OBSERVATIONS ON THE BIOLOGY AND PHYSIOLOGICAL ANATOMY OF SOME INDIAN HALOPHYTES

(Continued from page 116 of Vol. XI, No. 2)

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Sonneratia apetala, Ham. (Lythraceae).

The Lythraceae is represented in the salt-swamp by *Sonneratia apetala*, Ham. and *S. acida*, Linn. Of the two the former is rare but is found in the Bombay Presidency. *S. apetala* is an erect tree with drooping branches and veinless leaves which are held like phyllodes.

The young stem is quadrangular, having a thickly-developed cuticle whose outer surface is coated with wax granules. Secondary division-walls occur in the epidermis (Fig. 41). A 5–6-layered hypodermis holds anthocyanin and a few chloroplasts. The ridges of the young stem are formed entirely of collenchyma. The rest of the cortex is composed of loose parenchymatous cells. The lacunae are schizogenous in origin and are especially well developed in the region of the four ridges. Spicular cells occur between the hypodermis and the lacunar cortex. The spicules are elongated vertically and branch out at each end, forming pointed arms which project into the intercellular spaces (Fig. 42). The walls of the main body of the spicules are pitted and lignified. In the young parts, secretory cells are insinuated between the groups of hard bast. The secondary xylem is at first more vigorously formed on one side of the quadrangular stem. The secondary bast is marked by the occurrence of vertical rows of crystal cells. The primary rays hold starch or tannin and oil. Intraxylary phloem (holding a few bast fibres and crystal-cells) is more prominently formed on the side where the secondary xylem develops more vigorously. The inner face of the intraxylary phloem is rendered conspicuous by the presence of starch and secretory cells. The pith is feebly pitted and is distinctly lacunar towards the centre where it is supported by short, multiradiate, lignified sclereides (Fig. 43). Tannin and oil occur in the cortex and the pith. The phellogen layer arises subepidermally and the cork consists of lignified, phelloid cells. The secondary cortex is composed of tangentially-elongated cells (holding tannin and oil) and is supported by stone-cells.

The petiole repeats the general structure of the stem. Toward the morphologically upper surface, the cortical cells are radially elongated; the secretory cells are disposed in radial rows and the sclereides are more numerous (Fig. 44). Islands of intraxylary phloem occur in the petiole. In the leaf, the epidermis is the same in structure on both surfaces (Fig. 45). Schimper (13), in describing the epidermis of *S. acida*, says; " the epidermal cells have a very thick, ribbed outside." In *S. apetala*, the outer surface is also covered by a fine-meshed skeleton of a granular substance which dissolves very slowly in a solution of caustic potash. In the epidermal cells of *S. acida*, Schimper (13) also notes the regular occurrence of " a dark lump, perhaps a sphaerocrystal." In *S. apetala*, no such dark lumps are found. The cuticle is thickly developed and secondary division-walls occur in the epidermis. Stomata, with subsidiary cells, are equally abundant on both surfaces, being about 100 per sq. mm. The xerophytic character of the leaf is seen in the position and structure of the stoma. The latter is deeply sunk and the cuticular ridges are very prominently developed and closely approximated, both on the outer and inner faces of the stoma, thus forming small, outer and inner vestibules (Fig. 47). The leaf is isolateral in structure. Schimper (13), in describing *S. acida*, says: " the centre of the leaf is occupied by a thin-walled colourless aqueous tissue, which may be 2–3 mm. thick." The central aqueous tissue, in *S. apetula*, occupies nearly one-half the thickness of the leaf, being 0.3 mm. in a leaf 0.7 mm. thick. In a cross section, the aqueous tissue is seen to be composed of large, polygonal cells (Fig. 48). Tannin and oil occur in the outer cells. The aqueous tissue is supported by lignified, multiradiate sclereides (Fig. 49). The centre of the aqueous tissue is occupied by numerous veinlets. The terminal tracheides are enlarged and pitted, evidently acting as supplementary storage reservoirs (Fig. 50). The central aqueous tissue is surrounded by a cylinder of green assimilatory tissue, consisting of 4–5 layers of short palisade cells (Fig. 47). As a rule, the palisade tissue is slightly less developed on the morphologically lower surface. Tannin and oil occur in the palisade cells. Schimper (13) has noted the occurrence of large mucilage cells in *S. acida*. The mucilage cells of *S. apetala* are thin-walled and present a circular outline in cross section (Fig. 51). They are comparatively large (having a diameter of 0.07 mm.) and occur at short intervals, being separated by strips of palisade tissue. The delicately-ribbed thickening of the outer surface of the epidermis is seen to be more prominently developed above the centre of each mucilage cell. In surface view, it appears as a spinescent lump (Fig. 45, *l*); while in a cross section, it looks like a rough wart (Fig. 51, *l*). As previously noted, the skeletal coating dissolves very slowly in a solution of KOH. On treating the epidermis with KOH (for several hours) the lump of thickening over the mucilage cell dissolves away and leaves a gap (Fig. 46, *g*). It thus appears that the mucilage cells are derived from the epidermal cells which get excessively enlarged and sink to a lower level. Crystal cells (each holding an aggregate crystal of oxalate of lime) occur among the mesophyll cells, being mainly confined to the inner face of the palisade tissue. In the margin of the leaf (which is presented to the sky) the palisade tissue is absent, its place being taken by 6–7 layers of collenchyma. Intraxylary phloem occurs in the main vein. Areschoug (1) mentions the occurrence of cork-warts on the leaves of *S. caseolaris*, Engl. and *S. lanceolata*, Miq. They also occur on the leaves of *S. apetala*. Blatter (3) notes that, in *S. acida*, the thickness of the leaves varies according to the habitat, being thicker in plants growing in salt mud than in those living in common soil.

