...

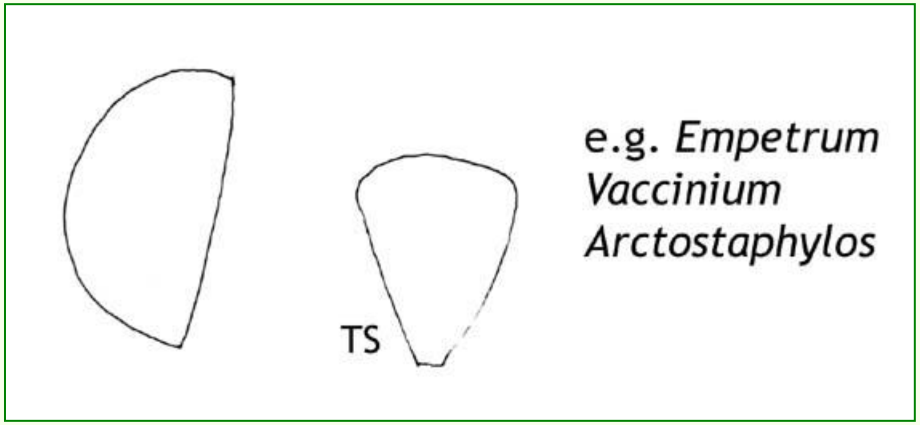
Ericaceae and Empetraceae

2 types:

(1) Very small, dust or balloon seeds from dry capsules



(2) Berry seeds. Larger, wedge-shaped. Various cell patterns, but never wiggly.

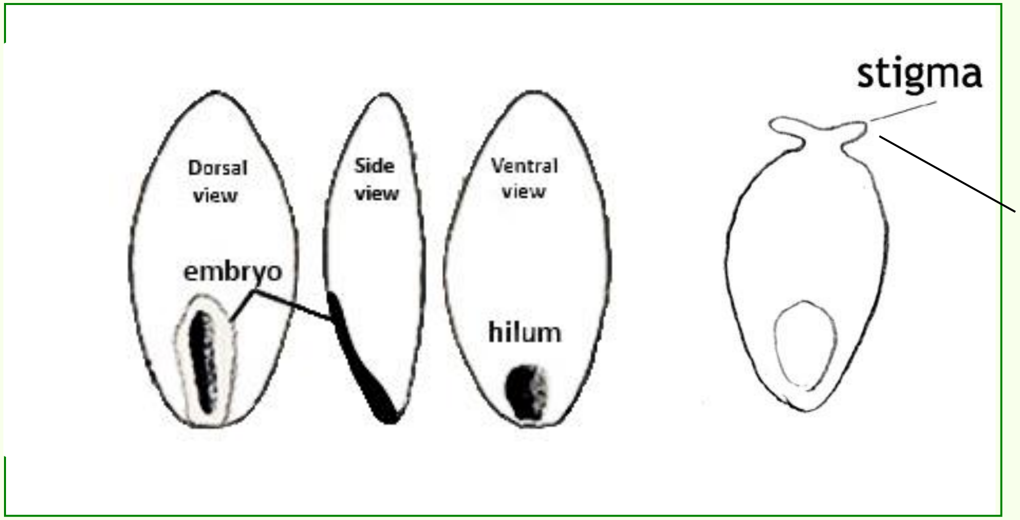


Gramineae and Juncus

Gramineae (Poaceae)

Usually only caryopsis preserved. Hard to identify without lemma and palea.

Includes cereals.

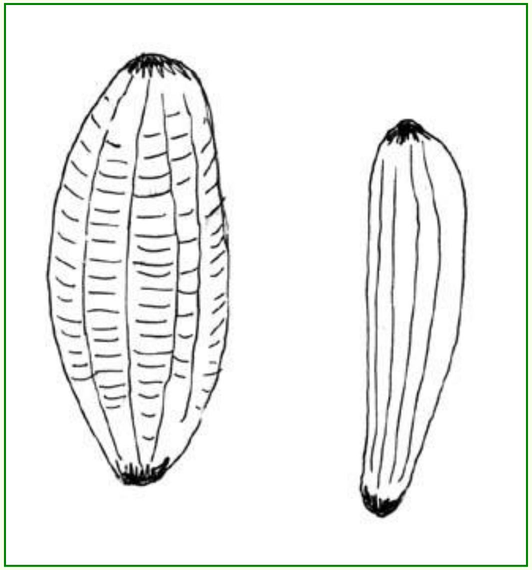


Glyceria is rather distinct.

Körber-Grohne (1964)

Juncus

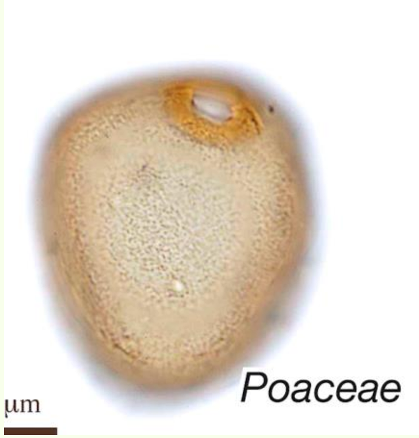
Small, sometimes abundant. Characteristic yellow colour.



Some have characteristic cell pattern (ladders).

Körber-Grohne (1964)

Poaceae



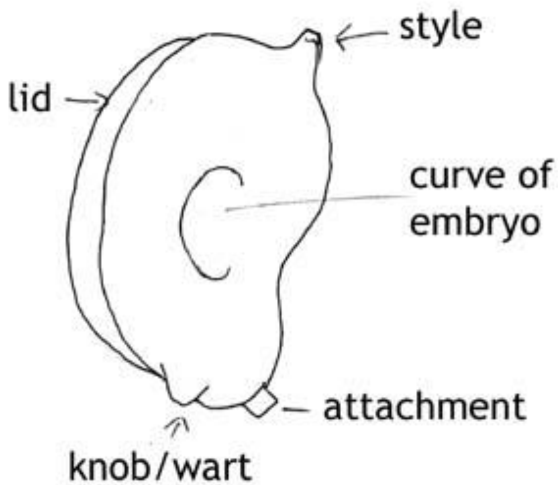
Poa cf. arctica

Agrostis

Hordeum

Some Aquatic Plants

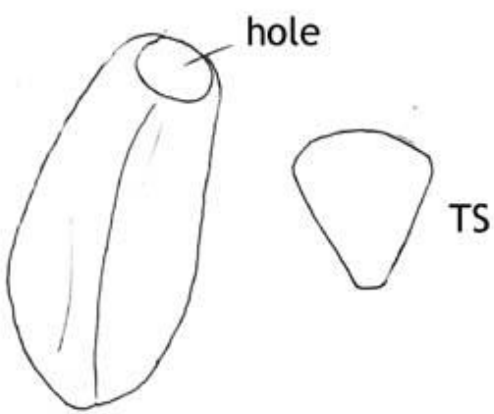
Potamogeton



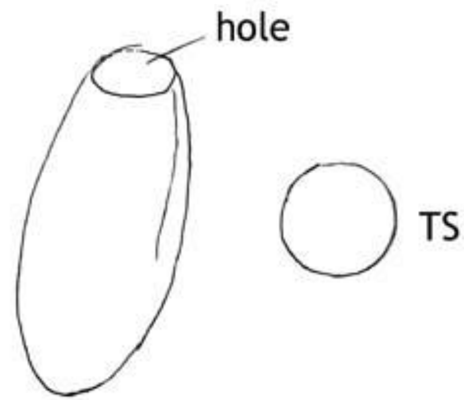
Use size, length of lid, TS of lid, distance between lid and style, curve of profile, position of style, and attachment.

See e.g. Aalto (1974)

