CHAPTER 9

Economic aspects of applied plant anatomy

Introduction

Many of the applied aspects of plant anatomy have been referred to in the previous chapters, but some do not fit well into descriptive text. We have therefore amplified some of these examples in this chapter and introduced new ones drawn from experience at our laboratories. In writing this chapter, we have had to be very selective – a whole book could be written on this subject alone – but we hope that the following interesting examples will serve to show the wide range of applications to which knowledge of plant anatomy can be put. Anatomy is particularly useful in taxonomically identifying disassociated plant parts whether those parts be leaves, roots, stems, fruits or seeds of living or fossil plants.

Identification and classification

It is not always appreciated how important it is to be able to give the correct name to a plant. Cytologists, geneticists, ecologists, plant breeders, chemists and anyone using plants for medicine, food, furniture, fabric or building material, or those conducting molecular research on plants, must be able to identify their source material or they may not be able to continue with their work. They would not know if further plant specimens or timbers were from the same species that they started with; their results and applications would be unpredictable; and the foundations for sound scientific botanical research would be undermined. Identification depends on a stable, logical, usable and basically sound system of classification. At present, many plants can be identified adequately if all organs, for example flowers, fruits, leaves, etc., are present. The traditional herbarium methods can then be applied. However, there are very large numbers of plants which have been classified using macromorphological features alone.

A more natural, accurate and reliable classification results from also taking into account features of morphology, anatomy, palynology, biochemistry, population studies and so on. This ideal can rarely be attained, but once the 'alpha' taxonomy of a family has been studied, the synthetic approach should be used for revisions, as has been done now for a considerable time. Should revisions based entirely on hand-lens studies of herbarium material be outlawed? Certainly not, but on the other hand once done the incorporation of anatomical and other data may well lead to better and easier identifications and classification.

Taxonomic application

Systematic anatomy has a long history. From the early days of microscopy it has fascinated people who saw first the wide range of variations in plant anatomy, then began to recognize patterns of similarity, and eventually realized that in many instances, plants sharing large numbers of anatomical characters in common were probably closely related. This led to a series of attempts to work through the plant kingdom in an orderly way, and record what was present. For the angiosperms, in particular, this process led to the production of series of books. The work was started in earnest on the dicotyledons, and when the first review was done the monocotyledons were started. In the present day, the work on dicotyledons is being revised, and completion of the first run through the monocotyledons is in progress. There is an enormous number of papers on angiosperm anatomy, and before setting out on new work it is sensible to find out what has already been published. In addition to the normal search engines, it is worth looking at the Plant Micromorphology Bibliographic Database on the website of the Royal Botanic Gardens, Kew. This is important, because it goes far back into the literature and is kept up to date. Quoting from the web site 'This is a unique bibliographic database maintained by the Micromorphology Group (Anatomy Section and Palynology Unit). It contains over 95,000 articles and is probably the most comprehensive computerized index to higher plant micromorphology in existence. It covers most work published on plant anatomy in the twentieth and twenty-first centuries, and is regularly updated with new literature. All aspects of angiosperm and gymnosperm plant structure are covered, together with vegetative anatomy of pteridophytes. Common subject areas include ontogeny, ultrastructure, techniques, palaeobotany, embryology and seed anatomy. Internet searches are available free of charge for scientific purposes. (If the searches are used in a publication, the "Micromorphology Group, Royal Botanic Gardens, Kew" should be acknowledged.) Contact: pa.database@kew.org.

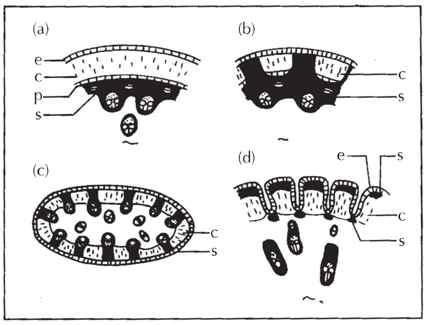

Fig. 9.1 Some differences between Restionaceae, Ecdeiocoleaceae and Anarthriaceae. (a,b) Restionaceae. Stem TS, most species have the general anatomy as shown in (a), with a continuous parenchymatous sheath; in some genera the sheath is interrupted by extensions from the sclerenchyma cylinder, as in (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 Ecdeiocoleacea has a parenchyma cylinder. c, chlorenchyma; e, epidermis; p, parenchyma cylinder (interrupted in (b)); s, sclerenchyma.