The root system is composed of the subterranean roots and the aerial pneumatophores. The terrestrial roots are soft in texture and whitish in colour, due to the development of a lacunar cortex. The latter is primarily adapted to serve as a breathing tissue and is based on the same plan as that of the three members of the *Rhizophoraceae* previously considered (Fig. 52). The cells appear, in cross section, to be mostly triradiate (Fig. 53) and are stiffened by thickening ridges. The sclereides of the previous mangroves are absent in *S. apetala*, but their places are taken by thick-walled vertically-elongated cells (Figs. 53, 54, *s*). The walls of these cells are pitted but not lignified. Tannin and oil occur in the cortex, pericycle and primary medullary rays. Lignification starts in the outer pith cells and later, the whole pith gets lignified. Cork arises superficially and is composed of phelloid cells.

The anatomical structure of the pneumatophores (Fig. 55) differs in several respects from that of the roots buried in the mud. In a cross section, the cortex appears lacunar like that of the terrestrial root, but the structure differs at the distal and proximal ends, especially in regard to the presence or absence of the sclereides. A cross section of the distal end (Fig. 56) shows the cortex to be composed of rounded cells with schizogenously-formed intercellular spaces. The outer 4–5 layers hold chloroplasts. Crystal cells and multiradiate sclereides occur in the cortex (Figs. 56, 57). Several sclereides often unite and form masses of lignified tissue. The sclereides are most abundant at the distal end, evidently acting as mechanical tissue for the erect, aerial part. Receding from the distal end, their number becomes less and less, till, towards the proximal end, the sclereides disappear altogether. The cortex at the proximal end resembles that of the terrestrial root and is supported by elongated, slightly curved lignified spicules (Fig. 58, *s*). In *S. acida*, Westermaier (18) has noted similar spicules in the proximal parts of the pneumatophores which are buried in the mud. He is of opinion that the spicules act as springs and bring about the expansion and contraction of the cortex, thus aiding in the respiration of the submerged parts. The xylem ring is broad and feebly lignified. Isolated groups of hard bast are present and the secondary phloem holds vertical rows of crystal cells. Sclereides occur in the pith at the distal end of the pneumatophore, but are absent in the proximal part. Tannin and oil occur in the cortex and pith of the distal part only. The structure and development of the cork in the pneumatophore of *S. acida* is studied by Goebel (5). According to him: the respiratory roots are covered by a number of thin cork-lamellæ which are superposed and consist of three cell-layers each. The structure of the cork in *S. apetala* (Fig. 59) is similar to that of *S. acida*. Thus the cells (*o*) of the outermost layer have their walls rounded off externally and are not suberised; the cells of the middle layer (*m*) are tabular and suberised; while those of the innermost layer (*i*) are elongated in the radial direction, rounded off internally and suberised. Between each pair of cork-lamellæ there are only two divisional layers of approximately spherical cells, so that a separation of the cork-lamellæ can take place at these points. In *S. apetala*, the cells separating each pair of lamellæ are more or less spherical, as described by Goebel (5), but some of them, especially those abutting on the inner cell-layer of the cork-lamella (Fig. 60, *s*), are radially elongated. The cells of this layer are thin-walled and loosely arranged. Goebel (5) is of opinion that this layer resembles the complementary cells of the lenticels. In *S. apetala*, the layer also seems to aid in the work of assimilation, as is evidenced by the presence of chloroplasts with included starch. The green colour of the tender respiratory roots can thus be traced to the presence of this cork layer and the outer layers of the cortex, both of which act as photosynthetic tissues.