Myriophyllum



Hippuris



Ranunculus Sect. *Batrachium*

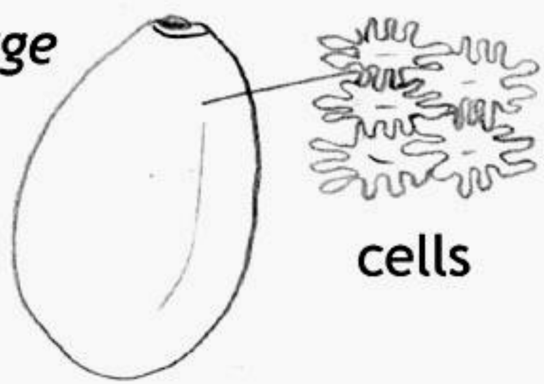
often splits in half

Typha

small, yellow

Nymphaea

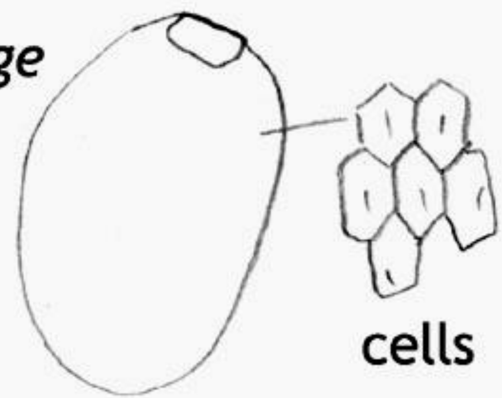
large



cells

Nuphar

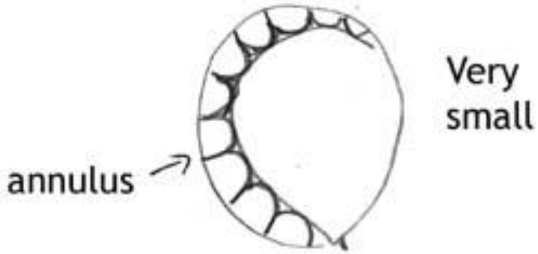
large



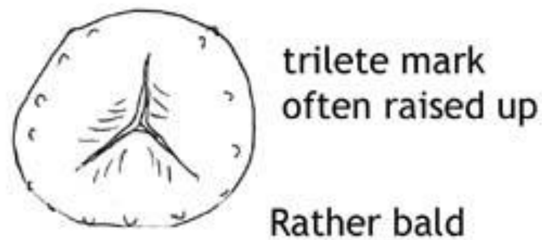
cells

Lower Plants

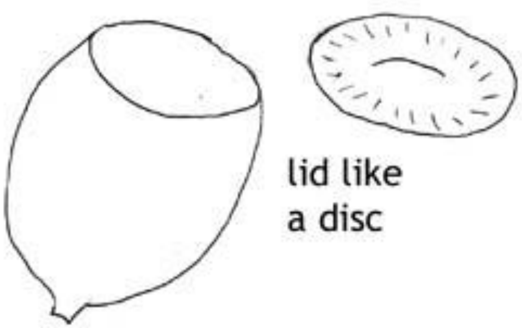
Fern sporangium



Selaginella

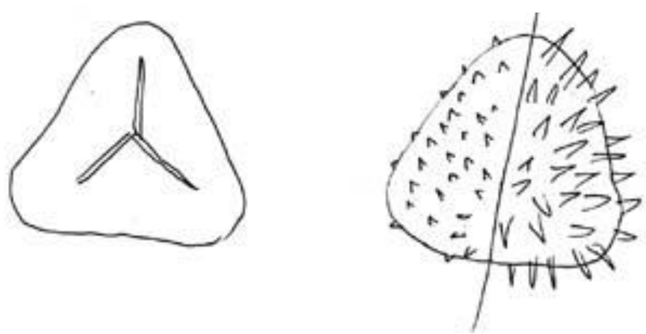


***Sphagnum* capsule**



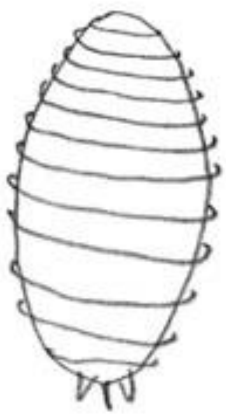
Isoetes

lacustris *echinospora*



Characeae

Chara oospore



lots of narrow spirals

Elongated shape

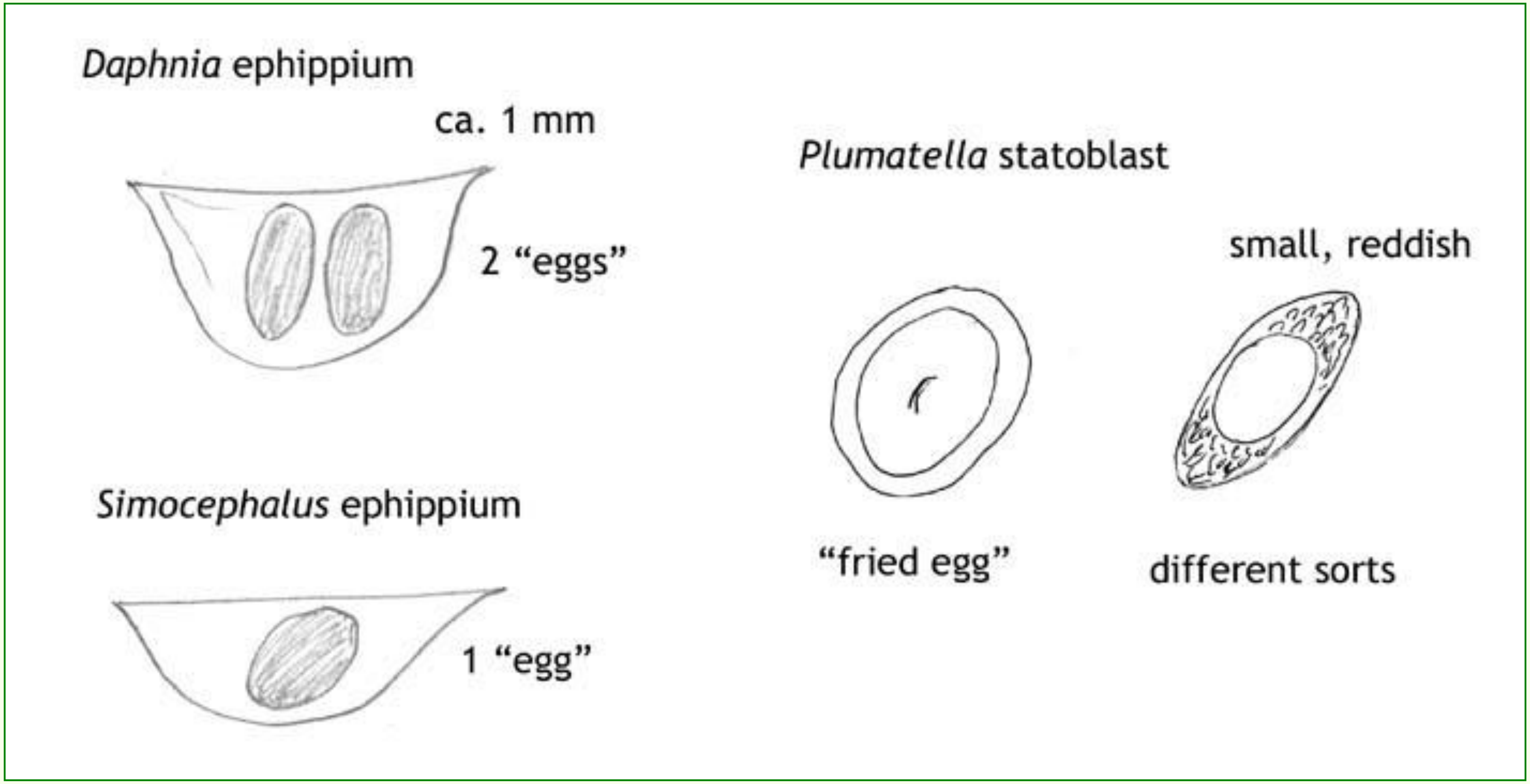
Can be lime-encrusted

Nitella oospore

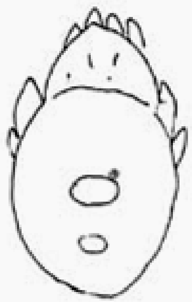
fewer, wider spirals, wider flanges

Rounder

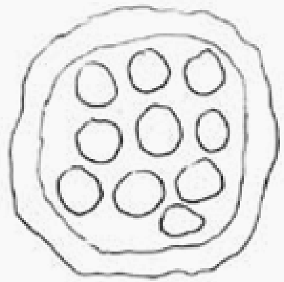
Common Limnic Animal Fossils



Oribatid mite e.g. *Hydrosetes*

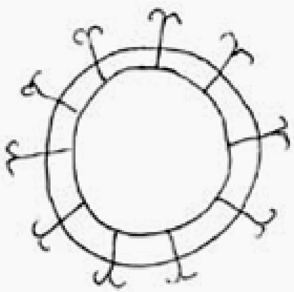


ca. 1 mm



Trichoptera operculum

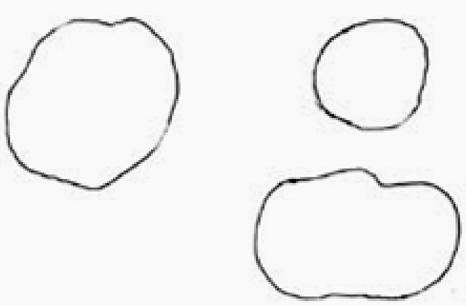
Cristatella statoblast



comes in 2 halves,
1without spikes

2 mm

Cenococcum sclerotia
- fungus fruit bodies

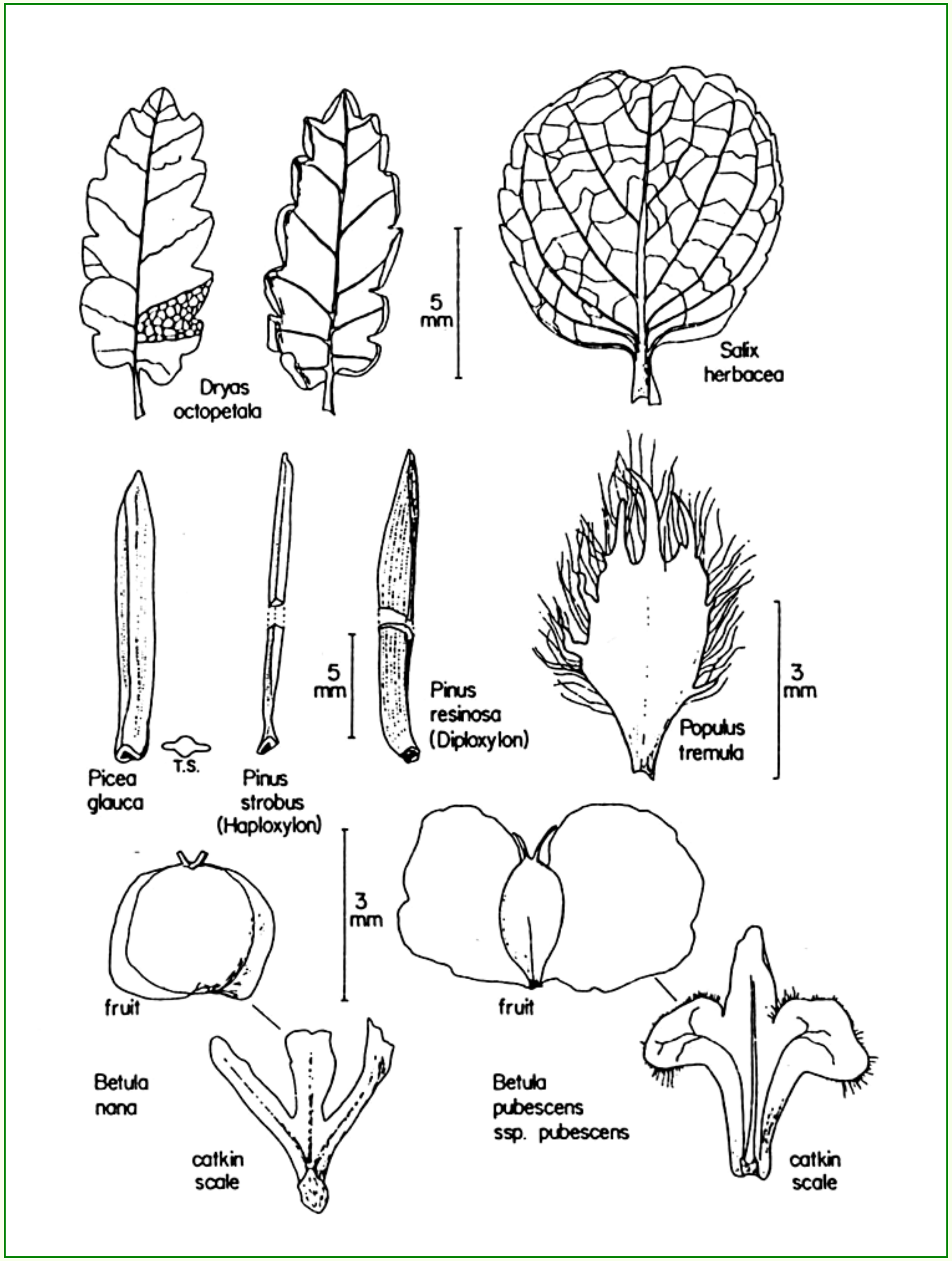


Small black balls.
Crush into dust

1-3 mm

Characteristic of soil.
Washed into lake sediments

Drawings of seeds and vegetative parts of terrestrial plants that are found as fossils

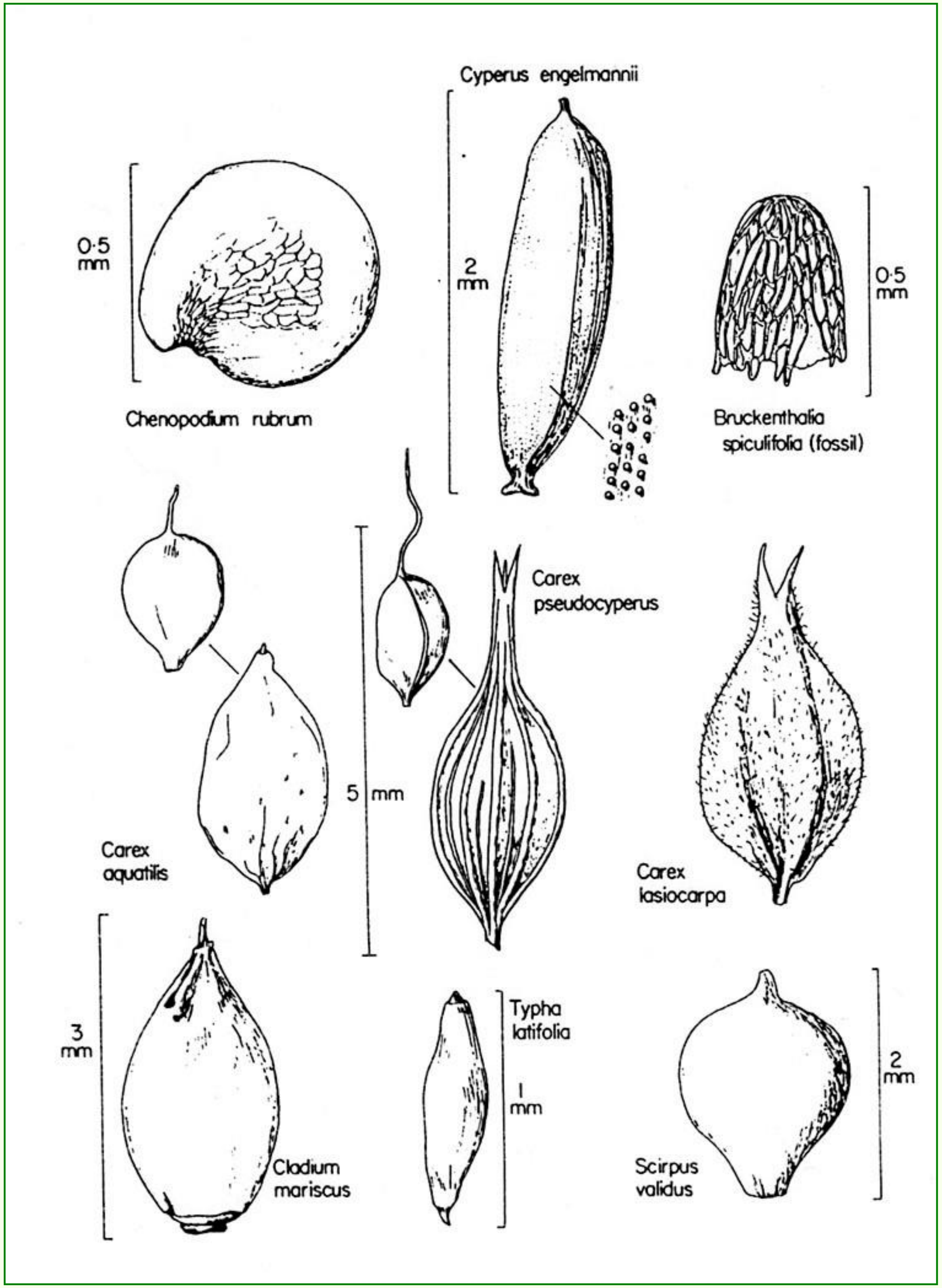


leaves

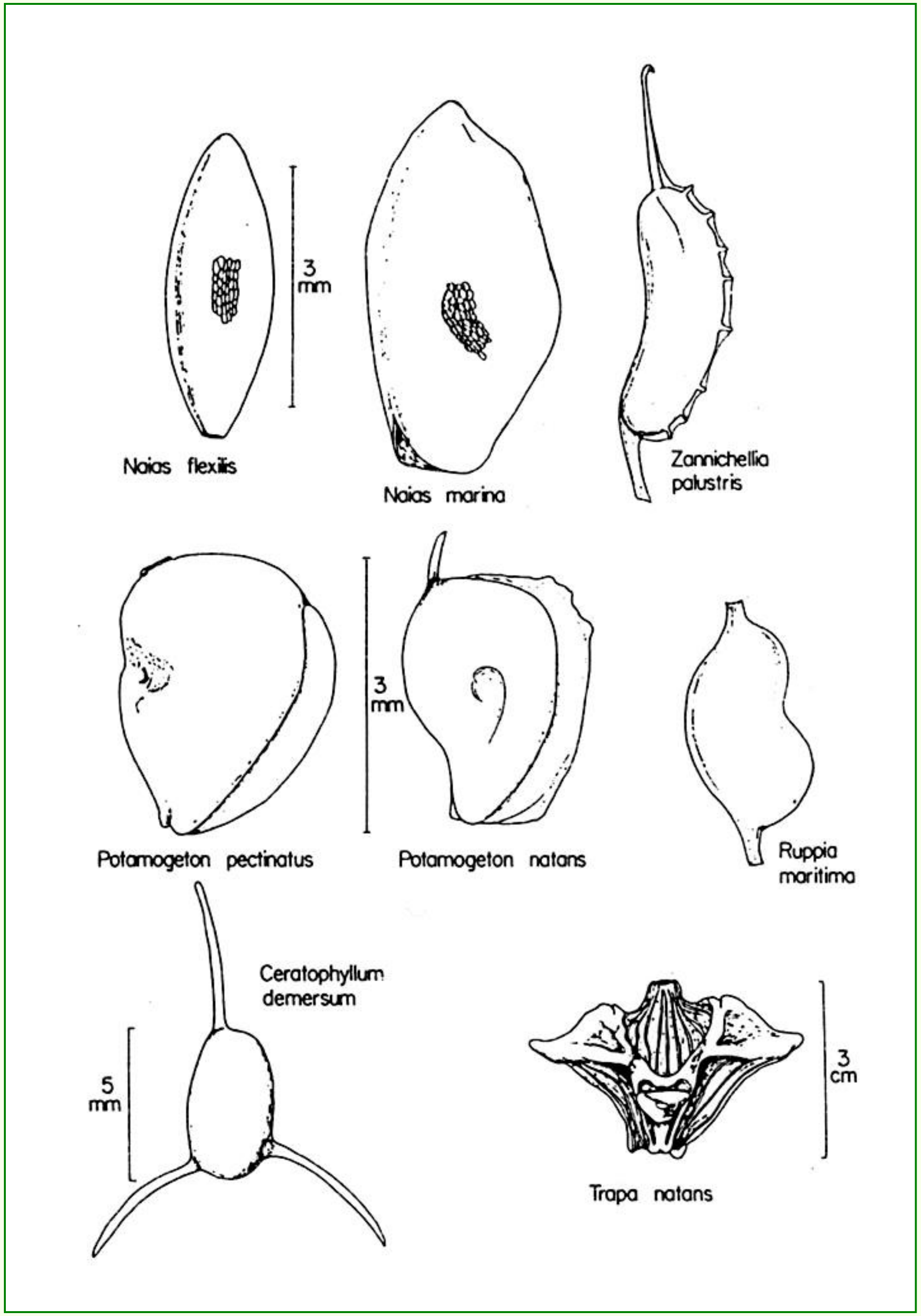
Betula

Birks (1980)

