

**Fig. 1.1** Some mechanical systems in monocotyledons. (a) A fleshy leaf of *Gasteria*; note lack of sclerenchyma in the section (b). (c) A mesic monocotyledon, C–D shows one type of sclerenchyma arrangement in leaf TS; E–F shows three of the main types of sclerenchyma arrangements in the stem TS; G–H shows a typical root section in which most strength is concentrated in the centre. en, endodermis; gt, ground tissue, which may be lignified.

**Fig. 1.2** Some mechanical systems in dicotyledons. A schematic plant with position of sections indicated. Liquid pressure occurs in turgid cells through the plant. Collenchyma is often conspicuous in actively extending regions and petioles. Sclerenchyma fibres are most abundant in parts that have ceased main extension growth. Xylem elements with thick walls have some mechanical function in young plants and give a great deal of support in most secondarily thickened plants.

**Fig. 1.3** *Juncus bufonius* leaf (TS,  $\times 48$ ), showing one row of vascular bundles, with the xylem poles directed towards the adaxial surface. Note the marginal sclerenchyma strands and the difference in size between adaxial and abaxial epidermal cells. Each small vascular bundle has a parenchyma sheath; in larger bundles sclerenchyma caps interrupt the parenchyma sheath.

**Fig. 2.1** Vegetative meristems. (a) Low-power diagram LS of *Rhododendron* apex,  $\times 15$ . (b) Detail of (a),  $\times 218$ . The second layer may be ‘tunica’ but has some periclinal division, as does that in (c), *Syringa*  $\times 218$ . (d) *Equisetum*  $\times 218$  has an apical cell and not a group of meristematic cells.

**Fig. 2.2** *Codonanthe*: (a) low-power diagram of details of apex of shoot shown in (b). Notice the very early division of cells in the adaxial epidermis of the leaves, leading to the formation of a multiple epidermis. (b)  $\times 248$ .

**Fig. 2.3** *Coleus* shoot apex, LS. Arrow = leaf buttress. C  $\times 100$ .

**Fig. 2.4** (a) Generalized monocotyledon root, diagram to show location of various zones. Root apex, LS, in *Allium* sp.; (b) low-power diagram to show location of various cell zones in (c) ( $\times 109$ ). a, apical meristem; c, column; ca, calyptragen; ce, central cylinder; ci, central cylinder initials; co, cortex; coi, cortex initials; pr, protoderm initials; r, root cap.

**Fig. 2.5** Endogenous development of a lateral root, in TS. c, cortex; ca, small cavity ahead of developing lateral root formed by lysis of cortical cells; en, endodermis; l, lateral root; p, pericycle; ph, phloem; x, xylem.

**Fig. 2.6** Diagram of fusiform cambial initials (f) and ray initials (r).

**Fig. 2.7** *Dianthus* (carnation) cutting. Adventitious roots will develop from the split sides. n, node.

**Fig. 2.8** *Ribes nigrum*, TS of sector of outer part of stem to show deep-seated cork cambium,  $\times 218$ . ck, cork; cu, cuticle; p, phellogen; pd, phellogen. Note cluster crystals in cortical cells.

**Fig. 2.9** Diagram of TS of conifer log showing resumed continuity of growth rings after lateral branch has been cut off.

**Fig. 2.10** Chip bud graft. (a) Chip with bud; (b) stock prepared; (c) chip inserted behind small flap of bark (f), ready for taping.

**Fig. 2.11** Twigs grafted across a damaged area of bark on a tree trunk.

**Fig. 3.1** *Alnus glutinosa*: SEM photograph of secondary xylem showing transverse and tangential longitudinal faces. af, fibres in axial system of cells; av, vessel of axial system; p, perforation plate (scalariform); r, uniseriate ray of radial system.  $\times 100$ .

**Fig. 3.2** (a) Transverse, (b) radial longitudinal and (c) tangential views of the wood of *Alnus nepalensis*. Note the narrow-diameter vessels. These have inclined compound scalariform-reticulate perforation plates. The vessels are interspersed with narrow tracheids and parenchymatous elements. Rays are of variable length and uniseriate. a,  $\times 70$ ; b and c,  $\times 250$ .

**Fig. 3.3** (a) Transverse, (b) radial longitudinal and (c) tangential longitudinal views of the wood of *Pinus sylvestris*. Rays are variable, from one to many cells high and of variable width. Wider rays may be associated with resin canals. a,  $\times 75$ ; b and c,  $\times 250$ .

**Fig. 3.4** Some types of cross-field pits in conifers. (a) Piceoid, e.g. *Picea*, *Larix*. (b) Cupressoid, found in most Cupressaceae and *Taxus*. (c) Taxodioid, e.g. Taxodiaceae, *Abies*, *Cedrus*, some *Pinus*. (d) Diagram showing location of cross-field pits (c) where ray and tracheid walls are adjacent. (e) Some *Pinus* spp. have large ‘window’ pits. r, ray; t, tracheid.