S. apetala does not show vivipary. Goebel (6) is of opinion that: the seeds of the species of mangrove which are marked by rapid development, *e.g.* *S. acida*, do not show vivipary and the rapid development is favoured by the rich deposit of reserve material. The indehiscent fruits of *S. apetala*, on falling in the mud, soon disintegrate and scatter the seeds. Seedlings of the plant were found growing at the foot of the parent tree in September. The stem of the seedling is typically quadrangular. The hypodermis is not yet differentiated, but the cortex shows prominent, schizogenous air-spaces. Most of the cortical cells hold chloroplasts. The spicular cells of the mature stem are absent. Secondary growth starts early and is seen to be more vigorous at two opposite sides of the stele. Small islands of intraxylary phloem are present and the pith is lacunar. The development of comparatively large air-spaces in the stem of the seedling seems to be induced by the fact that the seedlings are periodically submerged during high tides. The cortex of the primary root is also lacunar. The first leaves are somewhat cuneiform. The epidermis is composed of deep, clear cells which evidently act as water-reservoirs. The outer skeletal thickening of the mature leaf is absent and the stomata are not prominently depressed (Fig. 61). The central aqueous tissue acts also as the photosynthetic tissue; the palisade cells are broad and hold oil. The lamina of the first leaf is 0.3 mm. thick, the aqueous tissue being 0.15 mm. The large mucilage cells of the mature leaf are absent in the first leaves. The cotyledons are leaf-like and have feebly developed palisade cells. Starch and oil occur in the cotyledons, the latter being more abundant.

Aegiceras majus, Gaertn. (Myrsinaceae).

Aegiceras majus, Gaertn. (*A. corniculatum*, Blanco) is one of the most widely distributed species of the mangrove formation. The surface of the older parts of the stem is covered with wax and appears greyish, while the younger parts appear reddish-brown. The cuticle is well developed. The epidermis is followed by another layer similar to it which, in the young parts, holds tannin and oil; while, in the old parts, its cells dilate and remain mostly clear like those of an aqueous tissue. This second layer is followed by a typical hypodermis of 5–6 layers of collenchyma which are full of tannin and oil. Chloroplasts, with included starch, are present in the hypodermis and the inner cortex but are masked by the presence of tannin. In the older parts, the cells holding starch are arranged in vertical rows. The cortex is traversed by schizogenously-formed, vertical canals (Fig. 62). They hold a homogeneous substance which appears brownish in preserved material. The latter is not tannin and is insoluble in alcohol or KOH solution. The lacunar cortex is supported by vertically-elongated spicules, having pitted and lignified walls. Pericyclic hard bast forms an almost complete ring of lignified tissue. Secretory cells, holding tannin and oil, occur in the secondary phloem and similar cells are also present in the xylem parenchyma. The pith cells are minutely pitted and lignified (Fig. 63). The pith is supported by sclerenchymatous elements and vertical rows of crystal cells are present. Tannin and oil and secretory cavities, holding the brownish substance (as in the cortex), also occur in the pith. Cork arises superficially and lenticels are abundantly developed on the lower part of the stem.

The petiole repeats the structure of the stem and holds the same type of contents. The leaf is green on the upper and reddish-brown on the lower surface. The cuticle is more prominently developed on the upper surface and the epidermal cells hold tannin and oil. Stomata are wholly confined to the lower surface (Fig. 64) and are 150 per sq. mm. The leaf is typically xerophytic in structure. The stomata are depressed (Fig. 65) and the outer cuticular ridges are very thickly developed and are notched on their outer faces. Conspicuous salt-secreting glands occur on the leaf and are equally abundant on both surfaces (10). Similar glands also occur on the petiole. Schimper (13) has noted a subepidermal aqueous tissue, 2–3 layers thick on the upper and one layer thick on the under surface. In a cross section, the aqueous tissue, on the upper surface, is seen to be composed of 3–4 layers of large closely fitting, irregularly polygonal cells (Fig. 66). Towards the lower surface the hypodermal cells are much smaller and are full of tannin. The lamina is 0.50 mm. thick, the upper aqueous tissue occupying about 0.13 mm. of the total thickness (9). The leaf is bifacial. The palisade tissue consists of 2–3 layers of cells (Fig. 66), while the spongy tissue is made up of short, oblong cells with small intercellular spaces (Fig. 65). The lower 2–3 layers of the spongy tissue are full of tannin and oil. These layers, together with the epidermis, give the lower surface its characteristic colour. Small aggregate crystals of oxalate of lime occur in the spongy tissue. Van Tieghem (16) has demonstrated the presence of secretory cavities in the leaves of *Aegiceras*. In *A. majus*, the cavities are seen to traverse the leaf in the region of the vein, and resemble those of the stem in structure and contents.

In the root, the cortex is modified as an aerating tissue. The cortical cells present a roundish polygonal outline in cross section, but are slightly elongated vertically. Karsten (8) has shown the occurrence of peculiar thickening plates in the cortical parenchyma of the roots of *A. majus*. These plates are marked by oval or ring-shaped slits (Fig. 67) and seem to take the place of the thickening ridges of the previous plants. Secretory cells, holding tannin and oil, occur in the pericycle. The primary medullary cells are narrow and hold starch. The pith is full of starch and consists of polygonal cells which are thick-walled, pitted and lignified. Cork arises superficially and is composed of lignified, phelloid cells.