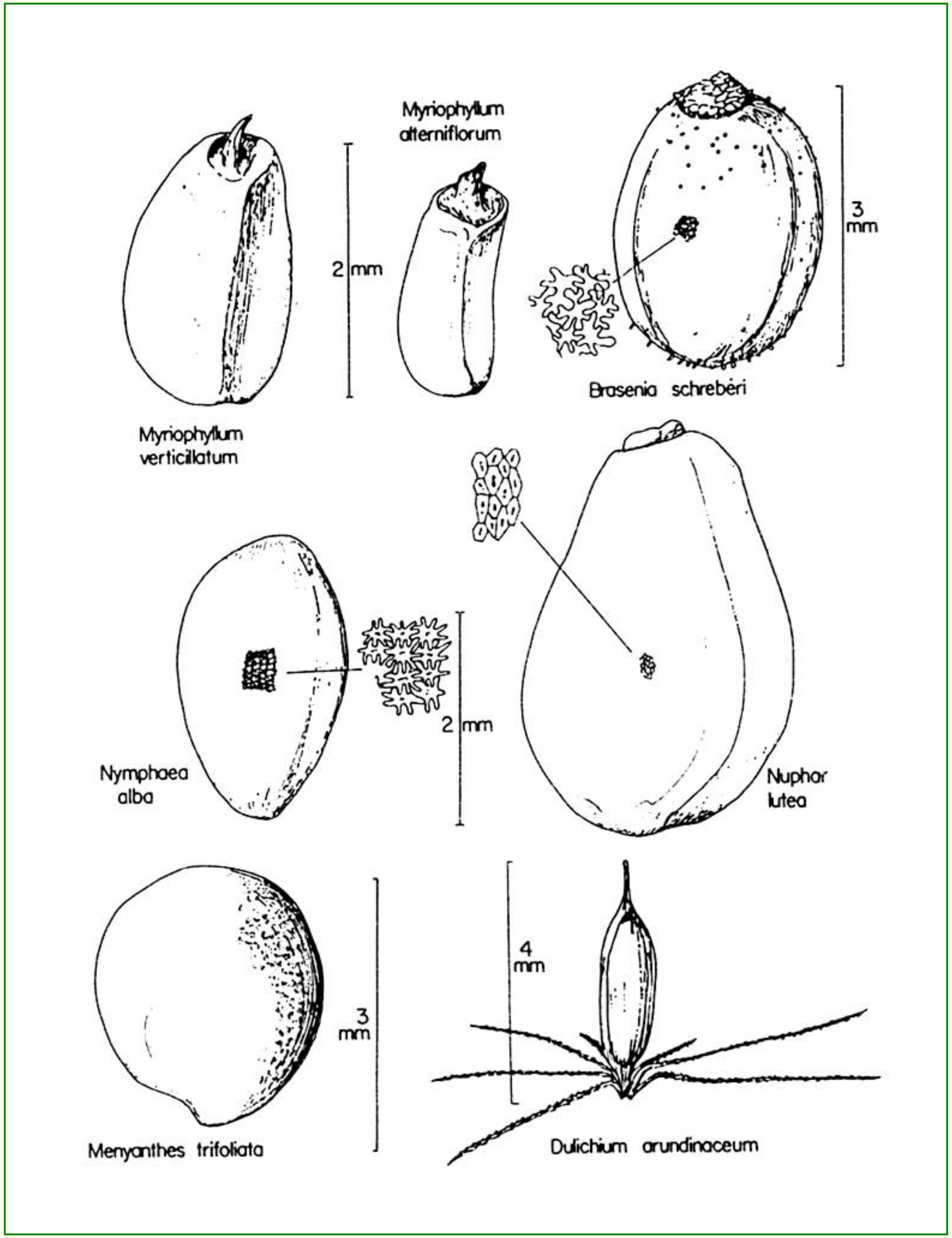
Drawings of seeds of some terrestrial and marsh plants that are found as fossils



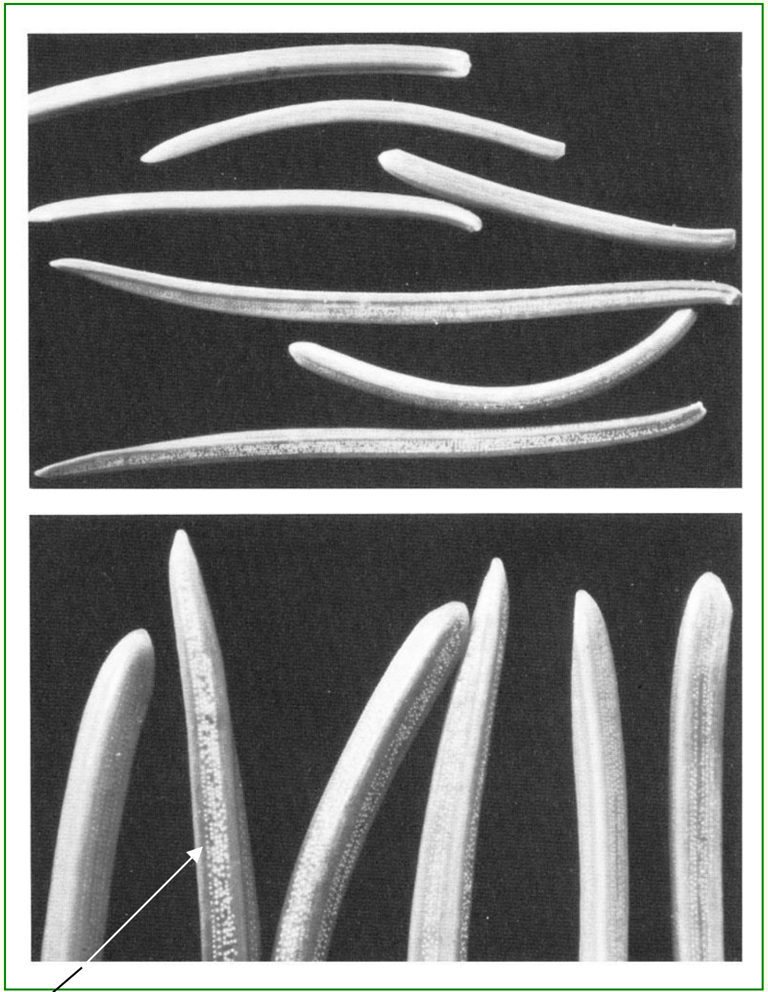
Drawings of seeds of some submerged and floating-leaved aquatic plants that are found as fossils



Drawings of seeds of some aquatic plants that are found as fossils

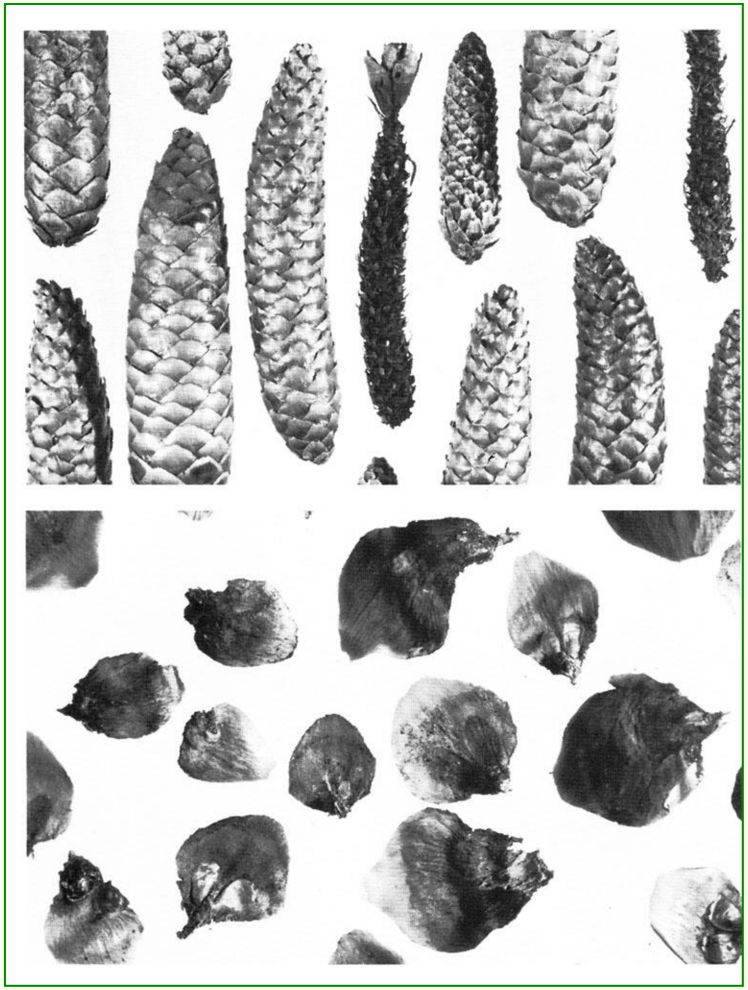


Photographs: light microscope and SEM



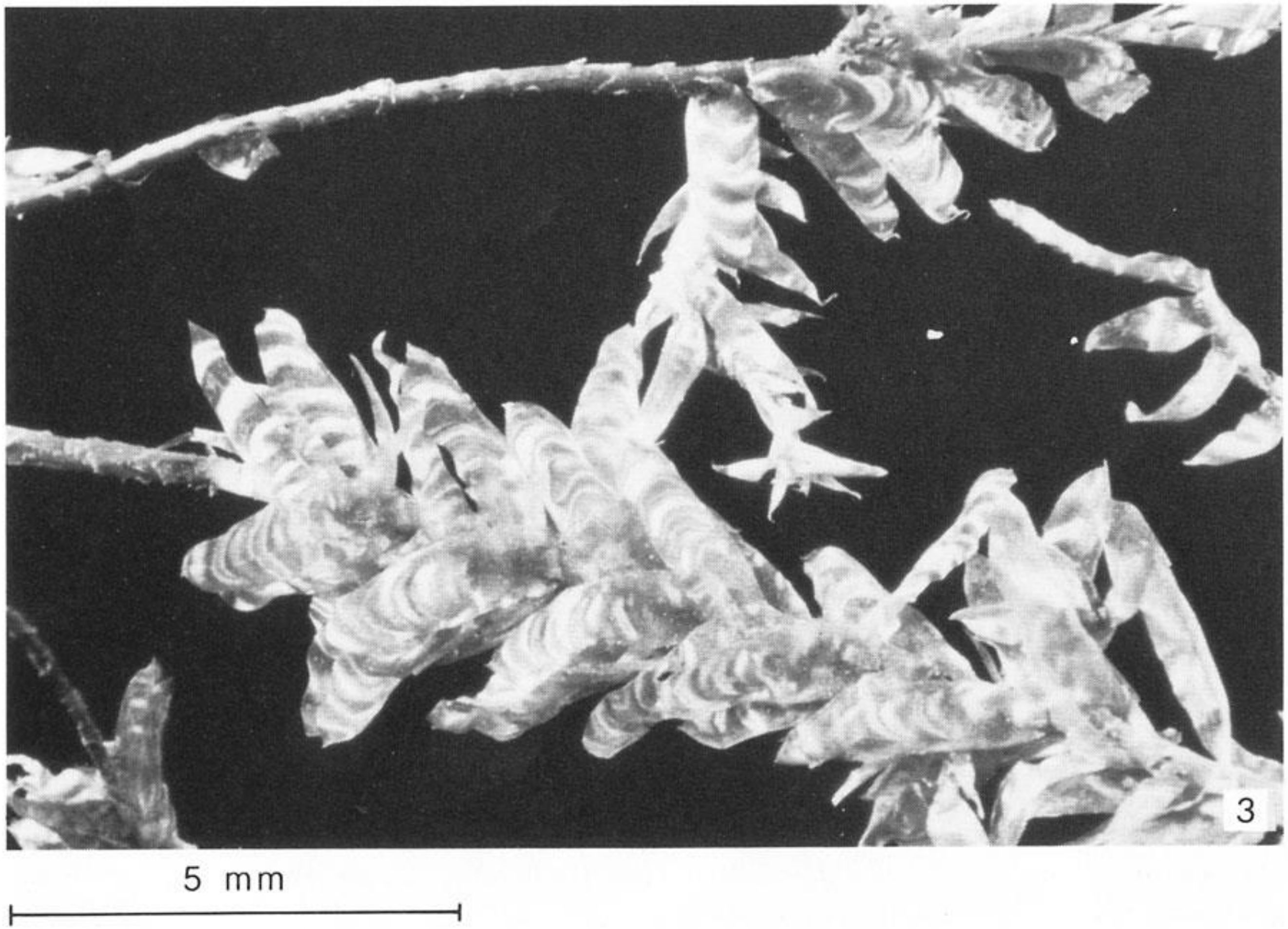
Picea abies needles

Rows of stomata



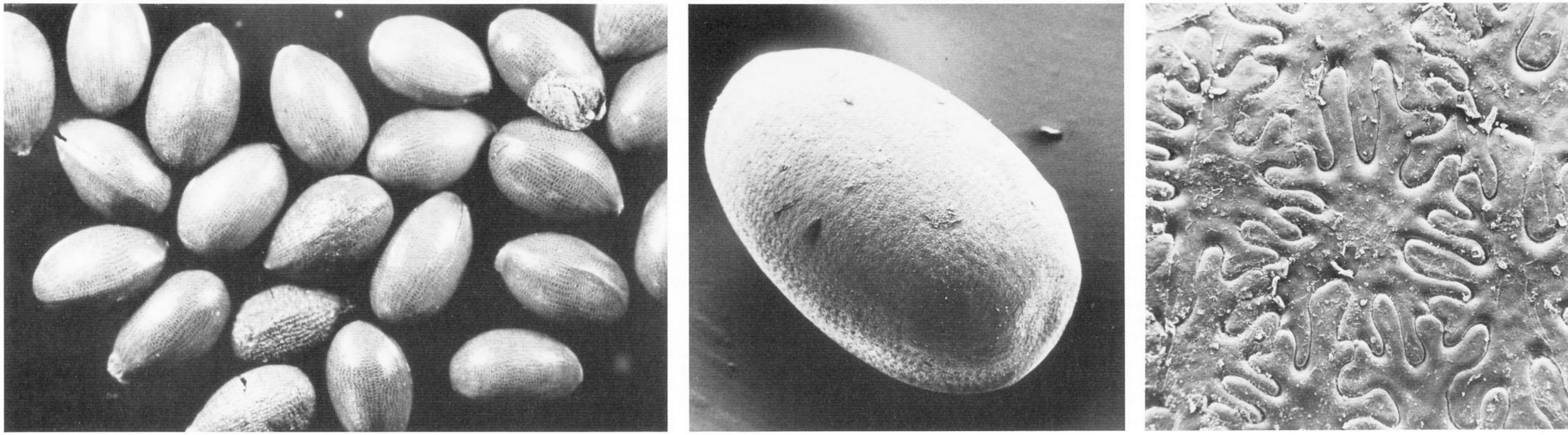
Picea abies cones and scales

Schoch et al. (1988)