**Fig. 3.5** A range of vessel element perforation plates and wall pitting. (a) *Camellia sinensis* scalariform. (b) *Liriodendron tulipifera*, scalariform; pits opposite. (c) *Sambucus nigra*, simple plate, pits alternate. (d) *Euphorbia splendens*, simple plate, pits alternate. (e) *Scirpodendron chaeri*, scalariform plate, pits opposite (from primary xylem). All  $\times 218$ .

**Fig. 3.6** *Tilia europaea*, LS, tertiary spirals on vessel element wall. SEM,  $\times 3000$ .

**Fig. 3.7** *Ockeroma pyramidalis*, wood TS; note the vessel, the thin-walled fibres and abundant parenchyma.  $\times 200$ .

**Fig. 3.8** *Guaiacum officinale* wood TS; note the numerous thick-walled fibres and the scattered parenchyma.  $\times 200$ .

**Fig. 3.9** *Quercus robur*, wood TS and TLS, SEM. Note wide spring-formed vessels (s) and narrow later-formed vessels (n). Numerous uniseriate rays can be seen (u). Small parenchyma cells of the axial system occur in more or less tangential bands among the fibres (f). A growth ring (g) is shown, as is vascentric parenchyma (v).  $\times 60$ .

**Fig. 3.10** Some ray types in TLS. (a) *Alnus glutinosa*, uniseriate, homocellular, all cells of procumbent type. (b) *Swietenia mahagoni*, multiseriate, heterocellular, with upright cells at margins and procumbent cells between. (c) *Sambucus nigra*, biseriate, with tall uniseriate portions, heterocellular. (d) *Musanga cecropioides*, multiseriate, heterocellular, procumbent and upright cells together in body of ray, upright cells at margins. All  $\times 72$ .

**Fig. 3.11** (a) Fibre, (b) tracheid and (c) vessel, contrasted; intermediate cell types exist between each.

**Fig. 3.12** Wood from members of the Fagaceae, TS. (a) *Quercus brandisiana*; (b) *Litbocarpus conocarpa*; (c) *Nothofagus solandri*. (a) Like *Q. robur* (Fig. 3.9) has uniseriate and multiseriate rays, although only part of a multiseriate ray can be seen to the left. (b) and (c) have only uniseriate rays. (a) and (b) have tangential bands of axial parenchyma. Tyloses are present in (a), and tracheids accompany the vessels in (a) and (b). Fibres in (a) and (c) are strongly thickened. (c) Has consistently narrower vessel elements than (a) or (b), and has short radial vessel multiples. Fagaceae constitute a very natural family. There are two main anatomical groups as far as wood is concerned. (a) and (b) represent one group, (c) the other. All  $\times 130$ .

**Fig. 3.13** *Platymitra siamensis*, Annonaceae, TS. Vessels diffuse, porous; rays uniseriate and multiseriate; axial parenchyma in uniseriate tangential bands; fibres thick-walled.  $\times 130$ .

**Fig. 3.14** *Carpinus betulus*, Carpinaceae. Vessels diffuse, porous, in long radial multiples. Rays uniseriate (aggregate rays also occur, but are not shown). Axial parenchyma is seen in poorly defined, interrupted tangential bands, the cells have dark contents.  $\times 65$ .

**Fig. 3.15** *Laurus nobilis*, Lauraceae. Vessels diffuse porous, narrow, solitary or in small multiples, perforation plates simple. Rays uniseriate and multiseriate, heterocellular. Fibres septate. (a) TS; (b) TLS; both  $\times 65$ .

**Fig. 3.16** *Aesculus pavia*, compound sieve plate.  $\times 720$ .

**Fig. 3.17** (a) Diagram to show location of phloem fibres in *Tilia* stem TS. (b) *Malvaviscus arboreus*,  $\times 218$ . (c) *Gossypium* sp.,  $\times 218$ . c, cambium; co, cortex; f, phloem fibres; p, functional phloem; r, ray; t, tannin; x, xylem.

**Fig. 4.1** Roots in TS. (a–c) *Juncus acutiflorus*: (a) diagram; (b) lacunate cortex,  $\times 54$ ; (c) root hair,  $\times 218$ . (d–f) *Cattleya granulosa*: (d) diagram; (e) velamen,  $\times 68$ ; (f) ‘solid’ cortex,  $\times 68$ .

**Fig. 4.2** *Stratiotes*, part of root TS, SEM photograph, note air spaces in the cortex,  $\times 75$ .

**Fig. 4.3** Root endodermis *Iris* sp. (a) Low-power, sector of root TS,  $\times 20$ . (b) Detail from (a),  $\times 290$ . c, cortex; en, endodermis; ep, epidermis; ic, inner cortex; oc, outer cortex; p, passage cell; pe, pericycle; ph, phloem; px, protoxylem.