In *A. majus*, the seed germinates within the pericarp of the curved, horn-shaped fruit which remains attached to the seedling for some time (Fig. 68). The primary root already shows a cortex typically modified as an aerating tissue. The pith, together with the xylem, forms a strong axile strand of lignified tissue, well adapted to bear vertical strain. In the first leaves, the upper aqueous tissue consists of a single layer of large, clear cells.

Acanthus ilicifolius, Linn. (Acanthaceae).

Though the members of the *Acanthaceae* are typically terrestrial in habit, *Acanthus ilicifolius*, Linn. is a common inhabitant of the mangrove swamp. The leaf blade is deeply sinuate and present the spiny portion to the sky. At maturity, the plants stand on stilt-roots (Fig. 69). The epigeous portions of the roots are often distinctly green.

In order to study the effect of a different environment on *A. ilicifolius*, two plants, of approximately the same size, were taken from their natural habitat and planted in pots containing ordinary garden soil. One plant (A) was allowed to grow as a mesophyte, while the other, pot (B), was submerged in fresh water so that the root system and a part of the stem were completely submerged. Both the plants were allowed to grow for nine months after which they were removed for examination (Figs. 70, 71). Both plants show some remarkable changes in the configuration of the leaves and the roots, which were evidently induced by the change of habitat. The halophytic form of the plant bears leathery leaves with undulating margin and hard spines. The leaves of plants A and B are soft in texture; the undulations of the margin are less prominently marked and the spines are less rigid. Thus under mesophytic conditions there is a tendency for the leaves to get flattened out and the upper surfaces are directly exposed to light. These changes are more prominently marked in the cases of the new stems which developed under the changed conditions. In plant B, as the new stem developed it had to grow through water for a time and bear leaves under water. These submerged leaves are quite flat and the marginal spines mostly suppressed. The root system of plant A is not much changed but that of plant B shows a remarkable modification. The roots of plant B differ from those of the halophytic or even mesophytic form, in that they become fibrous and branch most profusely. In both A and B no prop-roots developed during the period the plants were under observation.

The internal structure of the halophytic form show typical xerophytic peculiarities. In the stem, the epidermis is succeeded by 2–3 layers of photosynthetic tissue which is followed by 3–4 layers of collenchyma. The major portion of the cortex is lacunar. Crystal sand and acicular crystals of oxalate of lime occur in the cortex. Vesque (17) and others have noted the occurrence of medullary bundles in the various species of *Acanthus*. In *A. ilicifolius*, no medullary bundles are to be seen. The pith cells are pitted and lignified.

The vascular supply of the petiole is peculiar in that it consists of several complete steles, each being invested by a starch sheath. There are three major steles, the central one being the largest. On tracing the origin of the vascular supply of the petiole into the stem, it is seen that, at an internode, the stele presents a circular outline in cross section but, at a node, it assumes the shape shown in Fig. 72. A. At first, the stele forms bud-like protuberances (*a*) at the two poles, corresponding with the insertion of the opposite leaves. The protuberance (*a*) elongates and enters the petiole (*p*) on its side (Fig. 72, B), constituting the central, major stele of the petiole, and further up, the midrib of the lamina. As the branch (*a*) enters the petiole, two more branches (*b*) arise on either side of it. These also elongate and bending towards branch (*a*) enter the petiole (Fig. 72, C) and constitute its lateral steles. From the base of branch (*b*), a smaller branch (*c*) is given off on either side. These latter enter the spiny stipules.

In the leaf, the cuticle is thickly developed and seems to be impregnated with mucilage. The stomata are wholly confined to the lower surface and are about 150 per sq. mm. (Fig. 73). The guard cells are accompanied by subsidiary cells, placed transversely to the pore. The stomata are not sunk but are even with the surface and the outer cuticular ridges are distinct (Fig. 77). Salt-secreting glandular hairs (Fig. 74) occur on both surfaces, being more numerous on the upper surface (10). The leaf is bifacial. Schimper (13) has noted the occurrence of a 1–2-layered hypodermal aqueous tissue on the upper surface. The aqueous tissue is composed of large, thin-walled, clear cells (Fig. 75). In a lamina of 0.63 mm. thickness, the aqueous tissue occupies 0.15 mm. (9). Oil is very conspicuously developed in the palisade cells and, as the globules are arranged more or less at the same level in each cell, forms a striking feature of the tissue (Fig. 76). The spongy tissue consists of 9–10 layers of loosely-arranged cells (Fig. 77). Thg vascular supply of the midrib resembles the three major steles of the petiole. During the monsoon, *A. ilicifolius* stores up water in its leaves (9).