Anatomical data are easily applied to improving classifications and can often be used in making identifications. Take for example an instance where two new families were first recognized from their distinctive anatomy. The southwest Australian genera *Anarthria* and *Ecdeiocolea* were formerly treated as members of the Restionaceae. An extensive anatomical survey of the family Restionaceae showed the two genera to be misfits. Consultation with a classical taxonomist proved that there also were taxonomically valid distinctions at the macromorphological level. Co-operative research resulted in two new families being recognized, Anarthriaceae and Ecdeiocoleaceae. Figure 9.1 summarizes some of the main differences. These families have subsequently been shown to be chemically distinct, and molecular studies also support their separation. Thus, a hypothesis based upon macromorphology was tested using anatomy and other approaches and subsequently supported.

There are occasions when herbarium botanists find that it is difficult to ascribe a particular species or genus to a family, or where general affinities are suspected but there is insufficient evidence for them to place a taxon in a particular family. Here, additional anatomical evidence may be of help and

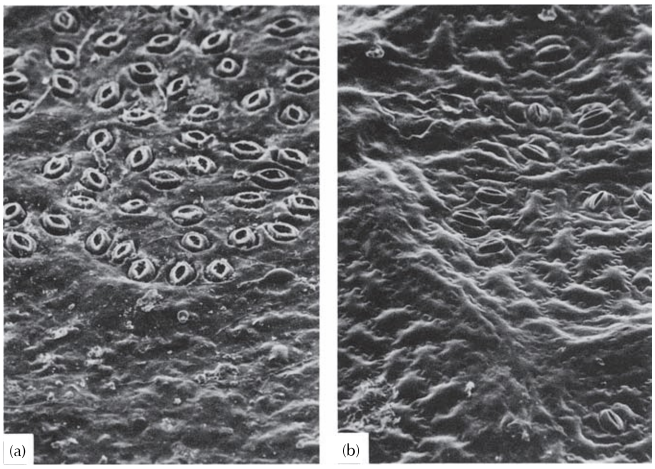

Fig. 9.2 Group of stomata in abaxial surface of *Eleutharrhena macrocarpa* (a). In (b), *Pycnarrhena pleniflora*, the stomata are scattered over the abaxial leaf surface. Both SEM, × 300.

there are many times when little extra helpful information comes from the anatomy. Recently, tree leaf material collected in China was examined anatomically; although there were no flowers or fruits on the herbarium sheet, the taxonomist thought that he knew the close relatives of the plant in question. The anatomy confirmed his views that the plant was *Pycnarrhena macrocarpa* Diels (Menispermaceae). A further study of species from this genus led to the discovery that two distinct genera were involved and a new genus *Eleutharrhena* was named by Forman to include *P. macrocarpa* using evidence from morphology, anatomy and palynology. In *Pycnarrhena*, stomata are scattered over the abaxial leaf surface; in the *Eleutharrhena* the stomata are in distinct clusters (Fig. 9.2).

Of course, the correct classification of plants is important, but it is often of more direct importance to know exactly to which species a specimen belongs. When flowers and fruits are absent, plant anatomists come into their own. Leaf fragments, wood and roots or twigs may have readily recognizable features which can be seen with a lens, but more often than not, identity has to be confirmed with the microscope. It is possible, for example, to check the identity of non-flowering aloes by looking at the leaf surfaces under the SEM. The appearance of the leaf surface in these plants can also indicate which subgroup they belong to.

Most of the drugs which are still extracted from plants come from leaves, bark, roots or rhizomes. Leaves often become fragmented and detached; bark, roots or rhizomes can be difficult to identify from their macroscopic appearance. The proper authentication of crude drug material is essential for standards of safety and quality to be maintained. For these purposes, accurate anatomical and morphological descriptions of the drugs have been published. The legal standards are found in such volumes as the British and European Pharmacopoeias and the British Pharmaceutical Codex, and those of other countries. In these books, the style of morphological and anatomical descriptions is very brief and to the point. Only those characters that will help to identify the material are given. Usually, these short monographs are carefully revised by a committee of experts. Herbalists are also aware of the need to have adequate control of the material they use, and work has been carried out to produce proper standards in reference works.