**Fig. 4.4** Some root vascular systems. (a) *Ranunculus acris* tetrarch root. (b) *Echinodorus cordifolius* diarch root. (c,d) *Juncus acutiflorus* polyarch root. ca, Casparian strip; en, endodermis; mx, metaxylem; p, passage cell; peri, pericycle; ph, phloem; px, protoxylem. (a,b,d,e),  $\times 300$ ; (c),  $\times 35$ .

**Fig. 4.5** *Ranunculus* (buttercup) root TS illustrating the relatively simple structure of a young dicotyledonous root. The xylem is tetrarch, and four strands of phloem alternate with the protoxylem. This root is just beginning to undergo limited secondary growth, with a cambial zone.  $\times 100$ .

**Fig. 4.6** *Iris* root TS, showing a very prominent endodermis – seen here as the layer of cells with striking thickening of the radial and inner tangential walls. The endodermis is the innermost layer of the cortex. The wall thickening forces water and other molecules to take a symplasmic route from the cortex to the stele, and vice versa, through the unthickened passage cells.  $\times 350$ .

**Fig. 4.7** Portion of a *Zea mays* root in this micrograph illustrates the arrangement of the separation of the cortical from the stelar tissues. *Zea*, like all primary roots, has an endodermis that forms the boundary between the cortex and the stele, and a layer immediately beneath this, the pericycle, that is the outermost layer of the stele. EN, endodermis; MX, metaxylem; Per, pericycle; PX, protoxylem; S, stele.  $\times 500$ .

**Fig. 5.1** Stem TS of *Zea mays*. Maize is a monocotyledonous plant, and resembles other grasses in the arrangement of tissues in the stem leaf and root. The stems of monocotyledons generally have a single ring of vascular bundles immediately beneath the epidermis, and internal to this a system of vascular bundles that are scattered throughout the pith.  $\times 225$ .

**Fig. 5.2** *Trifolium* (red clover) stem TS: a mature stem at the end of primary growth, that is, the vascular bundles contain very limited amounts of secondary xylem and secondary phloem. The cortex is very narrow and is composed of chlorenchyma. The cortex is separated from the vascular bundles and the underlying pith by a starch sheath. The pith is parenchymatous.  $\times 125$ .

**Fig. 5.3** Hypodermis in stem of *Salvadora persica*. c, cortex; h, hypodermis.  $\times 290$ .

**Fig. 5.4** Vascular bundle types from stems. (a) *Cucurbita pepo*, diagram of bicollateral bundle.  $\times 15$ . (b) *Piper nigrum*, diagram of collateral bundle; cambium remains fascicular.  $\times 15$ . (c) *Chondropetalum marlotbii*, detailed drawing of collateral bundle, lacking cambium.  $\times 110$ . (d) *Juncus acutus* detailed drawing of amphivasal bundle.  $\times 220$ . c, cambium; scl, sclerenchyma.

**Fig. 5.5** Albuminous cells in gymnosperm phloem, *Acmopyle pancheri*. a, albuminous cell; r, ray; s, sieve cell. TS,  $\times 290$ .

**Fig. 5.6** Diaphragm cells in leaves of Cyperaceae. (a) *Becquerelia cymosa*. (b) *Mapania wallichii*. (c) *Chorisandra enodis*. (d) *Mapaniopsis effusa*. (e) *Scirpodendron chaeri*. All  $\times 218$ .

**Fig. 6.1** Some possible evolutionary pathways leading to variations in vascular bundle arrangements in leaves. See text for fuller commentary. (a) One row of bundles; adaxial and abaxial surfaces distinct. (b) Adaxial surface much reduced. (c) Smaller adaxial surface, leaf becoming cylindrical. (d) Loss of adaxial surface, leaf cylindrical, bundles in one ring, but ‘marginal’ bundles still distinct (m). (e) Lateral compression, leaf of this type could arise from (d) or from (f), where the adaxial surface is progressively lost. (g) Could arise from secondary dorsiventral compression of the form in (d).

**Fig. 6.2** Diagram of vascular bundle pair in *Thurnia sphaerocephala*, leaf. The small bundle is inverted so that the phloem poles (ph) of the pair are opposite one another. TS,  $\times 57$ .

**Fig. 6.3** *Ilex aquifolium* leaf TS and surface. (a) Low-power ( $\times 22$ ) diagram of midrib region, A–B and C–D indicate where detailed drawings (b) and (c) were taken. (b) Detail of midrib. TS,  $\times 130$ . (c) Detail of lamina. TS,  $\times 130$ . (d) Abaxial surface.  $\times 200$ . a, air space; ab, abaxial epidermis with thick outer wall; ad, adaxial epidermis with thick outer wall; cr, crystal; h, hypodermis; m, midrib bundle; p, phloem; pm, palisade mesophyll; s, sclerenchyma; sm, spongy mesophyll; st, stoma; vb, vascular bundle; x, xylem.