In the terrestrial root, the primary cortex is modified as an aerating tissue. The cortical lacunae are schizogenous in origin and are separated by uniseriate bridges, as in a water-plant (Fig. 78). Karsten (8) has shown the occurrence of peculiar thickening plates in the cortical parenchyma. These plates are traversed by slits and resemble the plates occurring in *Aegiceras majus*. Tannin and acicular crystals occur in the cortex. The outer pith-cells are thick-walled, pitted and lignified. Cork arises superficially. In the aerial part of the stilt-root, the cortical lacunae are much reduced and the outer layers hold chloroplasts. Lignification is much stronger in the aerial part.

The internal structure of plants A and B differs in several respects from that of the halophytic form. Thus, in both plants A and B, the stem is softer in consistency due to the comparatively feeble lignification and the greater development of cortical parenchyma. The inner cortex is compactly built and the lacunae are much reduced. The chloroplasts are more abundantly developed and the endodermis (which in the halophytic form remains clear) holds large starch grains. Thus the inner cortex of the halophytic form is adapted to act as the breathing tissue, while under mesophytic conditions, it acts mainly as the assimilatory and storage tissue. Tannin is hardly developed and the outer pith cells are neither pitted nor lignified. Various forms of crystals of oxalate of lime occur abundantly in the cortex and in the pith of plants A and B. Schenck (12) and others have shown that when a land plant is submerged, the part of the stem under water swells up, produces fissures and, in several cases, lenticels and adventitious roots. In *A. ilicifolius*, the submerged part of the stem, in plant B, did not show any external change during the time it was under observation, but there was a remarkable change in the structure of the cortex. The cortex of the submerged stem is not compact like that of the aerial part, but is distinctly lacunar, being modified as an aerating tissue.

In both plants A and B, the lamina is nearly one-half the thickness of that of the halophytic form, the thinness being mainly due to the reduction of the aqueous tissue (9). The cuticle is not thickly developed and the glands cease to function as salt-secreting hydathodes (10). The mesophyll cells are typical of a mesophyte, the spongy tissue having wide intercellular spaces (Fig. 79). In the roots of A and B, the cortex is constructed on the same plan as in the halophytic form, though the lacunæ are much smaller in size. On the whole, there is very little change in the anatomical structure of the root. The lacunar cortex which is typical of the halophytic form, is seen to persist even in the case of plant A which was grown in a well-drained soil. This persistence of the air spaces in the roots of *A. ilicifolius*, irrespective of the *milieu* confirms Goebel's (7) suggestion that the lacunar system initiated by plants originally living in water has become hereditary so that the lacunæ make their appearance whether the original cause, *viz.* water, is present or not.

Avicennia officinalis, Linn. (Verbenaceae).

The *Verbenaceae* is represented among the mangroves by *Avicennia officinalis*, Linn. and *A. alba*, Blume. The latter plant is described, at times, as a variety of the former, but Cooke (4) has made the two plants quite distinct. *A. officinalis* is the "white mangrove" and occurs near the outer edge of the swamp or some distance up the tidal streams.

The internal structure again shows the common xerophytic peculiarities. The outer surface of the young stem is clothed with trichomes. Each trichome (Fig. 80) is composed of a short stalk-cell and a pear-shaped head which is seated horizontally and excentrically. The epidermal cell which acts as a pedestal for the trichome is situated at a lower level than the neighbouring cells. Thus the trichomes appear to be seated in pits, the heads projecting slightly beyond the cuticle. A few glandular hairs also occur on the young stems (10). The outer epidermal walls of the stem arch outwards and the cuticle is well developed. In the young parts, a 5–6-layered hypodermis acts as the photosynthetic tissue. The rest of the cortex is lacunar and the cells hold oil and minute aggregate crystals. The lacunar cortex is supported by slightly-elongated, lignified, sclerenchymatous cells. The mature stem exhibits an anomaly in the form of successive rings of growth as is shown by de Bary (2). A section of a branch 3 mm. thick and having one complete ring of growth, shows two masses of intraxylary phloem. The latter are situated at two poles and are surrounded by the inner sclerenchyma. In each group 1–2 bast fibres occur. These masses of intraxylary phloem do not form a constant feature, for, they disappear in the older parts. As shall be noted later, though they disappear in the stem, the intraxylary phloem persists in the leaf. The pith cells are prominently pitted and hold oil. Fusiform and acicular crystals occur in great abundance in some cells. Vertically-elongated sclerenchymatous elements, with wide lumina, occur among the pith cells. In the older parts, the whole pith gets lignified. Cork arises superficially and is of the phelloid type. The secondary cortex is very lacunar.