It is still often quicker to find out the identity of a crude drug (in the fragmented state) from its anatomy than from its chemistry. Importers of crude drugs are often experienced enough to know if they are buying pure material, or if adulterants are present. Sometimes samples will be sent for anatomical confirmation. For example Ipecacuanha, used in cough mixture can be adulterated with roots from alternative inferior species. Here microscopy can be used to give an indication of purity. The authentic source of the drug is *Cephaelis ipecacuanha* (Rubiaceae). Although rarely adulterated with other roots these days, there was a period when *Ionidium* (Violaceae) and other roots were regularly mixed in with the authentic material. Most of the adulterants have wide vessels in the xylem, whereas those in *Cephaelis* are narrow. The substitutes also lack characteristic starch granules, which are simple or, more usually, compound, with two or five or up to eight parts. The individual granules are oval, rounded or rounded and with one less curved facet, they rarely measure more than 15 μm in diameter. Sometimes *Cephaelis acuminata* is used as a substitute. This species is similar anatomically, but has starch granules up to 22 μm in diameter.

Sometimes closely similar substitutes are put on the market when the usual source of material is unavailable, for example, when Bolivian *Guarea* bark is difficult to obtain, and a substitute from Haiti is available. Microscopic study has shown that the substitute is from a different species, because the groups of phloem fibres are dissimilar but chemical tests prove it to be equally suitable for use. Occasionally the substitute may be poor and unsuitable. *Rheum officinale* root and rhizome is used medicinally, but *Rheum rhaponticum* is the vegetable. Fortunately, chemical and anatomical tests can be applied to detect which species is present. *Digitalis purpurea* and

D. lanata are used medicinally. They can be distinguished from one another on anatomical grounds, because the anticlinal walls of the abaxial epidermal cells are more beaded in *D. purpurea*.

Herbal remedies used as folk medicines from tropical parts of the world are often only available in fragmentary form. Those wishing to determine the identity of such fragments need to use anatomical methods.

Food adulterants and contaminants

Some herbs are used extensively as seasoning. These are often imported in the form of dried powdered plant parts, usually rhizomes, roots or leaves. Again it would be easy to introduce useless or sometimes even poisonous adulterants which would be difficult to detect with the naked eye. We have examined samples of dried mint, *Mentha* species, for purity, only to find considerable quantities of *Corylus* (hazel) leaf fragments included! *Ailanthus* leaf has also been used as a mint adulterant.

With the advent of the Trade Descriptions Act in the UK, manufacturers must state the contents of food products. It is essential for them to have adequate quality control, and to be able to identify all the materials they use.

Foreign bodies sometimes get into food by accident. Often these are small and fragmentary and can be identified only with the microscope. A splinter of wood in butter was found to come from a species of *Pinus*. The importer and packers hoped to be able to determine if the splinter could have come from the country of origin of the butter, or whether it might have been introduced during the packing stages. Buns and cakes containing sultanas periodically also contain other fruits which have become mixed with the sultanas during the drying process, when the sultanas are laid out in the sun. *Medicago* fruits are often involved. Some of these are prickly and unpleasant to eat! We have examined an object from a tin of baked beans which looked remarkably like a piece of a mouse. It turned out to be a piece of rhizome from the parent plant. It is often the case that odd-looking inclusions in food are only pieces of the parent plants.

Vitis, grape vine, stems have been found in currant buns, an *Avena* coleoptile, looking like a mouse tail, was present in a meat pie, and so on. Figure 9.3 shows an unsavoury looking shoot from a potato which occurred in a meat pie.

Starches from various plants have quite distinctive grain or granule features, so it is often possible to see if the stated materials have been used in a product unless the grains have become too hydrolysed (Fig. 9.4).

Animal feeds are made from the byproducts of other food manufacturing processes, or from seeds and fruits grown especially for the purpose.