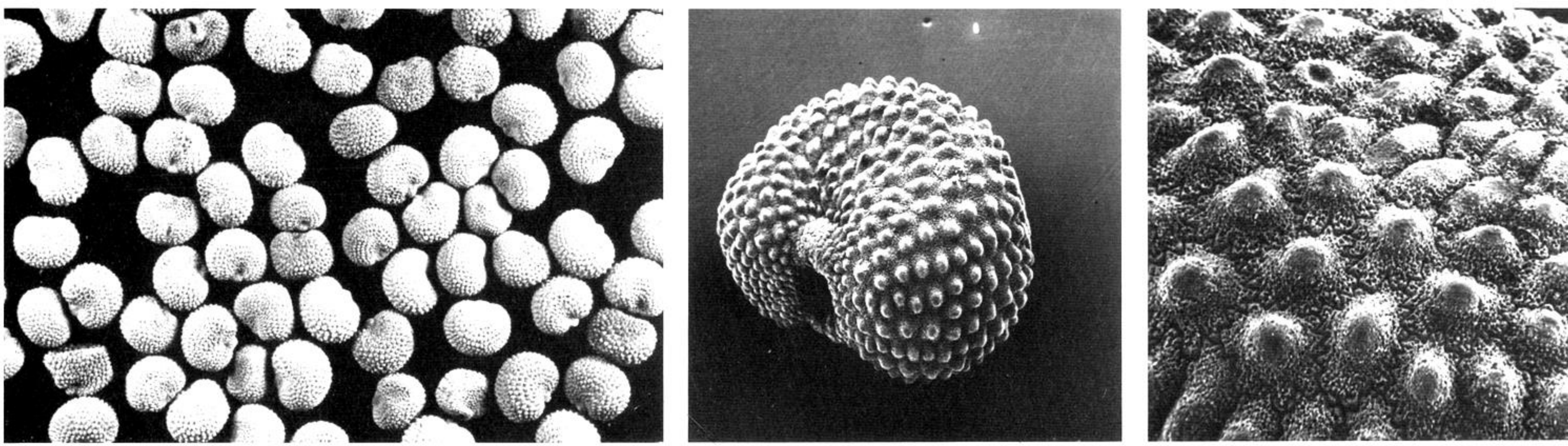


Neckera crispa - moss associated with the Iceman

Cell patterns

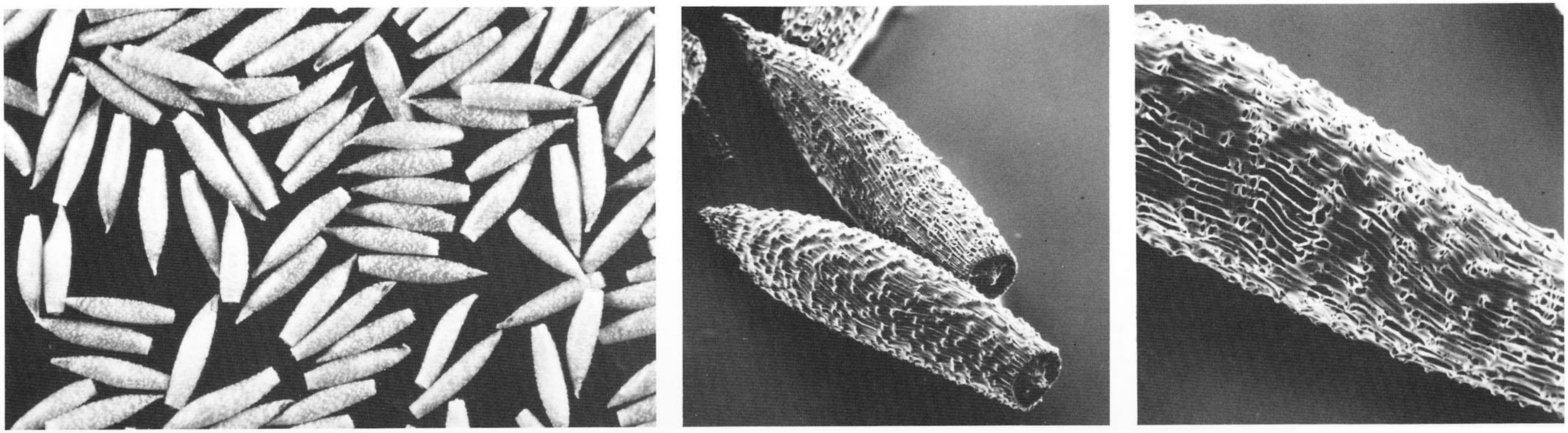


Nymphaea alba

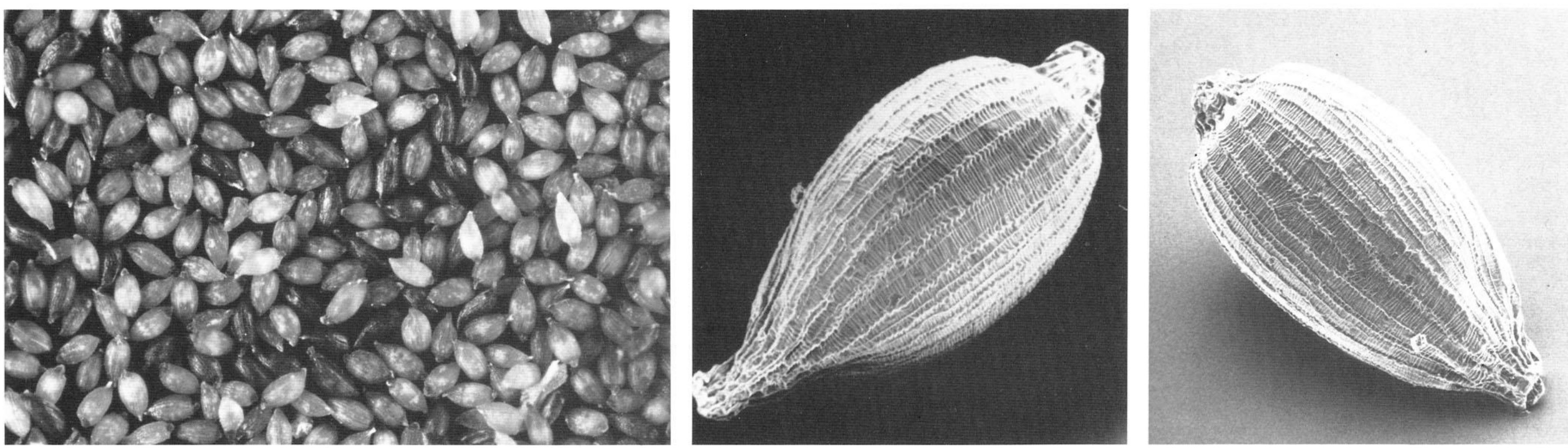


Silene alba

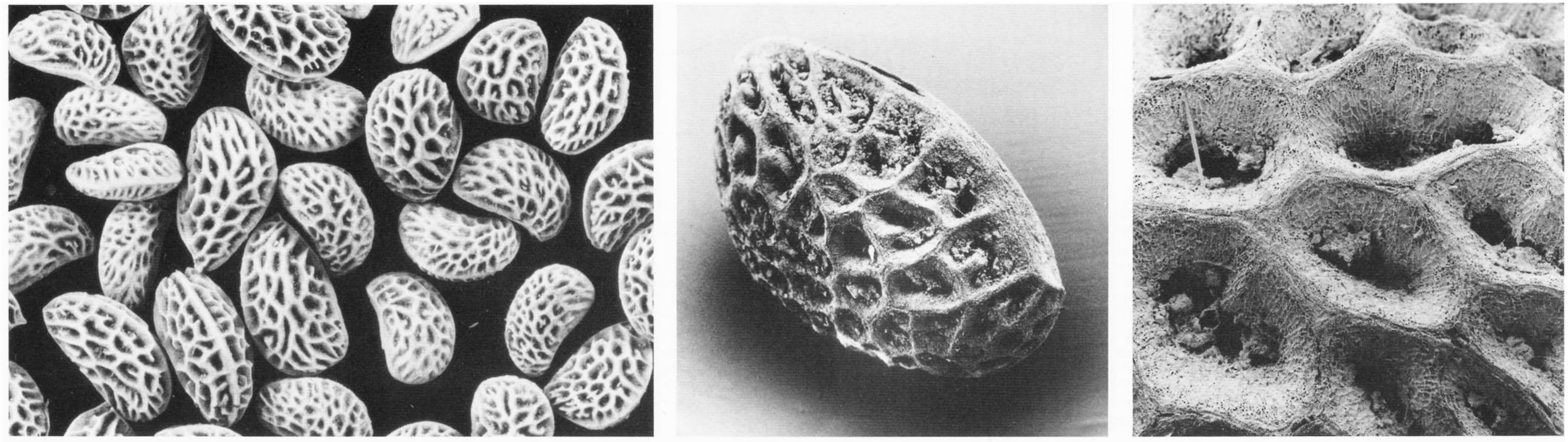
Small, often yellow



Typha latifolia

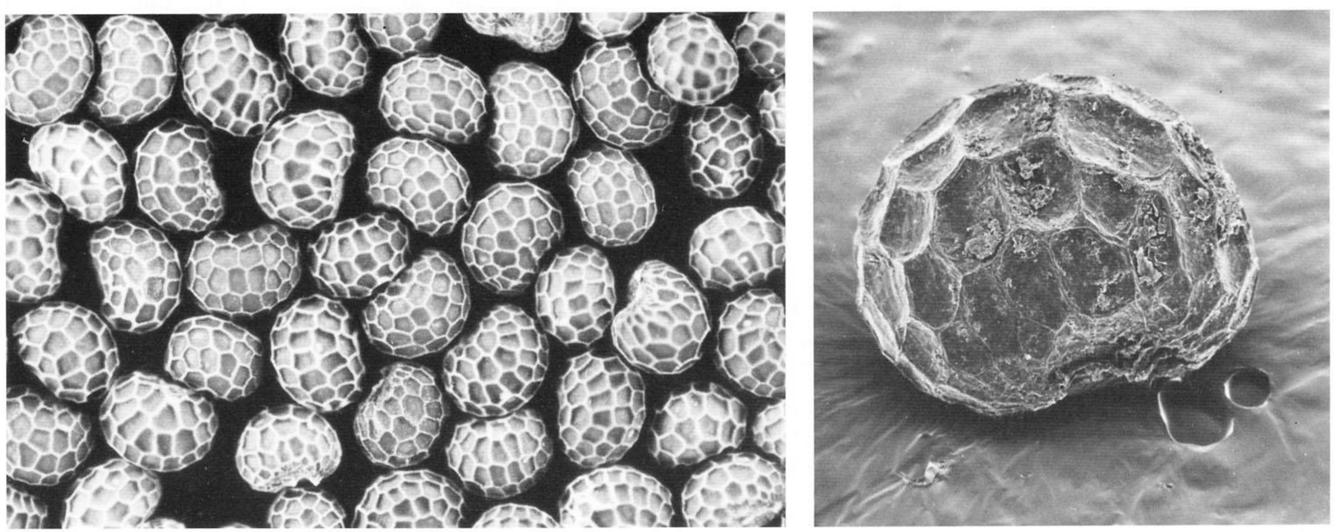


Juncus articulatus



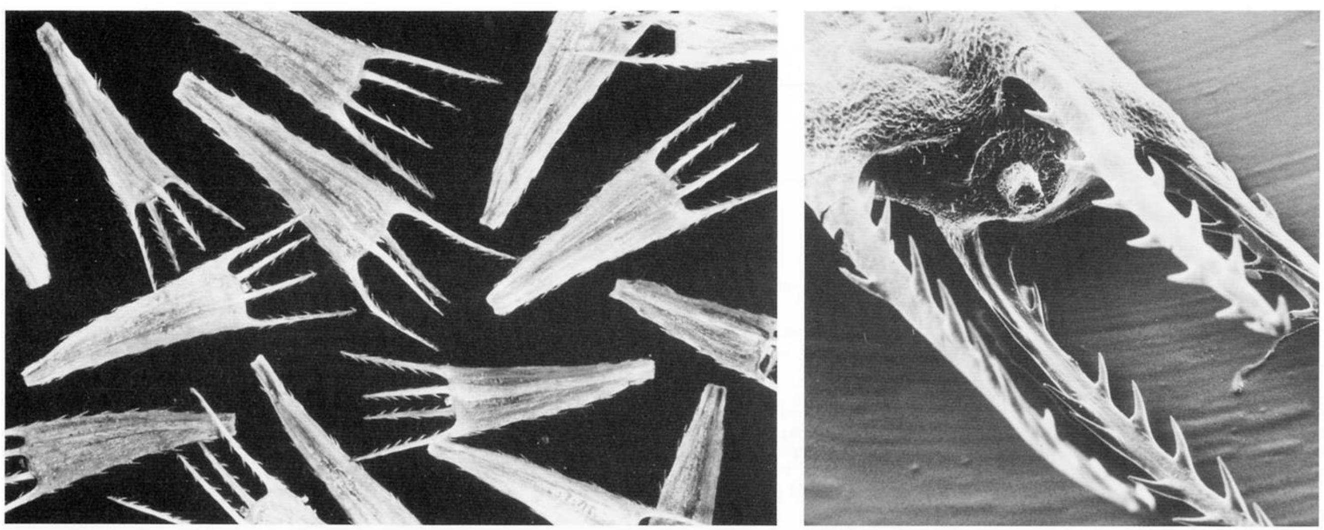
Reticulate

Rubus fruticosus



Papaver somniferum

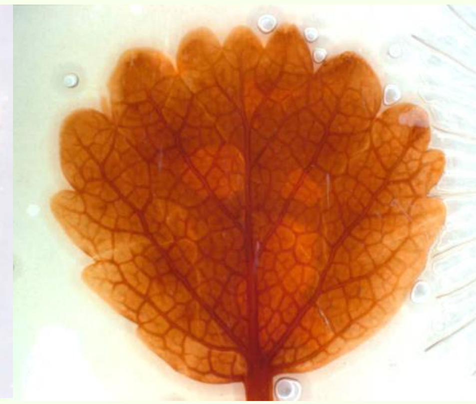
Avena sativa Cereal



Bidens cernua Asteraceae

Betula

Betula nana

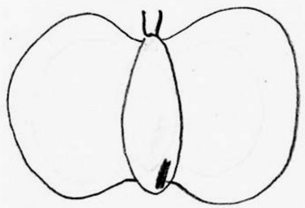


Betula pubescens

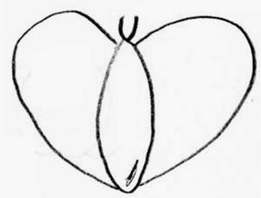
Betula

TREE BIRCH

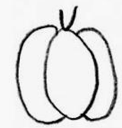
DWARF BIRCH