The adaxial surface of the petiole bears a narrow groove which runs along nearly half its length. Owing to the greater thickness of the lateral walls at the outer end, the epidermal cells appear conical in cross section. The abaxial surface and the sides of the petiole are covered with short trichomes, similar to those of the stem. The region of the groove is thickly lined with long trichomes and glandular hairs. The trichomes of the groove differ from those occurring in other parts of the petiole, being very long and uniseriate (Fig. 81). Each is composed of a short stalk-cell. seated upon an epidermal cell; 2–3 elongated body-cells, and a very long terminal cell. The body-cells hold granular contents, but the terminal cell is mostly clear. Occurring among the trichomes are glandular hairs (10). The petiole repeats the general structure of the stem. The leathery leaves are held stiffly and present their apices to the sky. The trichomes are absent on the upper surface, but salt-secreting glandular hairs (Fig. 85) are present (10). The lower surface of the leaf is thickly covered with trichomes which, being full of air, give a greyish-white appearance to the young stem and to the under surface of the leaves. Besides the shorter trichomes, described by Solereder (14), some longer ones (having two stalk-cells) also occur on the leaves (Fig. 82). Salt-secreting glands also occur on the lower surface (10). Stomata are small and are confined wholly to the lower surface where they are efficiently protected by the trichomes. In surface view each stoma appears to stand in the centre of a cavity (Fig. 83). As is seen in a cross section this is due to the fact that the guardcells are surrounded by subsidiary cells whose outer walls are depressed, thus forming a groove around the guardcells (Fig. 84). The subsidiary cells have very thin walls and seem to be able to raise or lower the stomata. The guardcells have thick walls and the outer cuticular ridges are prominently developed. The cuticle is thick on the upper surface; while the lower surface, which is covered with trichomes has a thin cuticle. Schimper (13) has noted a many-layered, subepidermal, aqueous tissue (Fig. 85). Except for the presence of oil and a few minute aggregate crystals the hypodermal cells are mostly clear. According to Van Tieghem (15), the many-layered hypodermis in *A. officinalis*, occupies half the thickness of the leaves. As shall be seen later Van Tieghem's statement applies more correctly to *A. alba*, for, in *A. officinalis*, the thickness of the hypodermis is only one-fourth that of the lamina, being 0.13 mm. in a leaf 0.50 mm. thick (9). The leaf structure is bifacial but inclines towards the isolateral type. The palisade tissue is 3–5 layers thick. Oil occurs in the leaf and forms a marked feature of the mesophyll (Figs. 84, 85). The spongy tissue is not typical but consists of 7–8 layers of oblong cells with poorly developed intercellular spaces (Fig. 84). Intraxylary phloem (which appears in the stem at one stage and then disappears) is a constant feature of the midrib. It occurs in the medullary zone and is supported on its inner face by groups of sclerenchyma. Worsdell (19) is of opinion that intraxylary soft bast is a vestigial structure, a remnant of the former system of medullary vascular bundles in which the xylem has disappeared. He believes that though it may get modified in the mature stem, its structure can be studied to better advantage in more conservative organs of the plant, *e.g.* leaves, as these have undergone less modification in the course of evolution. The minor veins are supported on the upper and lower surfaces by strands of sclerenchyma. Enlarged storage tracheides, with pitted walls, occur in the mesophyll.

The primary cortex of the root is typically modified as a breathing tissue. In a cross section, it is seen to be composed of bluntly radiate cells (Fig. 86) which are provided with annular thickening ridges. The latter are feebly lignified and form a pretty coherent supporting skeleton (Fig. 87). The pith is pitted and lignified. Cork develops superficially and is of the phelloid type. The surface of the pneumatophores is covered with cork (consisting of lignified, phelloid cells) and prominently developed lenticels (Fig 88). The outer layers of the cortex act as the photosynthetic tissue, while the inner ones are adapted mainly for an exchange of gases. The lacunar cortex is traversed by thickening plates with slit-shaped pits, similar to those noted in *A. majus*, etc. Goebel (5) and Schenck (11) have noticed the presence of isolated cells with peculiar thickening ridges. Such cells are larger than the cortical cells and the ridges are lignified and resemble those of the terrestrial root (Fig. 89). At the distal end of the breathing root, the pith is pitted and lignified; while at the proximal end it is not so. The pith is supported by large cells with thick pitted and lignified walls (Fig. 90). Oil occurs both in the cortex and the pith.

The seedlings are washed ashore in great numbers during the monsoon (Fig. 91). The cotyledons are thick and hold oil and chloroplasts. The hypocotyl is densely covered with anchoring hairs, as shown by Karsten (8), and shows a lacunar cortex. Oil occurs both in the cortex and the pith. Cork formation starts early and arises subepidermally. The first leaves differ in outline from the mature leaves, being linear-lanceolate. The primary root shows a lacunar cortex.

Avicennia alba, Blume. (Verbenaceae).

Avicennia alba, Blume. is a large evergreen shrub, often coming up in abundance on clear ground, forming an extensive bushy growth. The plant develops a large number of stilt-roots and pneumatophores (Fig. 92).