**Fig. 6.4** Anoptal contrast, *A. branddraaiensis*, the granular interface between the cuticle and cell wall makes interpretation of the cuticular pattern difficult.  $\times 400$ .

**Fig. 6.5** Cuticular patterns are more easily seen using the scanning electron microscope. (a) Low power view ( $\times 50$ ) of *Aloe raubi*  $\times$  *A. darwei* showing distribution of stomata. (b) *Gasteria lutzii*  $\times$  *Aloe tenuior* var. *rubra*. (c) *Haworthia cymbiformis*. Note that the rim to the stomatal pore is four-lobed in the hybrid plants, an *Aloe* characteristic. *Haworthia* belongs to the group of very succulent species within the genus, and has lobes which are fused into a cylindrical collar. (b, c)  $\times 600$ .

**Fig. 6.6** *Aloe lateritia* var. *kitaliensis* wax flakes on the four lobes surrounding a stoma. The guard cells are deeply sunken and can just be seen.  $\times 2200$ .

**Fig. 6.7** Monocotyledonous leaf surfaces. (a) *Phalaris canariensis*,  $\times 240$ . (b) *Kniphofia macowanii*,  $\times 80$ , note cuticular pattern. (c) *Arundo donax*,  $\times 120$ , note microhairs. (d) *Clintonia uniflora*,  $\times 70$ . (e) *Smilax hispida*,  $\times 150$ . (f) *Gloriosa superba*,  $\times 54$ , note elongated costal cells over vein and cells with sinuous walls between veins (intercostal cells). m, microhair; p, prickle hair; si, silica body.

**Fig. 6.8** Dicotyledonous leaf surfaces (abaxial): (a) *Acacia alata*; (b) *Aerva lanata*; (c) *Plumbago zeylanicum*; (d) *Cassia angustifolia*. All  $\times 120$ .

**Fig. 6.9** *Gasteria retata*, leaf surface, showing very thick anticlinal cell walls and small lumina (l).  $\times 145$ .

**Fig. 6.10** (a) Diagram of ratios of height to width; note how difficult it is to judge these by eye. (b)–(h) Epidermis of selected plants in TS. (b) *Gasteria retata*, note the thick outer wall and the outer part of the anticlinal walls. (c) *Dielsia cygnorum*, note that some cells are larger than

others. (d) *Elegia parviflora*, note the double epidermis. (e) *Cistus salvifolius*. (f) *Gloriosa superba*. (g) *Pinus ponderosa*, note the very thick walls. (h) *Thamnochortus scabridus*, note the wavy anticlinal walls; pits are also visible.  $\times 145$ .

**Fig. 6.11** Adaxial leaf surfaces, showing various stomatal types. (a) *Chrysanthemum leucanthemum*, anomocytic.  $\times 109$ . (b) *Justicia cydonifolia*, diacytic.  $\times 218$ . (c) *Plumbago zeylanicum* anisocytic.  $\times 218$ . (d) *Convolvulus arvensis*, paracytic. Note elongated cells over veins.  $\times 109$ . (e) *Acacia alata*, paracytic.  $\times 218$ .

**Fig. 6.12** Two routes for formation of the paracytic type of stoma. In (a)  $\rightarrow$  (b)  $\rightarrow$  (c) guard cells are derived from the cells flanking the guard cell mother cell. In (a)  $\rightarrow$  (b)  $\rightarrow$  (d) the guard mother cell divides to produce two cells, each of which divides once more. g, guard cell; m, guard mother cell; s, subsidiary cell.

**Fig. 6.13** *Limonum vulgare*, TS of salt gland from leaf. c, cup cell; e, excretory cell; p, pore; t, tannin-filled cells.  $\times 330$ .

**Fig. 6.14** Hairs in Centrolepidaceae (a)–(c) and Restionaceae (d)–(g). (a, b) *Aphelia cyperoides*.  $\times 75$  and  $\times 150$  respectively. (c) *Centrolepis exserta*.  $\times 75$ . (d) *Thamnochortus argenteus*.  $\times 218$ . (e) *Loxocarya pubescens*.  $\times 218$ . (f, g) *Leptacarpus tenax*. Surface view,  $\times 113$ ; longitudinal section,  $\times 120$ .

**Fig. 6.15** (a) *Mentha spicata*, range of hair types. (b) *Corylus* hair (*Corylus* also has multicellular outgrowths). (c) *Origanum vulgare* (marjoram) hair and sunken gland. (d) *Cistus salvifolius*, range of hair types, one dendritic, the other glandular. All  $\times 200$ .