Betula pubescens

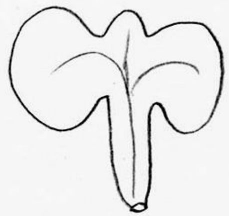


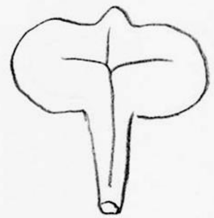
Betula pendula



Betula nana

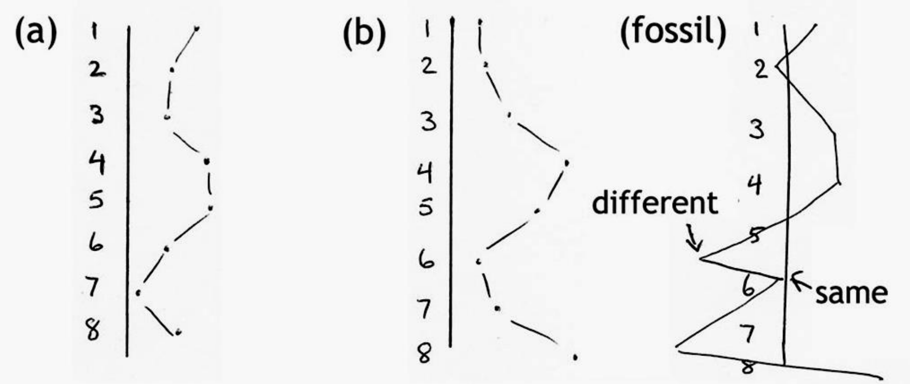
net-veined





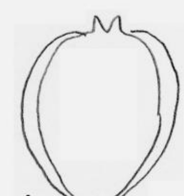
B. nana leaves are distinctive

SIZE-SHAPE ANALYSIS (Polish) Compare shape of fossils by subtracting values from the reference. Flattest curve is the best fit.



Betula nana characteristic of late-glacial.
Tree *Betula* characteristic of Holocene.

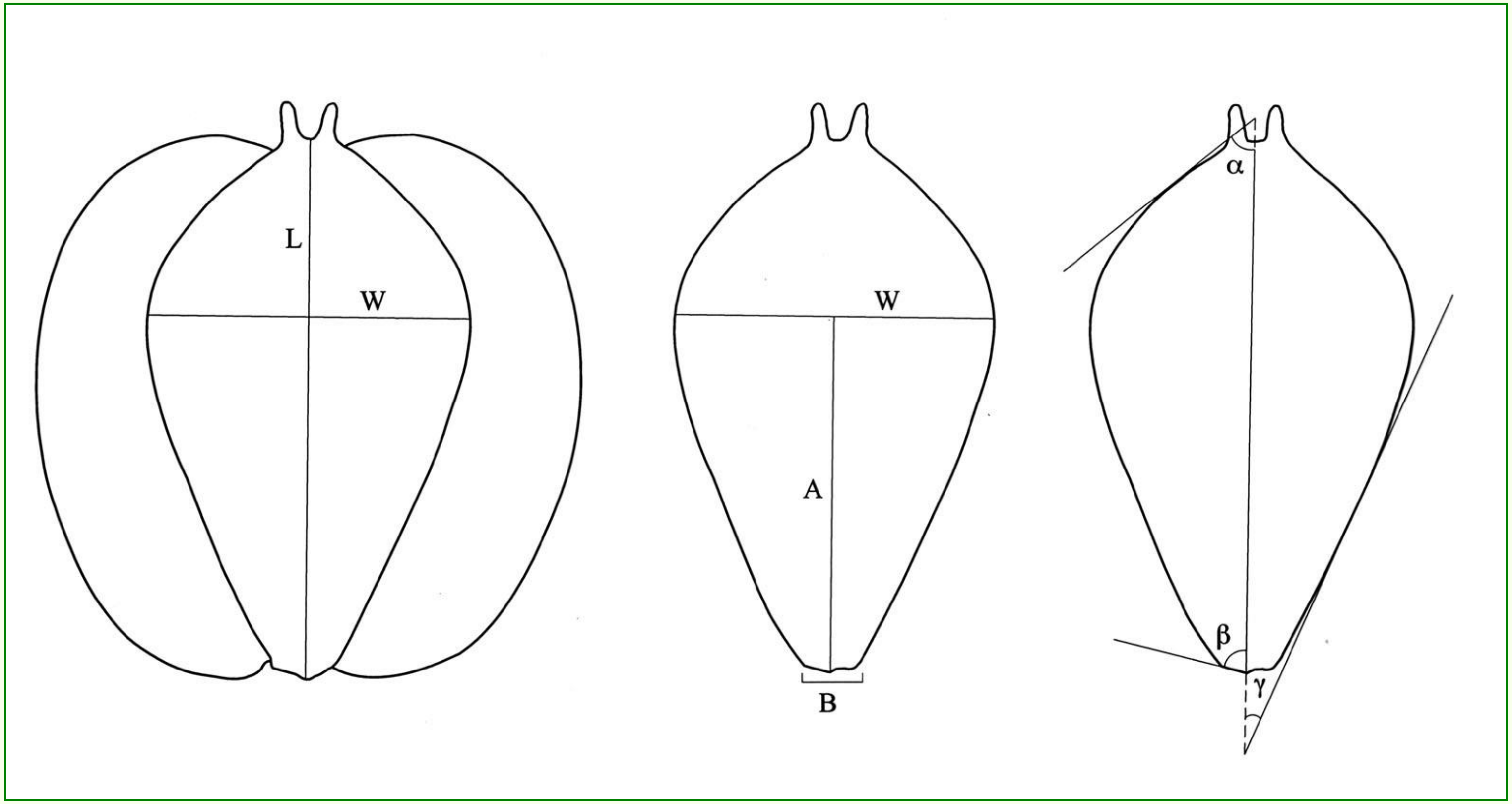
ALNUS



Fruit.
Narrow wing,
corky

Woody
catkin
scale

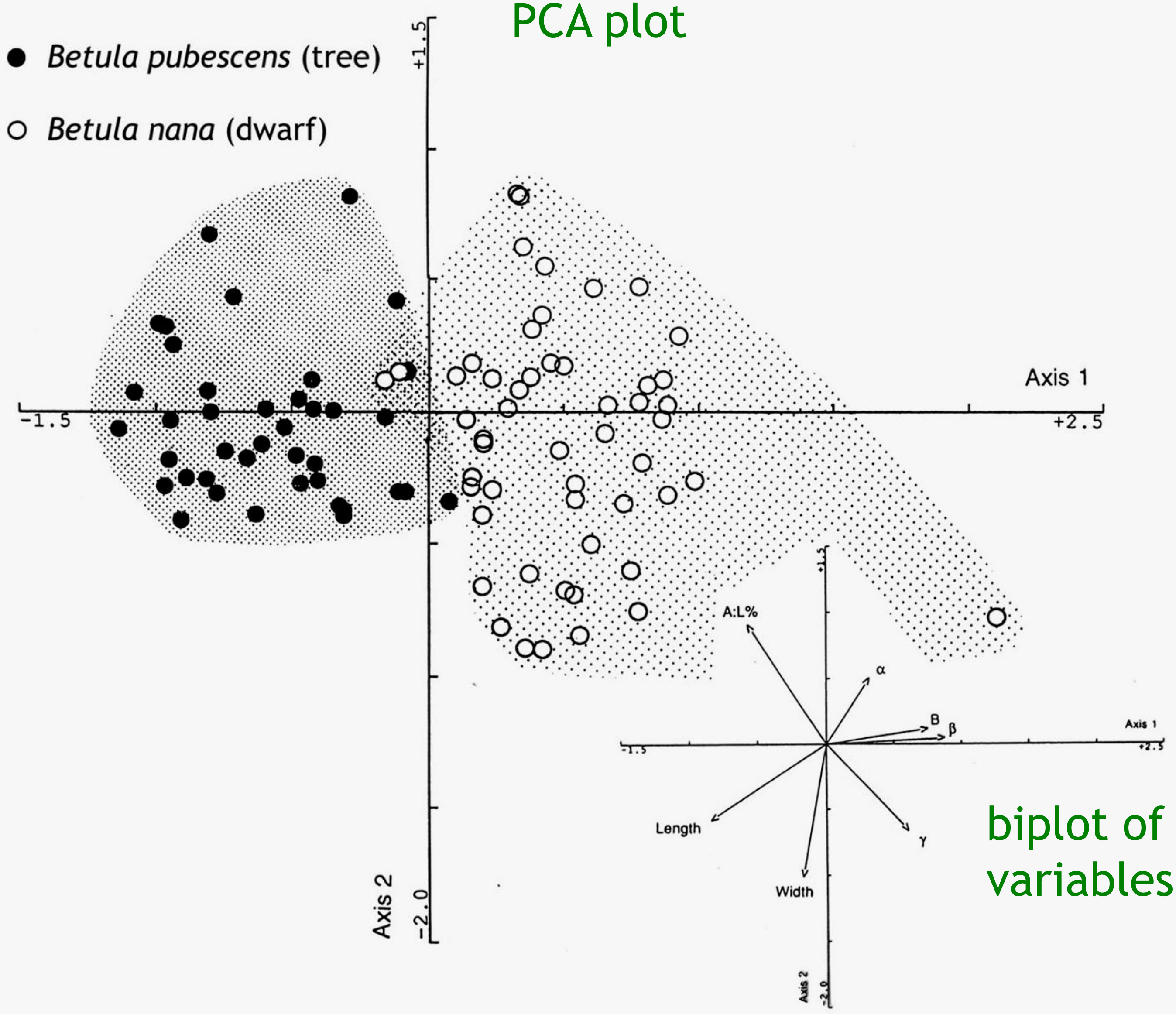
Identification of *Betula* Fruits Lacking Wings



Betula fruit

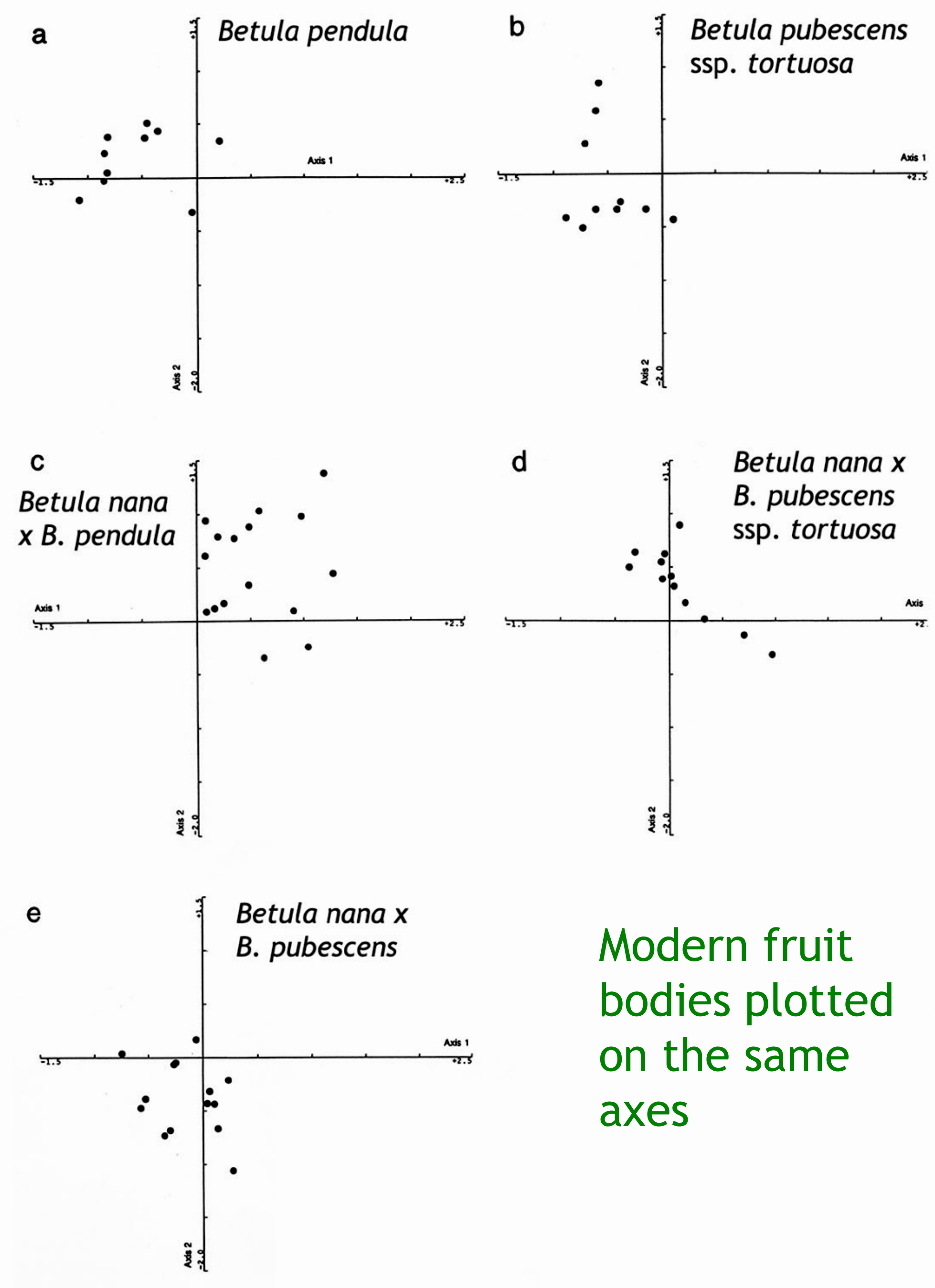
van Dinter & Birks (1996)