The young parts of the stem are thickly clothed with short trichomes. The latter are longer in *A. alba* and consist of two stalk-cells and a pear-shaped terminal cell (Fig. 93). Owing to their length the trichomes of *A. alba* project considerably beyond the outer surface of the stem. The internal structure resembles, more or less, that of *A. officinalis.* The inner cortex is lacunar, having schizogenously-formed intercellular spaces. A distinct endodermis is wanting, as in *A. officinalis,* but 1–2 of the innermost layers of the cortex hold starch and thus simulate a starch sheath. Tannin and oil occur in the cortex. The stele is broad and the vascular bundles are arranged normally in the young stem. Secondary growth starts early and the older parts show the same anomaly as in *A. officinalis, viz.,* the arising of successive rings of thickening of an extra-fascicular origin. The pith is pitted and lignified. Fusiform, prismatic and acicular crystals are abundant in the young parts. Cork develops superficially and is of the spongy type. The secondary cortex is modified as an aerating tissue (Fig. 94).

In *A. alba*, the narrow groove, on the adaxial surface, runs along the whole length of the short petiole; while the abaxial surface is covered with trichomes similar to those of the stem. The region of the groove is thickly lined with long, uniseriate trichomes (Fig. 95) and glandular hairs (10). The inner structure of the petiole does not differ from that of the previous plant. The lower surface of the leaves is of a dull greyish-white colour, being densely covered with trichomes. The latter are all of one type, each consisting of a short stalk-cell, an elongated body-cell, and a pear-shaped terminal cell placed horizontally and excentrically (Fig. 96). Salt-secreting glands occur on both surfaces (10). The stomata are wholly confined to the lower surface and are protected by the trichomes. The guardcells are surrounded by subsidiary cells which are placed in the same peculiar manner as in *A. officinalis* (Fig 97). The outer cuticular ridges are well developed. The upper epidermis is followed by a prominently developed aqueous tissue, consisting of 5–6 layers of large, irregularly polygonal cells (Fig. 98). The lamina in *A. alba* is 0.39 mm. thick, while the aqueous tissue occupies about 0.20 mm. (9). Thus Van Tieghem's (15) statement that the hypodermis in *A. officinalis* occupies nearly one-half the thickness of the leaf, is seen to apply more correctly to *A. alba.* Oil and minute aggregate crystals occur in the hypodermis. A subepidermal aqueous tissue is also present on the lower surface and is composed of 1–2 layers of clear cells which are elongated in the direction of the long axis of the leaf. The leaf structure inclines more towards the isolateral arrangement. The mesophyll tissue consists of 3–4 layers of more or less closely-packed parenchyma. Oil and tannin are present in the mesophyll cells.

The main roots appear white and soft because of an aerating tissue in the form of the lacunar cortex (Fig. 99). The latter is composed of cells similar to those in *A. officinalis* (Fig. 100). Crystals of oxalate of lime occur in the cortex and the pith. A cross section of the part of the root from which the pneumatophores arise shows a lacunar pith, the lacunae being formed by the undulations of the cell walls. Cork arises superficially and is composed of phelloid cells. The outer surface of the pneumatophores is covered with phelloid cells (holding oil) and lenticels. The cork layer is followed by 3–4 layers of slightly collenchymatous cells forming a sort of an exodermis. Towards the distal end these cells often hold oil and chloroplasts, the latter making the pneumatophores appear green to the naked eye. The comparison of the lacunar cortex of the terrestrial root (Fig. 99) with that of the breathing root (Fig. 101) shows the great increase in size of the lacunæ in the roots which are buried in the mud than in those which are in the air. The isolated cells, with thickening ridges, noted by Goebel (5) and Schenck (11) in the cortex of *A. officinalis*, are few in number and are to be found only in the elder parts of *A. alba* (Fig. 102). The sclerenchymatous cells occurring in the pith of *A. officinalis* are rare in that of the pneumatophores of *A. alba*. Oil and acicular crystals occur in the pith.

The seedlings are washed ashore during the latter half of the monsoon (Fig. 103). The cotyledons are full of chloroplasts, oil and large compound starch grains. The primary root shows the typical lacunar cortex. Cork formation starts early in the outer layers of the cortex. The hypocotyl also possesses a lacunar cortex. Oil and starch are present in the cortex and in the pith. Trichomes do not occur on the epicotyl whose cortex is again lacunar. Glandular hairs make their appearance on the first leaves.

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Explanation of Plates.

The initial magnification is indicated after each figure. All figures have been reduced to about one-third in reproduction.

Sonneratia apetala. Ham.

Fig. 41.—T. S. young stem. (×500).
Fig. 42.—L. S. stem, showing the cortical cells with a spicule. (×240).

Fig. 43.—T. S. stem, showing the pith cells with a sclereide. (×240).

Fig. 44.—T. S. petiole, showing the lacunar cortex with a sclereide. (×500).

Fig. 45.—Upper epidermis of the leaf. (×500).

Fig. 46.—Upper epidermis of the leaf, after treating with KOH. Explanation in the text. (×500).