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

When ground as a powder the constituents are difficult to detect by methods other than microscopy. There is plenty of scope for adulteration in feeds, and careful microscopical quality control is essential.

There are also examples of marjoram being adulterated with *Cistus*. These impurities were readily spotted, because some hairs did correspond

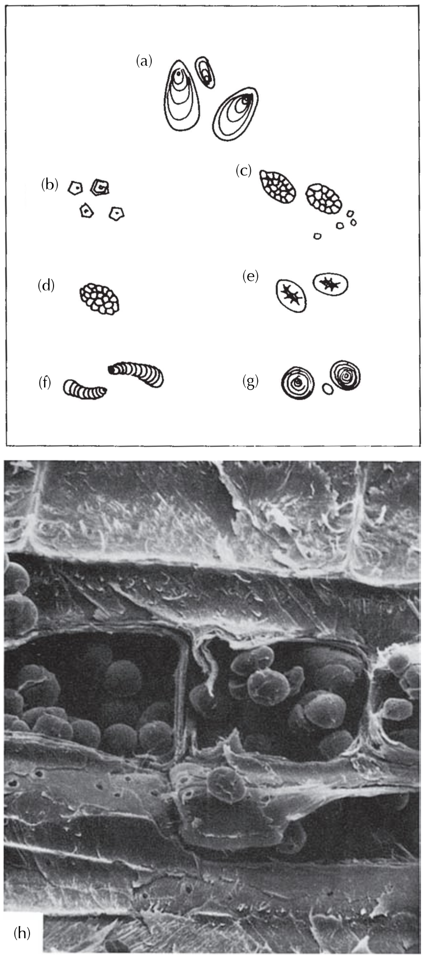

Fig. 9.4 Starch grains: (a) potato; (b) maize; (c) oat; (d) rice; (e) pea; (f) banana; (g) wheat. (h) Starch grains in xylem ray tissue of *Fabrisinapis*, SEM. (a–g) × 200; (h) × 3000.

to the species labelled while others corresponded to the adulterant, thus revealing a mixture.

Mucuna hairs, from the fruit pods, are very sharp and brittle, and contain an oil that is irritant. We came across them being used by a landlord who wished to evict a tenant. He had sprinkled them liberally in the blankets of a bed, causing the tenant to come out in a rash! A sample of the fine powder composed of hairs was sent to the New York Botanical Garden for identification because it was used as an irritant in mail to a judge. The sample turned out to be the specialized hairs, glochids, of the cactus genus *Opuntia*, which traditionally were used as itching powder. *Hedera helix* (ivy) hairs on a garment have been valuable in helping identify the scene of a crime in a recent murder case. In another murder case, fragments of partly decomposed oak (*Quercus*) leaves on shoes could be identified on a range of anatomical characters, including hairs. This with other evidence showed that a suspect had been near the place that a body had been found.

Tobacco (*Nicotiana*), together with other members of the Solanaceae, have rather characteristic glandular hairs. Some small cigars are enclosed in a paper made from macerated tobacco plant. In Great Britain, the law states that such cigars must be made entirely of tobacco. At Kew, we once looked at some so-called tobacco papers to ensure that only *Nicotiana* had been used. The presence of glandular hairs of the correct type was quickly established, and epidermal cells with sinuous walls were also found. However, we also discovered some hardwood vessel elements and softwood tracheids, and obviously other pulp had been added to strengthen the paper.

Animal feeding habits

Animal pests sometimes consume crop plants. It is often possible to find out what has been eaten by studying the composition of faeces, or stomach contents. A true estimate of potential losses can then be obtained. We have looked at faeces from rabbits, foxes, badgers, coypu, etc. and even millipedes! Of course the fragments of plant are very small when they have passed through an animal's digestive system. They are first fixed in FAA, and then washed in water. Then there is a sorting process, using a binocular microscope. Similar looking fragments are put into a petri dish, and the sample divided as far as possible into its components. Following this fragments from each dish are examined using temporary mounts under the light microscope. We always hope for good characters like silica bodies, hairs, stomatal types and so on. It is a big help to have a set of reference slides made from vegetation growing in the area from which the animal concerned was captured. It was suspected that some African cattle were being injured by eating grasses with sharp silica particles in them. The cattle only ate the grass concerned when other plants were unavailable. We examined the faeces and reported that there were silica bodies and sharp hairs present. Domestic animals occasionally eat poisonous plants, and we may be called upon to identify the fragments. The owner of the animals can then take precautionary measures against further livestock poisoning.