PCA plot



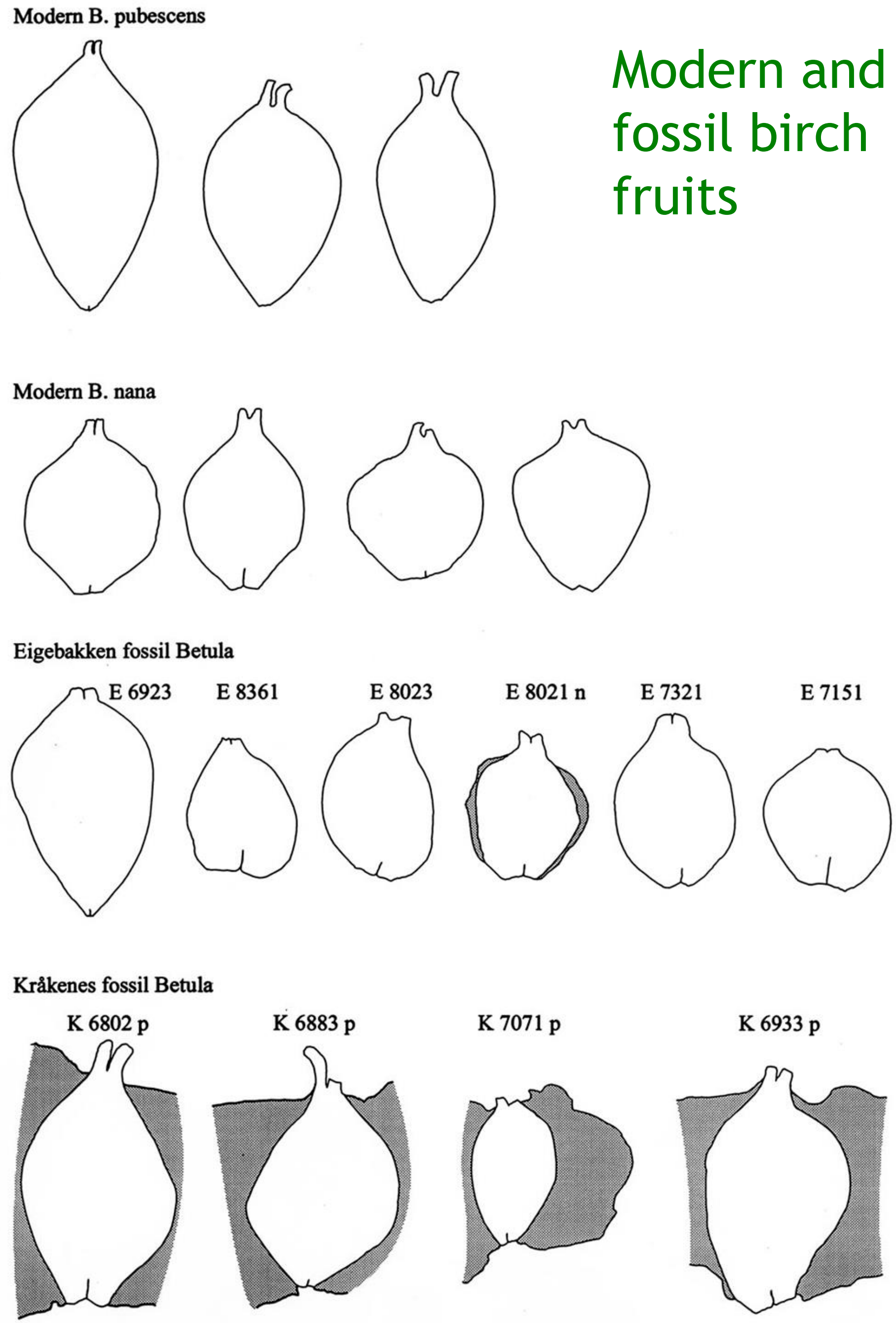
biplot of variables

PCA plots of modern tree birches and hybrids

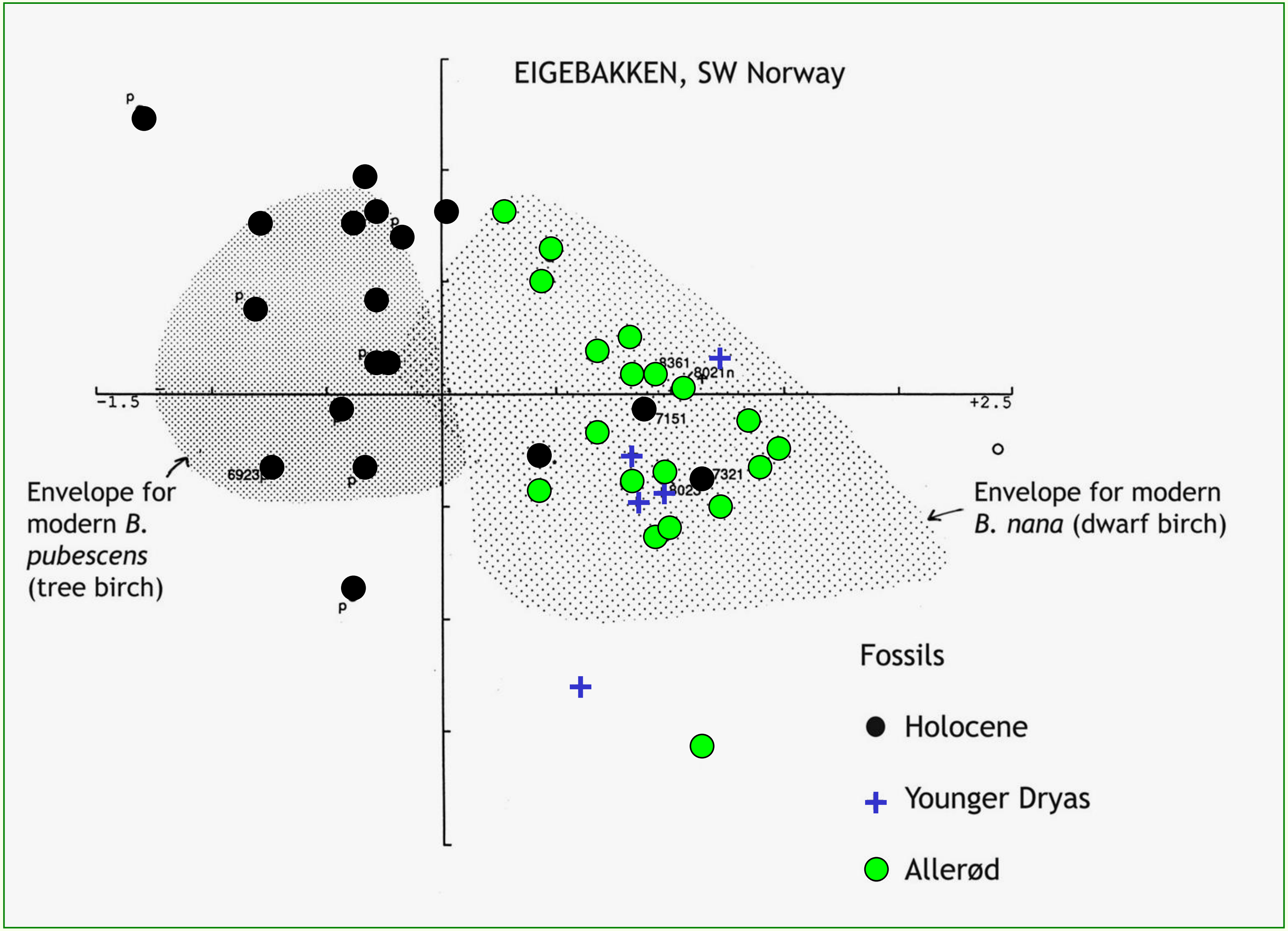


Modern fruit bodies plotted on the same axes

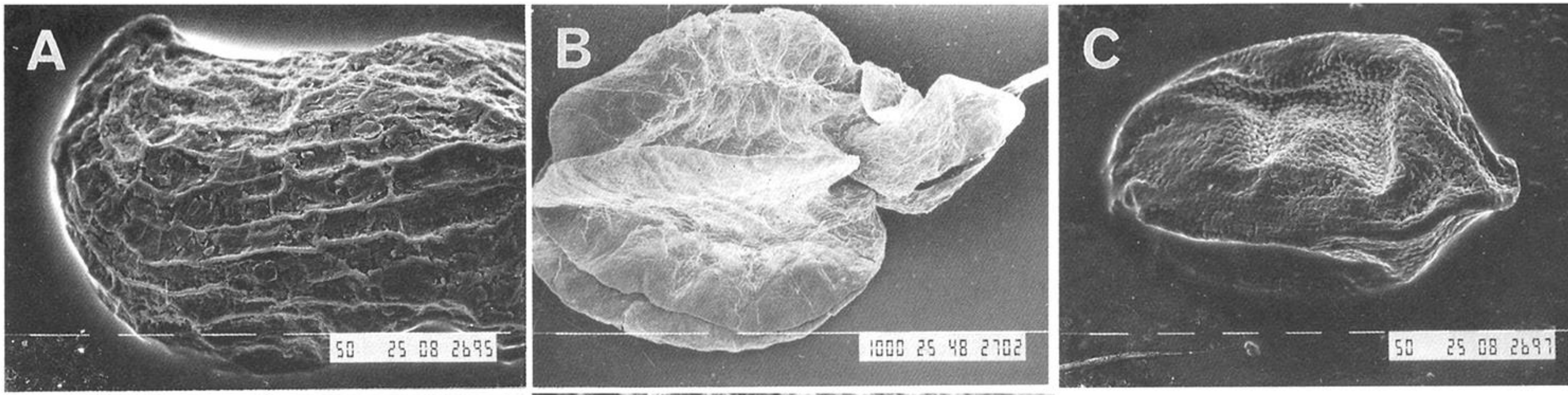
Modern and fossil birch fruits

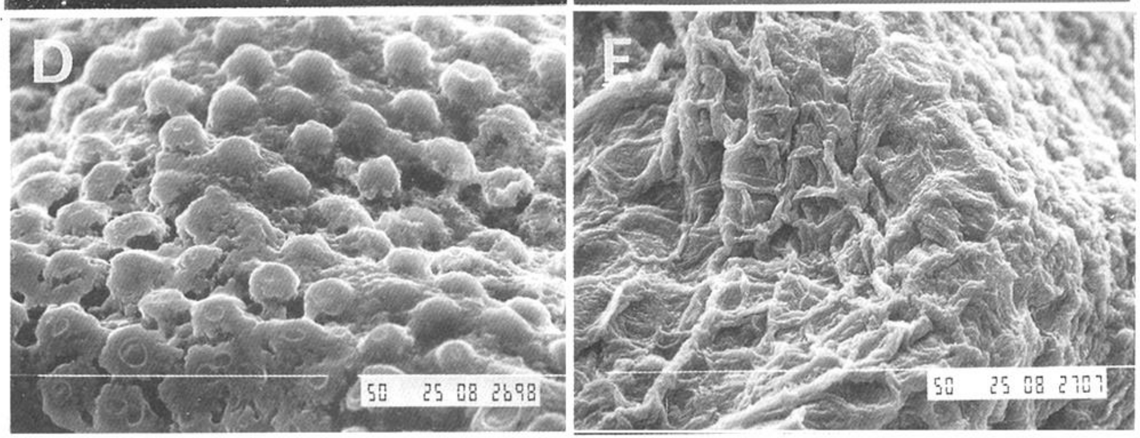


Plot of *Betula* fossils from Eigebakken, S. Norway, positioned on PCA axes

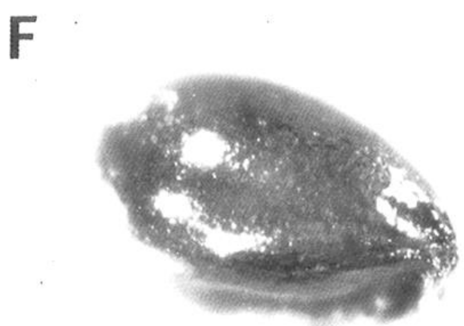


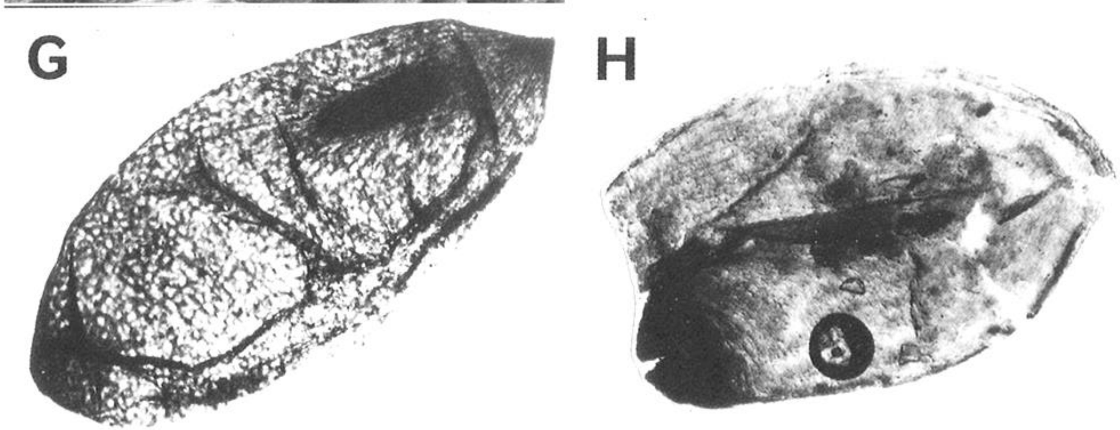
Fossils from Andøya full-glacial



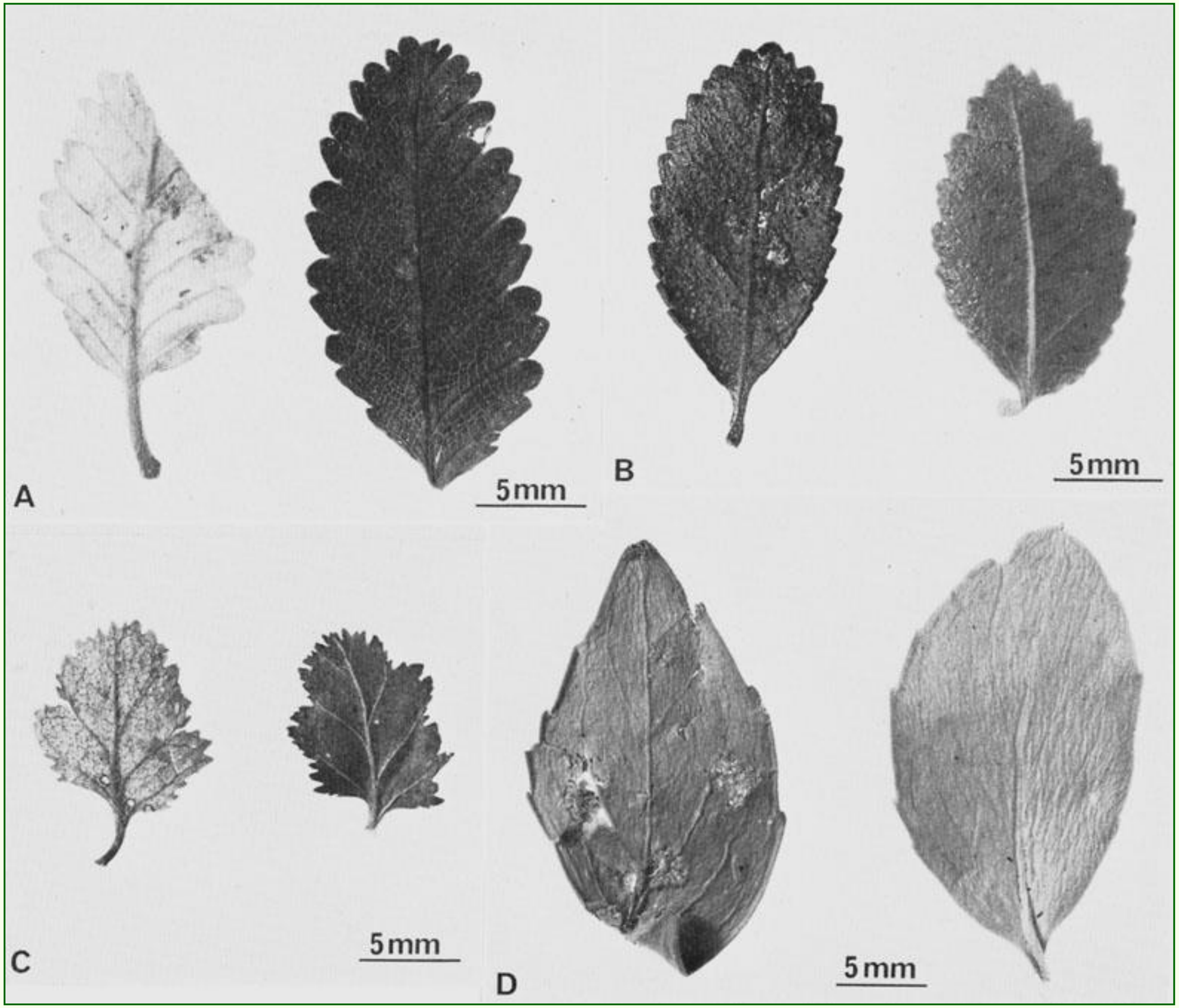


A. *Papaver radicatum* sl 0.8mm
B. *Rumex acetosa* fruit 4.5mm
C. *Saxifraga cespitosa* 1mm
D. *Saxifraga cespitosa* surface
E. *Cardamine nymanii* surface
F. *Chrysosplenium* 0.8mm
G. *Puccinellia* 1.5 mm
H. *cf. Braya linearis* 1 mm





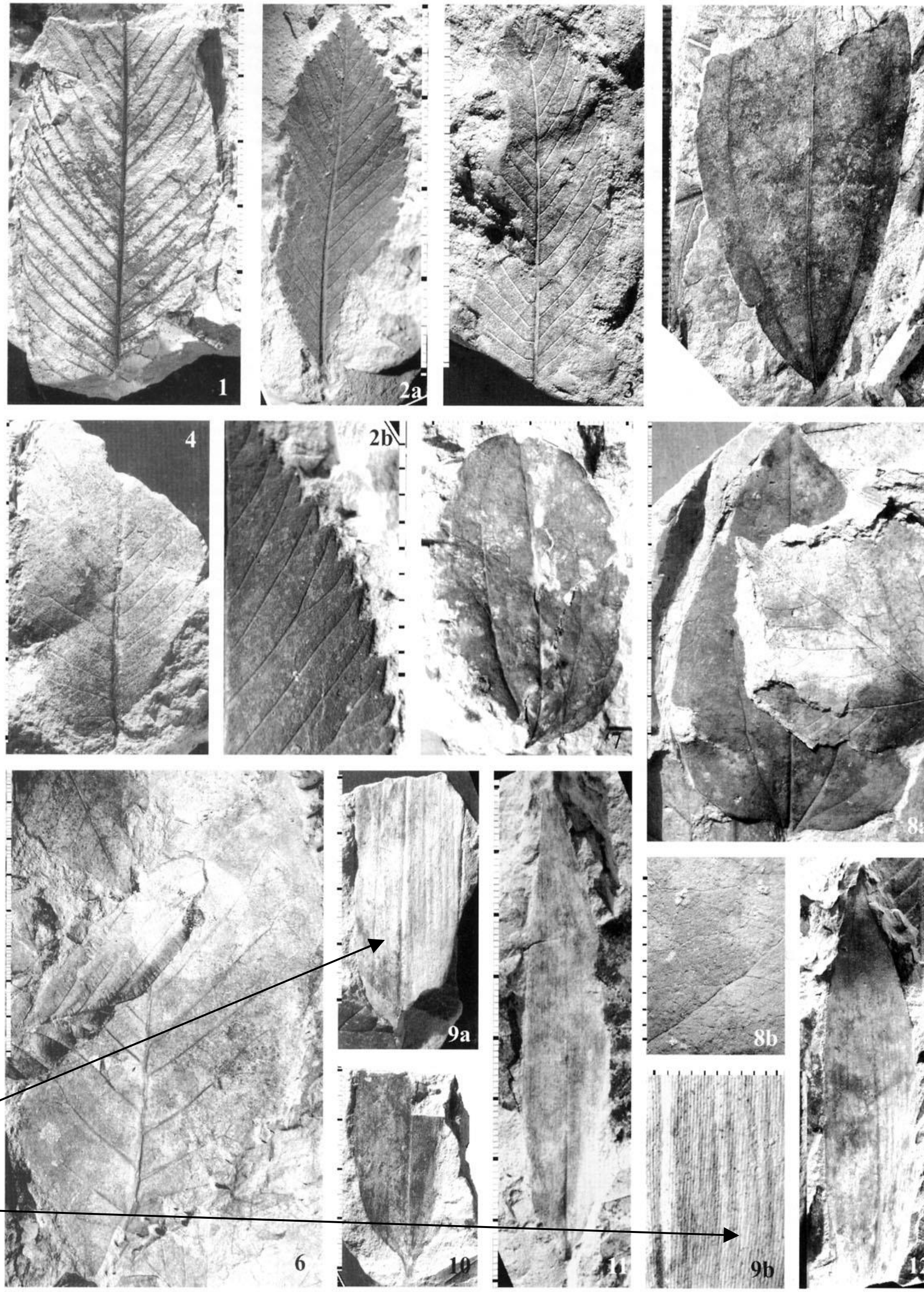
Alm & Birks (1991)



Leaves of tree species prominent in Mylodon cave deposits (Argentina); in each case modern leaf at right, and fossil (ca. 7800 BP) at left. A, *Nothofagus pumilio*; B, *Nothofagus betuloides*; C, *Nothofagus antarctica*; D, *Maytenus magellanica*.