**Fig. 6.16** Glandular hairs. (a) *Mucuna*, brittle, sharp hair containing irritant oil droplets.  $\times 145$ . (b, c) *Urtica dioica*: (b) low-power hair on multicellular base,  $\times 20$ ; (c) fragile, sharp tip which can be broken off easily,  $\times 290$ . (d) *Salvia officinalis*, multicellular and bicellular hairs.  $\times 290$ . (e) *Justicia*.  $\times 290$ . (f) *Convolvulus*.  $\times 145$ .

**Fig. 6.17** Non-glandular hairs. (a) *Salvia officinalis*.  $\times 220$ . (b) *Convolvulus floridus*.  $\times 108$ . (c) *Coldenia procumbens*.  $\times 220$ . (d) *Justicia*.  $\times 220$ . (e, f) *Trigonobalanus verticillata*.  $\times 220$ . (g) *Verbascum bombiciforme*.  $\times 54$ . (h, i) *Artemisia vulgaris*,  $\times 220$  and  $\times 300$ , respectively.

**Fig. 6.18** *Pariaria bicolor*, showing bulliform and fusoid cells. (a) Low-power ( $\times 54$ ) diagram of leaf TS, to show location of (b), detail drawing,  $\times 218$ . a, arm cells of mesophyll; b, bulliform cells; f, fusoid cell (typical of certain bamboos); scl, sclerenchyma girders.

**Fig. 6.19** *Clintonia uniflora*, paradermal views (through the epidermis) of arm cells, part of the spongy mesophyll (stippled). Note large air spaces between the cells. (a) Abaxial,  $\times 115$ ; (b) adaxial,  $\times 80$ .

**Fig. 6.20** Strengthening tissue in the leaf, as seen in TS. Sclerenchyma in *Agave franzoninii* (a, b), *Aegilops crassa* (c, d), *Phalaris canariensis* (e). (a) Outline of leaf TS to show location of diagram (b,  $\times 40$ ). (c) Leaf margin,  $\times 109$ . (d, e) Vascular bundles and their associated bundle sheaths and girders. (d)  $\times 109$ ; (e)  $\times 230$ . adg, adaxial sclerenchyma girder; abg, abaxial sclerenchyma girder; c, chlorenchyma; is, inner bundle sheath; ms, marginal sclerenchyma; mx, metaxylem; os, outer bundle sheath; p, prickle hair; ph, phloem; vb, vascular bundle; x, xylem.

**Fig. 6.21** *Pinus ponderosa*, plicate mesophyll cells from TS.  $\times 145$ .

**Fig. 6.22** Selected sclereids from leaves. (a) *Olivacea radiata*. (b, c) *Olea europaea*. (d) *Camellia japonica*. All  $\times 290$ .

**Fig. 6.23** Crystals, cystolith and tannin and latex cells. (a) Styloid crystal, typical of many Liliaceae. (b) *Acacia alata*, crystals from leaf. (c) Cluster crystals in *Passiflora foetida* leaf. (d) *Ficus elastica*, leaf TS showing cystolith; dark cells contain latex. (e) *Oscularia deltoidea*, leaf TS with large tanniniferous idioblasts (t) and raphides, (r). All  $\times 125$ .

**Fig. 6.24** Various silica bodies. (a) *Cymophyllus fraseri* (Cyperaceae) leaf TS. Note location of silica bodies (si) in epidermal cells above sclerenchyma girder.  $\times 218$ . (b) *Aegilops crassa* (Poaceae) abaxial leaf surface. p, prickle hair; si, silica body; st, stoma.  $\times 109$  (c–h) Isolated silica bodies. (c) *Zea mays* (Poaceae).  $\times 200$ . (d) *Bambusa vulgaris* (Poaceae).  $\times 200$ . (e) *Agrostis stolonifera* (Poaceae).  $\times 200$ . (f) *Evandra montana* (Cyp.).  $\times 200$ . (g) *Cyperus diffusus* (Cyp.).  $\times 200$ , first body in surface view, second in side view. (h) Typical of many palms and Restionaceae.  $\times 300$ .

**Fig. 6.25** SEM photograph of a fragment of chaff from one of the Gramineae, found in fragments of a bell mould from ruins at Cheddar. Note the outline of silica bodies.  $\times 1000$ .

**Fig. 6.26** Aspects of Hickey's classification system. Many species have first order lateral veins that emerge from the midrib vein, which then arc outwards and upwards towards the lamina margin, without terminating at the leaf margin. This is defined as eucamptodromous. In (b) the first order lateral veins arc outwards and upwards from the midrib, and terminate at the leaf margin, where their endings often form teeth. This is defined as simple craspedodromous. In (c) the first order lateral veins overarch beneath the leaf margin, forming a primary interconnected network. This is defined as brochidodromous. In (d) the leaf contains three similar-sized veins, which effectively form three compartments in the leaf. This is an example of an actinodromous leaf. In (f) the first order lateral veins overarch, and extensions continue to the leaf margin, which is serrated in the semicraspedodromous leaf. The first order lateral veins branch several times near the margin of the lamina in the cladodromous leaf illustrated in (g). In reticulodromous leaves, the first order lateral veins branch many times towards the margin of the lamina. In parallelodromous leaves the three orders of lamina vein make up a longitudinal system of parallel veins. In palinactodromous leaves (e) the leaf is dissected at its base into a number of arms. In (d) and (e) each of the basally attached veins is the same size. (Redrawn from Hickey, 1973.)