Wood: present day

Trunk wood

Most samples sent to Kew for anatomical identification consist wholly or mainly of wood. The samples are derived from many different sources and can be broadly divided into wood of recent origin and archaeological material. Furniture is made from woods carefully selected for their appearance and strength. Fashions have changed and it is common for certain species to have been selected for a period and then superseded by others. In addition, some woods were unavailable at certain periods. Consequently, by knowing which species were involved in the manufacture of antique furniture, it may be possible to date the piece, and occasionally the furniture expert may be able to get a good idea of who made it. Some craftsmen worked only with a carefully selected, characteristic range of woods. When repairs are necessary, it is also helpful to know which species should be used. The only way of being absolutely certain which woods were used is, in most instances, by making a microscopical study. Those who claim to be able to identify woods 'on sight' are either extremely experienced or over-bold, and many make errors.

The country of origin of carved wooden items can sometimes be established from the identity of the wood. Care must be taken because woods can be transported and then carved a long way away from their original sources. We have looked at items collected by Captain Cook on his voyages to try to determine where they could have come from, and this has proved successful. We once had for identification a wooden mask, carved in the likeness of a dog. This proved to be alder wood and its association with North American Indians was confirmed.

The Trade Descriptions Act has again provided problems for builders and manufacturers where woods are concerned. If they state that a particular wood has been used, this must be correct. The British Standards Institute has published a list of common names and the species from which the woods come, and this is the authoritative work which has to be followed in the UK. The only way to be certain that the correct wood has been used is to compare sections of it with those from a standard reference collection of microscopic slides. On one occasion a door said to be made of solid mahogany was brought to the laboratory. It turned out to be laminated, and no true mahogany was found in it – in fact the middle layer of veneer was birch.

Properties of woods related to structure have been mentioned in Chapter 3. We are occasionally asked to suggest substitute woods for some specialist purpose, when the supply of the normally used species has ceased. This can be difficult, but it is sometimes possible to suggest other species, which from their anatomical make-up might be expected to have similar properties.

Wood used as a backing for paintings, such as icons, is brought to the laboratory from time to time. The purpose in finding out the identity is often related to establishing the name of the artist, or the country of origin. We have examined the wood from a good many walking sticks; an amazingly wide range of species has been used for this purpose!

Preservation of wood is of considerable economic importance. A great deal of experimental anatomy is carried out in various parts of the world in order to establish the nature of the process of decay, the identity of the organisms involved and the prevention of their degrading activities. The 'sound' wood has to be very carefully examined and described. Close observations then have to be recorded on all stages of the decay processes and the action that the various organisms have on the wood.

Tree roots

Considerable damage, running into millions of pounds, is caused each year to buildings either directly or indirectly by the action of roots of trees or shrubs. There may be a number of different tree species near to the buildings concerned. All or some of them might have roots beneath the foundations. It would be excessively expensive to try and trace the roots back to their parent trees by excavation. Fortunately it is possible to identify most roots of trees growing in the British Isles from aspects of their root anatomy, largely from features of the wood (secondary xylem). In some instances it is possible to identify to the species level, but more often only the genus can be identified, for example *Quercus*, oak, or *Fraxinus*, ash, and *Acer*, maples and sycamore. In the Rosaceae, identifications can be made only to the subfamily level, for example Pomoideae and Prunoideae. Current research is aimed at finding additional characters in this family.

Sometimes it is not possible to get closer than the family, as for example in Salicaicae. In trunk wood, *Salix* and *Populus* can normally be separated because Salix usually has heterocellular rays and *Populus* homocellular rays. However, in the root wood this distinction does not hold. Indeed, root wood is often slightly dissimilar in its anatomy from trunk wood of the same species. This means that one cannot rely on the descriptions contained in reference works on wood anatomy for accurate identification of roots. Root anatomy is also quite variable within a species, so the only way to be sure of making the proper identification is to compare the root sections with reference microscope slides taken from a range of authenticated specimens. Figure 9.5 shows two roots of *Acer pseudoplatanus* (TS) grown under very different conditions and some normal trunk wood for comparison.