(Moore 1978)

Leaf remains in Pliocene sediments, Cervo River, north Italy



Leaves of thermophilous trees from the Pliocene of northern Italy

Bambusa (bamboo)

Martinetto (2003)

Method of Plant Macrofossil Analysis

1. <u>Obtain sediment sequence</u>:

   (a) Open section

   (b) Core - open water

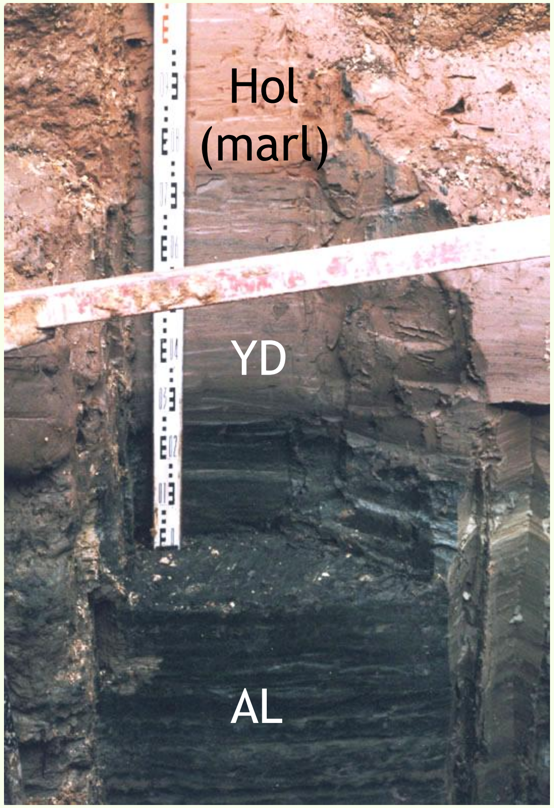
   ice

   marsh/bog

   (c) Spot samples, e.g. archaeological excavation

Open section –

Whitrig Bog



Archaeological sections

Iron Age site at Corfe Castle, S England

Roman site at Fishbourne, S England

Bryggen, Bergen

Archaeological evidence

Waterlogged sites. Ditches, latrines
(e.g. Bryggen, Bergen,
lake dwellings, crannogs)

Dry sites. Hearths, occupation floors, post-holes

Impressions in pottery

Artefacts (wood, cloth, leather)

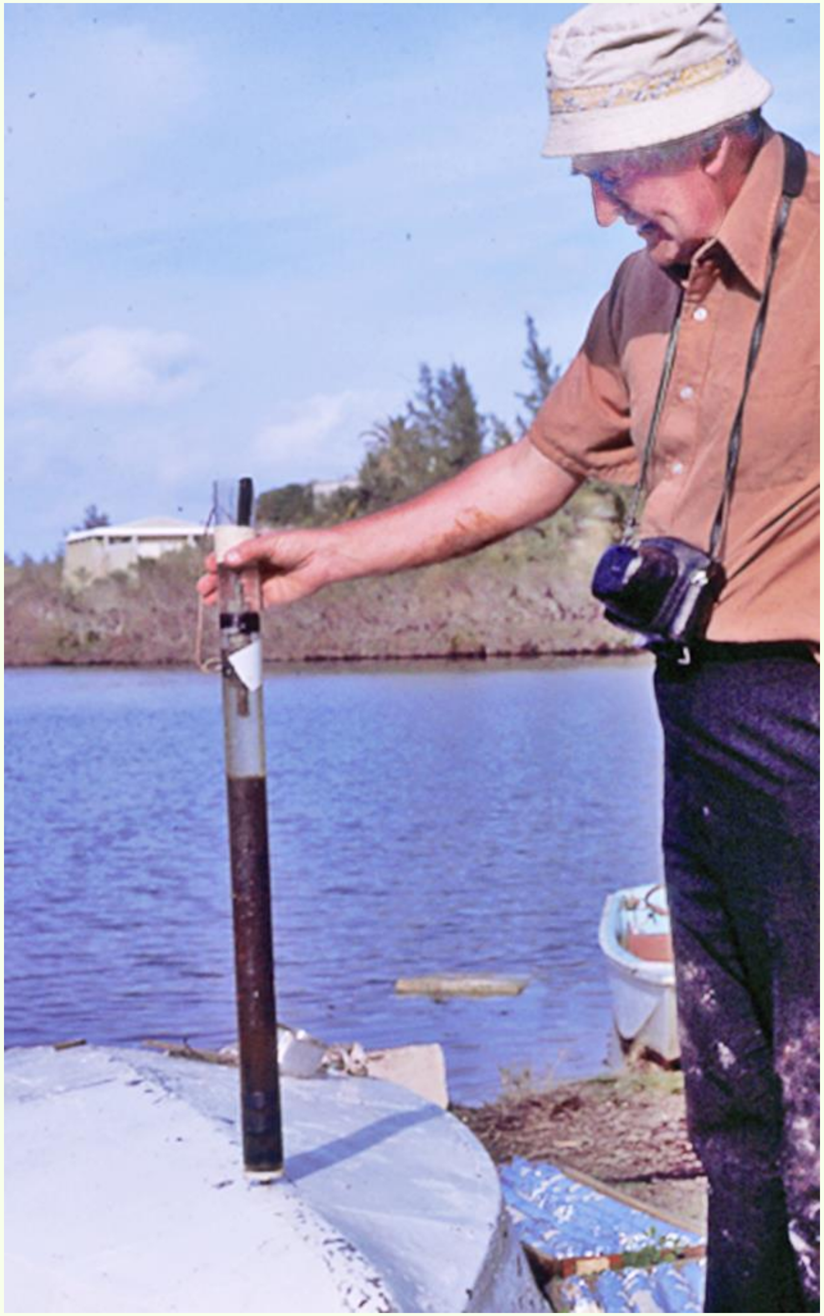
Models, drawings, writing (e.g. Pharoah tombs,
temples, scrolls)