**Fig. 6.27** *Plumbago zeylanicum*, paradermal view of veins to show open type of venation. Note enlarged tracheids (t) at veinlet ends.  $\times 20$ .

**Fig. 6.28** Micrographs showing the size change relationships between the companion cell and the sieve tube cell in loading, transport and unloading phloem, in *Nymphaoides*. (a) Minor vein in leaf lamina. (b) Phloem in central vascular bundle in the submerged petiole. (c) Phloem strand from a root. Scale bars: (a)  $20\ \mu\text{m}$ ; (b, c)  $10\ \mu\text{m}$ . CC, companion cell; S, sieve tube member; T, tracheary element. (a)  $\times 250$ ; (b, c)  $\times 500$ .

**Fig. 6.29** Bundle sheaths. (a) *Briza maxima*, inner mestome (sclerenchyma) sheath, outer parenchyma sheath, abaxial and adaxial sclerenchyma strands and radiate chlorenchyma.  $\times 120$ . (b) *Gloriosa superba*, parenchyma sheath only.  $\times 120$ . (c) *Cymophyllus fraseri*, parenchyma, followed by mestome sheath and outer parenchyma sheath.  $\times 128$ . (d) *Fimbristylis*, three sheaths, inner parenchyma, followed by mestome sheath and outer parenchyma sheath.  $\times 218$ .

**Fig. 6.30** (a, b) Line drawings based on electron micrographs of typical Panicoid and Pooid leaf blade bundle anatomy. BS, parenchymatous bundle sheath; IS, intercellular space; MS, mestome sheath; PS, parenchymatous (Kranz) sheath; VP, vascular parenchyma cell.  $\times 1000$ .

**Fig. 6.31** Electron micrograph, showing a small transverse vein of *Saccharum officinarum* in transverse view. This vein is surrounded by two sheaths; an outer bundle sheath (BS) and an inner mestome sheath (MS). Bundle sheath mestome sheath interfaces are often associated with a suberin lamella. The vascular tissue consists of metaxylem vessel and associated parenchyma, whilst the phloem contains several sieve tubes and associated parenchyma and companion cells.  $\times 1650$ .

**Fig. 6.32** Line drawings (a–c) showing the basic anatomical features of leaf blade bundle structure in the Cyperaceae. The variation of cell thickness is most notable in the cell walls of the endodermis. Note the distribution of chloroplasts in the border parenchyma and the

presence of large chloroplasts (agrana in some species) in the border parenchyma. Examples are, left: *C. fastigiatus*; *C. esculentus*; *Mariscus congestus*; centre: *C. sexangularis*; *C. pulcher*; *C. acutiformis*; right: *C. albostratus*; *C. textilis*; *C. papyrus*. E, endodermis; IS, intercellular space; PS, parenchyma sheath.  $\times 850$ .

**Fig. 7.1** Floral vasculature of (a) *Gaylussacia frondosa* (Ericaceae) with common bundles and (b) *Nestronia umbellulata* with inverted bundles that give rise to the carpel bundles. DC, dorsal carpel bundles; IB, inverted bundles.

**Fig. 7.2** Surface details of two pollen grains for comparison. A, *Crocus michelsonii*, B, *Crocus vallicola*, both SEM photographs,  $\times 1,000$ .

**Fig. 7.3** *Tradescantia pallida*, pollen grain germinating on stigma. p, pollen grain; pt, pollen tube; s, papilla on stigma. Freeze dried, viewed in SEM,  $\times 1,000$ .

**Fig. 7.4** Fruit wall and seed coat details in TS. (a) *Aesculus hippocastanum*, outer part of fruit wall.  $\times 109$ . (b) *Fagus sylvatica*, outer part of fruit wall.  $\times 109$ . (c) Outer part of seed coat of *Delphinium staphisagria*.  $\times 109$ , note small outgrowths from epidermal cell walls. (d) *Cicer areitinum*, seed coat.  $\times 218$ . (e) *Cola acuminata*, seed coat.  $\times 218$ . (f) *Cucurbita pepo*.  $\times 109$ . c, cells with U-shaped wall thickening; e, epidermis; ep, epicarp; h, hour glass cell; ie, inner epidermis; m, mesocarp; oe, outer epidermis; p, parenchyma; pa, palisade cells; pc, pitted cells; r, reticulate spongy parenchyma; s, sclerenchyma; sl, sclerenchyma layer.