Wood: in archaeology

Wood or charcoal is often preserved in sites from antiquity. The best preservation occurs in localities which are either very dry or continuously wet. Fluctuating drying and wetting encourages the activity of microorganisms and/or insects and can lead to the rapid decay of wood.

Charcoal, usually in the form of fire ash or the burnt remains of structural posts in post holes, often retains even very delicate features of vessel element wall pitting and perforation plates. Figure 9.6 shows Romano-British *Alnus* charcoal. It can be difficult to see details of the anatomy on first examination of the surface of a piece of charcoal, because it is often damaged and dirty. After a period of drying in an oven at 50°C, the charcoal will fracture readily. If care is taken to snap it along the radial longitudinal, tangential longitudinal and transverse planes, good surfaces for study can be produced. The specimens are mounted in plasticine or blue-tack on a microscope slide, and examined under the epi-illuminating microscope.

We have tried embedding and sectioning charcoal (with a diamond saw), but so much material is lost in the process that it was found not to be worthwhile. The very small fragments can be examined in the SEM, after coating, but generally the light microscope is adequate.

It can be determined if the makers of the fire had selected particular woods for their burning properties, or if the remains merely represent what was growing locally and easily accessible. Moreover, an idea may be gathered about the composition of the vegetation of an area at particular times.

Some sites are very rich in waterlogged or dry, preserved wooden objects. The Sutton Hoo burial ship, for example, contained many wooden grave goods. Interesting examples from this site are some small pots with silver gilt rims. On excavation these were thought to be made from small gourds, fruit from the Cucurbitaceae. Microscopical study of thin sections showed the structure to be of walnut wood, probably from near the rootstock, where burr-wood could be obtained.

With improved techniques for recovering wooden wrecks and, subsequently, conserving them by special impregnation techniques, interest has

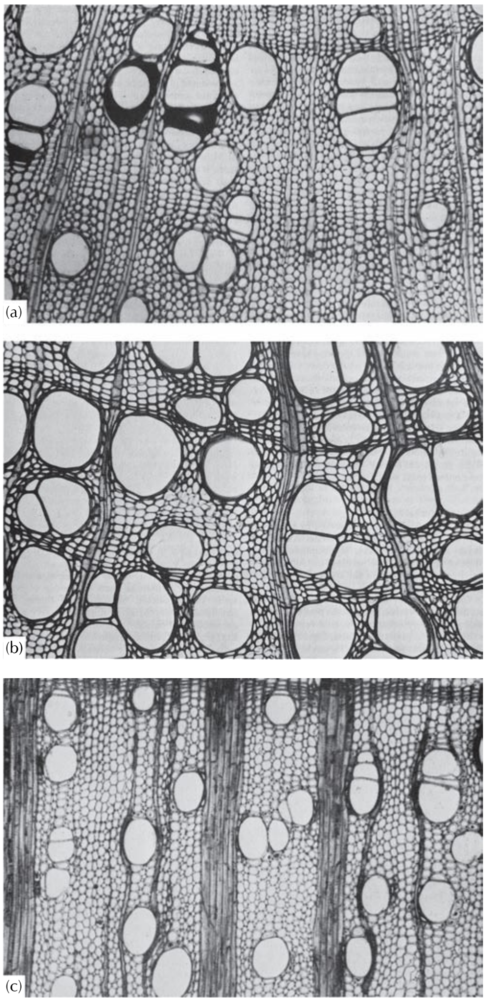

Fig. 9.5 *Acer pseudoplatanus* roots grown under different conditions (TS). (a) From normal and (b) from waterlogged soils. (c) Normal trunk wood. All × 130.