Jacomet 2007,
Jacomet & Kreuz 1999


Lake Coring

From open water
Livingstone
piston corer

Short core of uppermost lake sediment



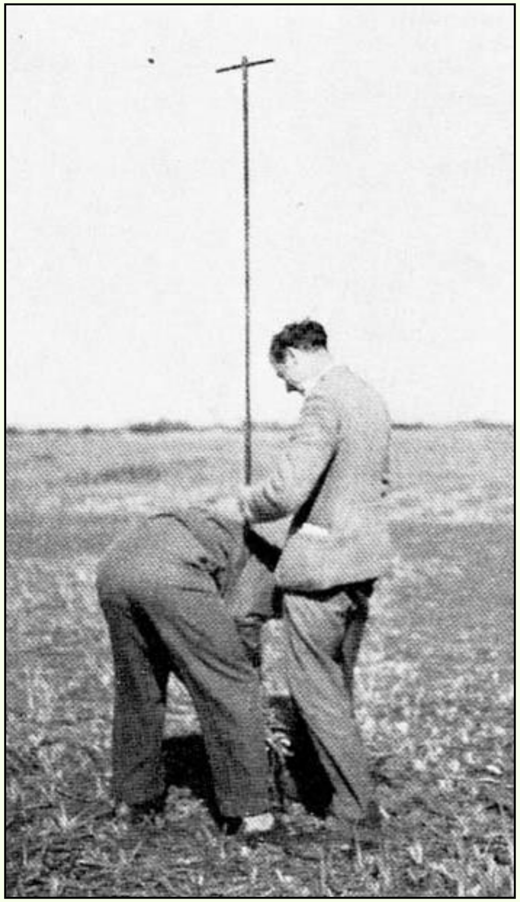
Bill Watts in Bermuda

Wide-diameter cores for macrofossil analyses

2 m long, 11 cm diameter
‘Nesje’ piston corer

‘Nesje’ corer on open water;
6 m long core-tube

Coring from a marsh or bog



Hiller peat borer

‘Russian’ corer

11 cm diameter, 2 m long, piston corer and heavy frame; Kråkenes

Shallow sediments

Cores

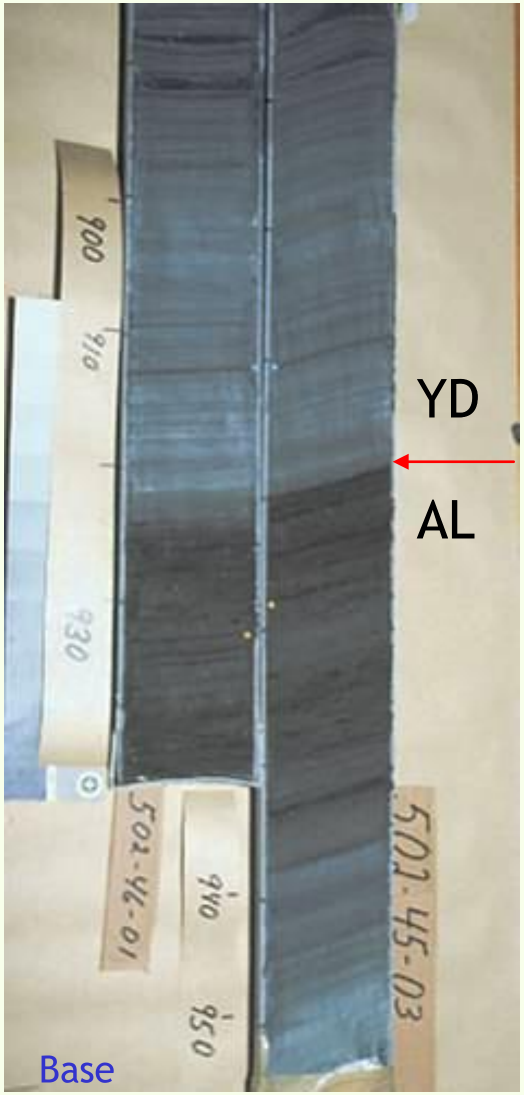
'Russian' core

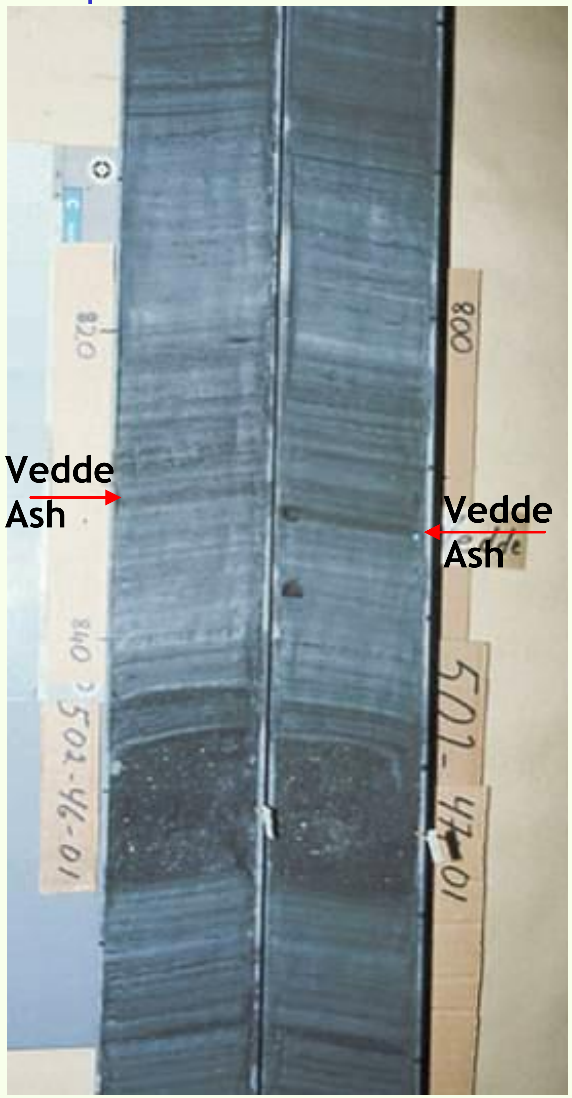
Piston core

Kråkenes Cores Late glacial is 2 metres long

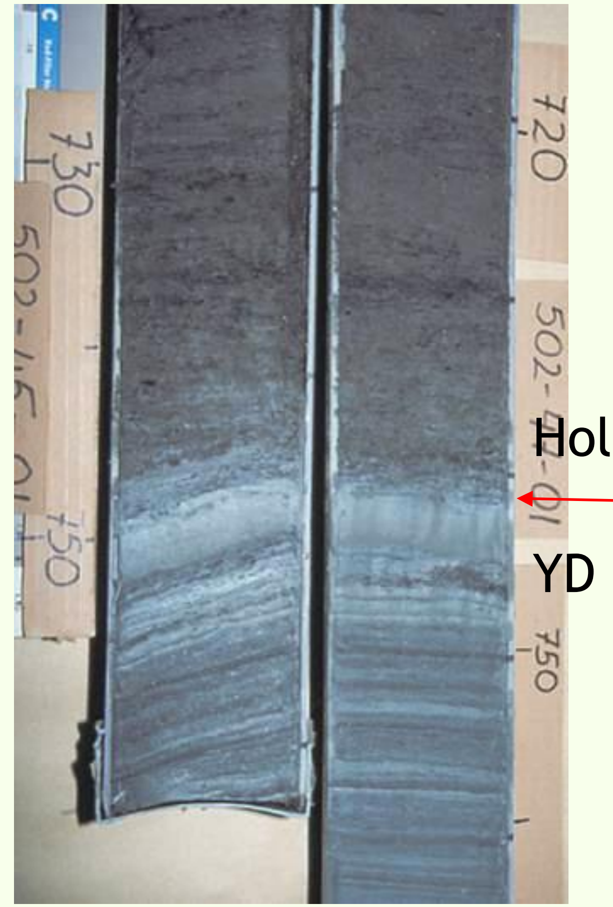
Two parallel cores

11cm diameter piston cores





Top



Allerød/Younger Dryas → Mid Younger Dryas with Vedde Ash → Younger Dryas/Holocene boundary

Site Selection

The deepest point in the middle of a lake is not always an ideal site for macrofossils.

Watts (1978); "an ideal site for macrofossil analysis is a small, deep lake with sloping shores and no marginal reedswamp that would trap macrofossils (cf. Marion Lake), no inflow and outflow streams to create currents and sorting, and a stable water level to prevent re-deposition from shallow-water sediments."

This applies to a temperate lake.

Temperate Lakes

Sheelar Lake with *Quercus* fringe, Florida, USA

Låketjønn, Lindås, Norway

Leaves preserved in the sediments

Characteristics of Arctic/Alpine or Late-Glacial Sites suitable for macrofossil analysis

- Small lakes with steep slopes and small inflowing streams
- Braided river systems
- Buried vegetation

Skardtjørna, Spitsbergen

Small lakes

Lille Kjelevatn, Hardangervidda

An Druim, Eriboll, Scotland

Kråkenes Lake, Norway

Method of Plant Macrofossil Analysis, continued

2. Take sediment samples of known volume, usually ca. $50 cm^3$ but good results can be obtained with $20\text{-}30\ cm^3$.

   Describe sediments (Troels Smith 1955).

   Store cold (4^oC or frozen)

3. If necessary, soak sediment in Na pyrophosphate or dilute NaOH.

4. Sieve: 125 μm mesh, + coarser sieve if necessary.

5. Transfer residue to storage bottle. Keep cool or frozen.

6. Suspend residue in 2 - 3 mm water in small dish. Examine systematically and pick out remains of interest. If too numerous, can be designated ∞ and not picked out. If fairly numerous and hard to catch, can be counted but not picked out.

   If in doubt, pick it out!

Method of Plant Macrofossil Analysis, continued

7. Sort fossils and identify them.
8. Count and record each taxon. Calculate for a basic volume, e.g. 100 cm^3.
9. Store identified material in vials in glycerine + phenol or other fungicide.
10. Tabulate the results.
11. Make a diagram (TILIA + TILIA.GRAPH). From 8, it will be a *concentration* diagram. If sediment accumulation rate is known, can make an *influx* diagram.

Data Presentation

(Wasylikowa, 1986)

1. TABLES of presence or absence, or of numbers
2. ORDINAL VALUES e.g. abundant, frequent, occasional, rare
3. QUANTITATIVE ESTIMATES and DIAGRAMS

   (a) Percentages (Watts & Winter, 1966)

   (b) Absolute numbers

Concentration	Number per unit volume (volumetric samples)
Influx	Number per unit area per year calculated from concentration and known sedimentation rate

Sources of Error

1. WRONG DETERMINATIONS - important to keep material
2. WRONG INTERPRETATION - matter for discussion
3. CONTAMINATION
   - (a) Dirty sampling
   - (b) Long distance dispersal from other vegetation zones (Spicer & Wolfe, 1987, Trinity Lake, USA; Burrows, 1980, New Zealand)
   - (c) Redeposition e.g. Interglacial material redeposited in full glacial deposits, reworking from shallow water (e.g. Warner & Barnett, 1986)
   - (d) Sorting during deposition, e.g. streams (Holyoak, 1984, Spitsbergen); lake (Glaser, 1981, Alaska); filtering by marginal vegetation (Wainman & Mathewes, 1990, Marion Lake)
4. THE SIGNIFICANCE OF ABSENCE

Significance of Absence

(Nowak *et al*. 2000)

Woodrat middens. Woodrats (packrats) collect seeds etc. and bring them to their nests where they are preserved in desert conditions
Could be applied to sediments

Question: is the organism really absent or just not represented?

4 Categories

True Presence		False Presence		False Absence		True Absence	
Fossil +	Veg +	Fossil +	Veg -	Fossil -	Veg +	Fossil -	Veg -

1. Paired modern veg with modern midden
2. Paired fossil middens of same age

Assumed same age and vegetative source, and woodrat behaviour

Computed probability of the 4 categories

Mean probability of false absence = 7-11%

Reasons: Cannot identify to species

Random chance (less with larger samples)

Past vegetation might not have been the same as modern

Selectivity of woodrats

Woodrat (packrat) behaviour affects representation of plant species

Lesser and Jackson (2011) Paleobiology 37

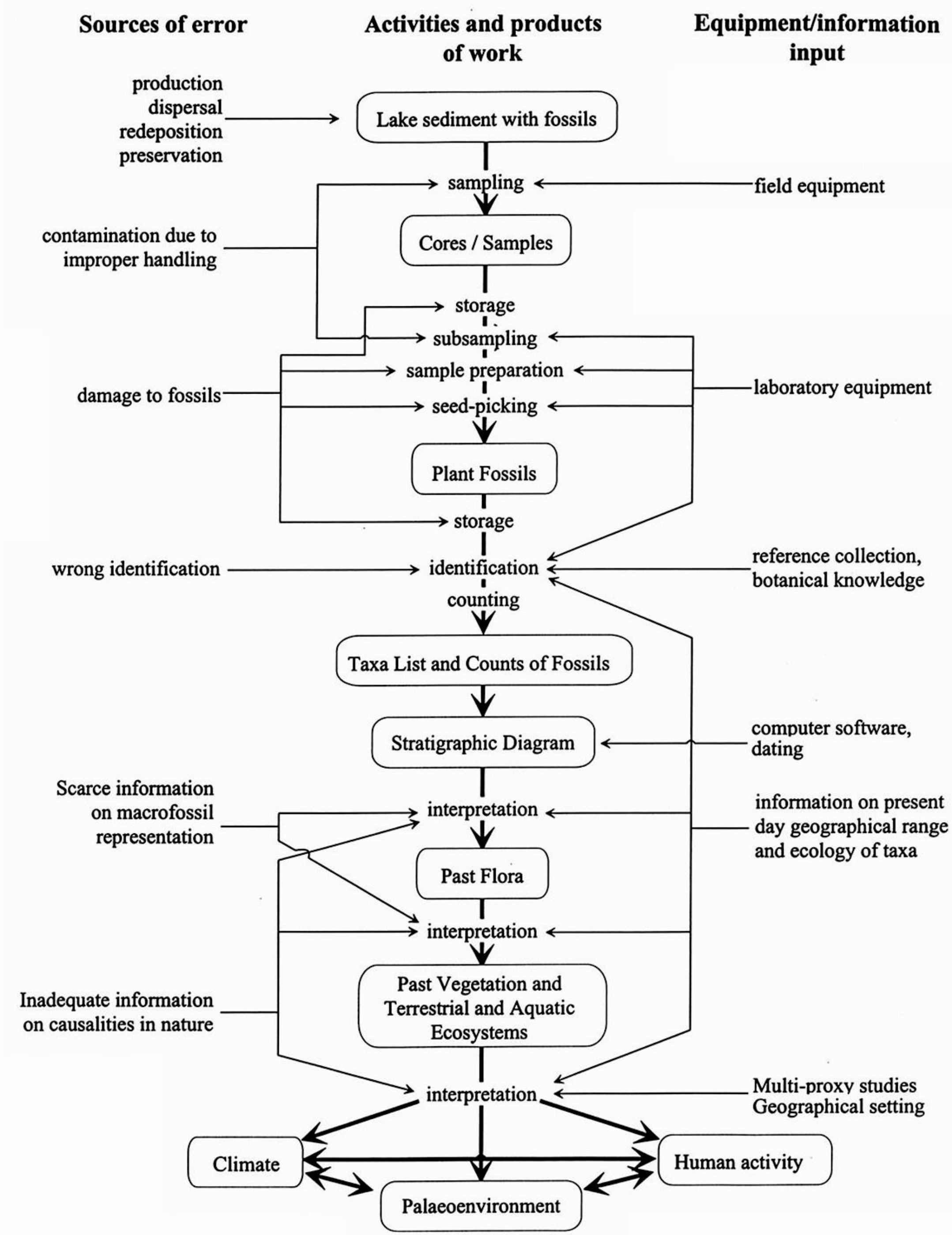
Neotoma cinerea

Woodrats in SE Colorado forage mostly within 20-30 m of their midden (nest).
Therefore only plants that are within this range are likely to be collected. So absence in the midden could mean that the species was growing too far away or else that it was very rare or absent in the vegetation

Pinus ponderosa was consistently present if trees were within 30m but beyond that its presence was very much reduced. *Pinus edulis* showed a similar pattern, but woodrats also collected it from further away.

Therefore, the behaviour and preferences of woodrats combined with the abundance of the species is important in assessing the representation of species in woodrat middens.

Summary



Birks (2001, 2007)