**Fig. 7.5** Transverse sections of the exocarp of the fruits of *Anthemis* showing anatomical variation: (a) *A. perigina*; (b) *A. arvenis*. MS, macrosclerid; SC, slime cell; Scler, sclerenchyma; TI, tracheoidal idioblast. (After J. Briquet 1916.)

**Fig. 7.6** Epidermal slime trichomes on the exocarp of *Matricaria lamellata*. (a) Surface view of a slime trichome cluster. (b) Transverse section of a slime trichome cluster. (c) Longitudinal section of a slime trichome cluster. (After Alexandrov & Savchenko 1947.)

**Fig. 7.7** Transverse sections of the pericarps of two species in the Mint Family. Note the tall palisade like sclereids. (a) *Coleus barbatus*. (b) *Lavandula spica*. EN, endocarp; IE, inner epidermis. (After S. Wagner 1914.)

**Fig. 7.8** Diagrammatic representations of the development of the stony endocarp in fruits from the inner epidermis (IE) and inner hypodermis (IH). (a) From the epidermis only. (b) From the hypodermis only. (c) From the epidermis and the multiple hypodermis. (d) From a multiple epidermis only. (e) From a multiple hypodermis only. (f) From both a multiple epidermis and a multiple hypodermis. Stippling indicates stony layer.

**Fig. 7.9** Examples of ruminant endosperm in (a) *Asimina triloba* and (b) *Hedra helix*.

**Fig. 7.10** Anatomy of the winged seeds of two genera in the Lecythidaceae in transverse section. (a–d) *Couratari asterotrichia*. (a) The whole seed. (b) Transverse section of the whole seed. The areas labelled C and D in (b) are magnified in (c), the seed body, and (d), the seed wing. (e–g) *Cariniana legalis*. (e) The whole seed. (f) From the seed body. (g) From the seed wing. EX, exotesta; MS, mesotesta; EN, endotesta. (Drawings courtesy of Scott Mori.)

**Fig. 8.1** (a) *Aloe somaliensis*, outer part of leaf TS.  $\times 218$ . (b) *Haworthia greenii*, outer part of leaf TS.  $\times 218$ . Note the sunken guard cells (g), the thick cuticle (c) and the thick outer wall to the epidermal cells (e). Both have succulent leaves, with little mechanical tissue.

**Fig. 8.2** *Ammophila arenaria*. (a) Low power, plan leaf TS. (b) Detail of rib (black areas represent thick walled cells). (c) Adaxial epidermis with stoma.  $\times 300$ . (d) Abaxial epidermis with very thick cuticle.  $\times 300$ . s, sclerenchyma; V, vascular bundles; h, hairs; st, stoma.

**Fig. 8.3** (a,b) *Crassula* sp. (c–e) *Senecio scaposus*. (a,c) Plan TS leaf; mechanical tissue absent, central mesophyll cells store water. (b) Detail of outer part of (a). (d) Outer part of (c). (e) Central part of (c). (b,d,e)  $\times 54$ . c, chlorenchyma; h, hair; t, tannin; v, vascular bundle; w, water storage tissue.

**Fig. 8.4** (a,b) *Hakea scoparia*, leaf TS. (c,d) *Leptocarpus tenax*, stem TS. Note sunken stomata (st) in both and abundant strengthening sclerenchyma (s). Hairs (h) cover the *Leptocarpus* and tannin (t) is present in the chlorenchyma of *Hakea*. The pillar cells (p) in *Leptocarpus* divide the chlorenchyma into longitudinal channels. c, chlorenchyma; v, vascular bundle. (a,c)  $\times 15$ ; (b,d)  $\times 120$ .

**Fig. 8.5** *Ecdeiocolea*, outer part of stem. Fibres and sclereids show as lighter cells. This xerophyte has a deeply grooved stem, with stomata on the flanks of the grooves. Note the strong development of hypodermal fibres to the outer side of the thin-walled chlorenchyma. TS in polarized light,  $\times 550$ .

**Fig. 8.6** Small parts of mesophyte leaves (lamina) in TS. (a) *Arbutus unedo*.  $\times 109$ . (b) *Corylus avellana*.  $\times 120$  (c) *Olea europaea*.  $\times 109$ . c, cluster crystal; h, hair; p, palisade; sc, sclereid; sp, spongy mesophyll; st, stoma; v, vascular bundle.

**Fig. 8.7** *Codananthe* sp. Part of leaf TS showing multiple epidermis (m), a single palisade (p) and a large quantity of spongy mesophyll (s).  $\times 102$ .

**Fig. 8.8** *Limmophyton obtusifolium*, part of midrib, TS. (a) Diagram showing large air spaces around central vascular complex.  $\times 15$  (b) Laticifer.  $\times 110$ . (c) Central vascular tissue.  $\times 200$ . a, air space; l, laticifer; lp, loose palisade chlorenchyma; p, phloem; t, tracheary element.