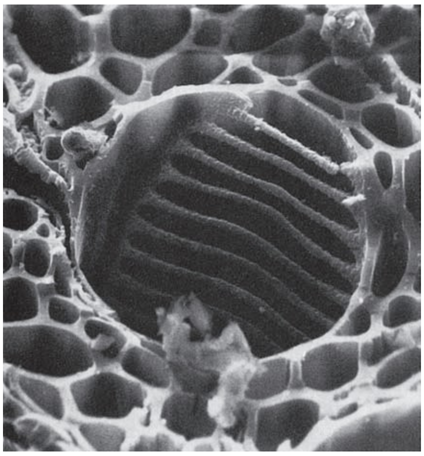

Fig. 9.6 Charcoal of *Alnus glutinosa* from Romano-British London. Details of the structure are well preserved, particularly the scalariform perforation plate.

increased in naval architecture. The timbers of a warship from the Punic wars were remarkably well preserved and were readily identified after many centuries in sea water. An oak Iron Age boat from Brigg in South Humberside also proved to be fascinating. No 'nails' were used to secure one timber to another, but the main logs were sewn together with twisted willow twigs passed through regularly pierced holes along the edges of the baulks of timbers In the Bronze Age, trackways were built across swampy ground in Somerset. The hazel faggots (*Corylus*) used in these were well preserved in the waterlogged conditions. We look at archaeological material from all sorts of wooden objects: spear shafts, shields, buckets, right through to structural timbers. Much of this work is very time-consuming. Often some details of the anatomy are lost, and very careful comparisons with reference materials need to be made before identifications are given Because of the potentially enormous quantity of fragments of wood that could come from even one fire, it is sensible to sort them visually into groups and limit the initial sampling to some examples from each group.

Wood products

Archaeological plant remains other than from wood can sometimes be remarkably well preserved. The sandal shown in Fig. 9.7 from ancient Egypt is such an example. *Cyperus papyrus* is a major constituent of the sandal, and

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

some *Borassus* (palm) is also present). However, some of the samples are waterlogged and compressed. It is often possible to 'revive' such material. The secret is to section it in the compressed form and revive the sections, by floating them briefly in sodium hypochlorite solution or in chlor-zinc-iodine. Temporary mounts are best made in 50% glycerine.

The structural properties of wood are utilized in modern building methods by using not only solid timber, but also laminates, plywoods, chipboards, hardboards and the like. These materials are tested to destruction so that their properties can be properly evaluated. Microscopic examination of the failure areas can give a good guide to areas of weakness.

Forensic applications

Forensic work often involves the identification of small pieces of plant material other than wood, although in addition to safe ballast, wood splinters might come from such things as windows, doors and their frames, weapons and the like, and thus play an important part in police work. A wide range of particles of plants may become attached to clothing or footwear which relate to the scene of a crime. Plant fragments found on suspects may link them with the location of the crime. Clothing itself is made from a variety of fibres, a number of which may be of plant origin. Microscope slides of macerated textile fibres make up part of the reference collection of forensic laboratories. Drug plants, such as *Cannabis sativa*, frequently have diagnostic characters whereby quite small pieces may be identified microscopically.

An increasing number of plant species are being sold for consumption as drugs – some as adulterants, others as substitutes. It is a hard task to keep up with the introduction of additional species, particularly because the product is often in a very finely powdered form. Quite a lot of time and effort has to go into analysing such finely powdered drugs. Anatomical characters can be used with such confidence for identification that they may contribute part of the evidence given under oath in court.

Palaeobotany

Just as anatomical features can aid in the identification of archaeological materials, they can be employed in the identification of fossils and place them among extant plant families and genera. Fossils are usually composed of only some plant parts with the crucial identifying features associated with flowers and fruits being absent. Anatomical features, however, allow us to determine if the plant part is a root or stem or leaf simply by the presence of exarch or endarch protoxylem in the case of the first two. Further examination and comparison to a reference collection of extants may allow us to assign the fossil to an extant taxonomic group. Some fossils may be sectioned, others may be ground down to thin sections suitable for microscopy, and still others are fossilized in the form of charcoal which may be treated in the same way as recent charcoalified archaeological artefacts.

Postscript

In this chapter, we have seen the basic cellular structure of the vegetative parts of a number of common and less common plants described in simple terms. The evidence presented here shows that plant anatomy is not just an academic subject but has been drawn from a wide range of applications, many of economic importance, others of legal consequence and a number which simply served to answer intriguing questions.