**Fig. 9.1** Some differences between Restionaceae, Ecdeiocoleaceae and Anarthriaceae. (a,b) Restionaceae. Stem TS, most species have the general anatomy as shown in (a), with a continuous parenchymatous sheath; in some genera the sheath is interrupted by extensions from the sclerenchyma cylinder, as in (b). No vascular bundles occur in the chlorenchyma in all but one or two species. None of the species has hypodermal fibres or lacks a sclerenchyma cylinder as exhibited by Ecdeiocoleaceae (d). Anarthriaceae (c) differ in addition by having subepidermal fibre strands associated with vascular bundles; they may also have a sclerenchyma cylinder. Neither Anarthriaceae nor Ecdeiocoleaceae has a parenchyma cylinder. c, chlorenchyma; e, epidermis; p, parenchyma cylinder (interrupted in (b)); s, sclerenchyma.

**Fig. 9.2** Group of stomata in abaxial surface of *Eleutharrhena macrocarpa* (a). In (b), *Pycnarrhena pleniflora*, the stomata are scattered over the abaxial leaf surface. Both SEM,  $\times 300$ .

**Fig. 9.3** Shoot of potato from meat pie, mistaken for something worse!

**Fig. 9.4** Starch grains: (a) potato; (b) maize; (c) oat; (d) rice; (e) pea; (f) banana; (g) wheat. (h) Starch grains in xylem ray tissue of *Fabrisinapis*, SEM. (a–g)  $\times 200$ ; (h)  $\times 3000$ .

**Fig. 9.5** *Acer pseudoplatanus* roots grown under different conditions (TS). (a) From normal and (b) from waterlogged soils. (c) Normal trunk wood. All  $\times 130$ .

**Fig. 9.6** Charcoal of *Alnus glutinosa* from Romano-British London. Details of the structure are well preserved, particularly the scalariform

perforation plate.

**Fig. 9.7** An Egyptian sandal from antiquity, found to be made from papyrus (*Cyperus papyrus*) and palm species of *Borassus*.

**Fig. 10.1** A simple apparatus for producing a steam jet to soften wood prior to sectioning.

**Fig. 10.2** Preparing a cork for holding material to be sectioned A–D for TS, E–H for LS; note that the oblique cut in cork E helps to prevent cylindrical stems from being released from the cork on clamping.

**Fig. 10.3** The wrong way to cut cork for making LS of material. When clamped, the cork curls back and the specimen is released.

**Fig. 10.4** Long leaves can be folded several times before sectioning. Several sections will then be obtained with each cut.

**Fig. 10.5** Drawing a curled section onto a microscope slide.

**Fig. 10.6** Preparing leaf surface for microscopy by the scraping method.

**Fig. 10.7** Selection of standard levels for comparative work. For wood, a cube is prepared so that it will provide working transverse, tangential longitudinal and radial longitudinal faces.

**Fig. A2.1** A screen dump showing the contents page of *The Virtual Plant*. Note the Presentation Files, Digital Plant Anatomy and The FactFiles links.

**Fig. A2.2** Starch grains, iodine-potassium iodide negative image.

**Fig. A2.3** A typical *Virtual Plant* roadmap, from which elements of the exercise may be selected in any order. It illustrates the specimens which have been included in this exercise. Clicking on these will short cut the reader to the specimen concerned. So, if you want to look at the *Trifolium* stem, simply double click on the image. All images are shown as 24-bit colour thumbnails for web viewing.

**Fig. A2.4** Screenshot of the *Nymphaea* exercise.

**Fig. A2.5** Screenshot of the *Nymphaea* exercise, detailing the anatomy of the waterlily.

**Fig. A2.6** Screenshot of the *Nymphaea* exercise.

**Fig. A2.7** Illustration of secondary wood structure in this *Virtual Plant* exercise.

**Fig. A2.8** Detail page with information relating to a cross-section of the wood of the conifer *Fitzroya cupressoides*.

**Fig. A2.9** Vanishing-point reconstruction in 3D.

**Fig. A2.10** Screenshot of the *Oldenburgia* exercise.

**Fig. A2.11** Screenshot of a *Nymphaea* vascular bundle, from plant adaptiveness.

**Fig. A2.12** Screenshot of leaf anatomy from the plant adaptiveness exercise.

**Fig. A2.13** Screenshot of *Crassula* from the plant adaptiveness exercise.

**Fig. A2.14** Typical screenshot from the Glossary – the glossary definition for an endodermis.

**Fig. A2.15** Screenshot of the digital plant anatomy pages.

**Fig. A2.16** Screenshot of the digital plant anatomy pages, showing 12 thumbnails of leaf images.

**Fig. A2.17** Screen shot of index to PowerPoint Presentations.

**Fig. A2.18** Screen shot of the Factfile Index.