Fig. 47.—T. S. leaf, showing the structure of the stoma; *p*, palisade cells. (×500).

Fig. 48.—T. S. leaf, showing the palisade cells, *p* and the aqueous tissue, *a*. (×500).

Fig. 49.—T. S. leaf, showing a sclereide in the aqueous tissue. (×240).

Fig. 50.—T. S. leaf, showing the enlarged tracheides. (×500).

Fig. 51.—T. S. leaf, showing the mucilage cell, *m* and the thickening *t*. (×500).

Fig. 52.—Photomicrograph. T. S. terrestrial root, showing the aerating system. (×82).

Fig. 53.—T. S. terrestrial root. Explanation in the text. (×240).

Fig. 54.—L. S. terrestrial root. Explanation in the text. (×240).

Fig. 55.—Photograph, showing the pneumatophores.

Fig. 56.—T. S. pneumatophore, showing the cortex at the distal end (×240).

Fig. 57.—L. S. of the above, showing a sclereide. (×240).

Fig. 58.—T. S. pneumatophore, showing the cortex at the proximal end. (×240).

Fig. 59.—T. S. pneumatophore, showing a cork-lamella. Explanation in the text. (×500).

Fig. 60.—T. S. pneumatophore, showing the structure of the outer surface. Explanation in the text. (×500).

Fig. 61.—T. S. first leaf of the seedling. (×500).

Aegiceras majus, Gaertn.

Fig. 62.—T. S. stem, showing a secretory cavity (*c*) in the cortex. (×500).

Fig. 63.—T. S. stem, showing the pith cells. (×500).

Fig. 64.—Lower epidermis of the leaf. (×500).

Fig. 65.—T. S. leaf, showing the stoma and the spongy tissue. (×500).

Fig. 66.—T. S. leaf: *e*, upper epidermis; *a*, aqueous tissue; *p*, palisade cells. (×360).

Fig. 67.—L. S. root, showing the thickening plates. (× 500).

Fig. 68.—Photograph, showing the seedlings.

Acanthus ilicifolius, Linn.

Fig. 69.—Photograph, showing the halophytic form of the plant.

Fig. 70.—Photograph, showing the mesophytic form: plant A.

Fig. 71.—Photograph, showing plant B which was submerged in water upto the point indicated by the arrow.

Fig. 72.—Diagrammatic figure, showing the origin of the stelar system of the petiole. Explanation in the text.

Fig. 73.—Lower epidermis of the leaf. (×500).

Fig. 74.—T. S. leaf: *g*, gland; *a*, aqueous tissue. (×500).

Fig. 75.—T. S. leaf: *e*, upper epidermis; *a*, aqueous tissue; *p*, palisade cells. (×240).

Fig. 76.—Photomicrograph. T. S. leaf, showing the palisade cells with oil globules. (×500).

Fig. 77.—T. S. leaf, showing the spongy tissue. (×500).

Fig. 78.—Photomicrograph. T. S. terrestrial root, showing the lacunar cortex. (×82).

Fig. 79.—T. S. leaf of plant B, showing the spongy tissue. (×240).

Avicennia officinalis, Linn.

Fig. 80.—A trichome from the stem. (×500).

Fig. 81.—A trichome lining the groove of the petiole. (×240).

Fig. 82.—Short (A) and long (B) trichomes on the lower surface of the leaf. (×500).

Fig. 83.—Lower epidermis of the leaf—trichomes removed. (×500).

Fig. 84.—T. S. leaf, showing the stoma and the spongy tissue holding chloroplasts and oil. (×500).

Fig. 85.—T. S. leaf: *e*, upper epidermis; *g*, gland; *a*, aqueous tissue; *p*, palisade cells. (×500).

Fig. 86.—T. S. terrestrial root, showing the lacunar cortex. (× 500).

Fig. 87.—Radial L. S. terrestrial root, showing the skeleton formed by the thickening ridges. (×500).

Fig. 88.—Photograph, showing the pneumatophores.

Fig. 89.—T. S. pneumatophore, showing the lacunar cortex. (×240).

Fig. 90.—T. S. pneumatophore, showing the pith region with a large sclerenchymatous cell. (× 240).

Fig. 91.—Photograph, showing the various stages of the seedling.

Avicennia alba, Blume.

Fig. 92.—Photograph, showing a plant with stilt-roots and pneumatophores.

Fig. 93.—A trichome from the young stem. (× 500).

Fig. 94.—T. S. old stem, showing the secondary cortex. (× 240).

Fig. 95.—A trichome and a glandular hair from the groove of the petiole. (× 240).

Fig. 96.—A trichome on the lower surface of the leaf. (× 500).

Fig. 97.—T. S. leaf, showing the stoma and the spongy tissue. (× 500).

Fig. 98.—T. S. leaf: *e*, upper epidermis; *a*, aqueous tissue; *p*, palisade-cells with oil. (× 500).

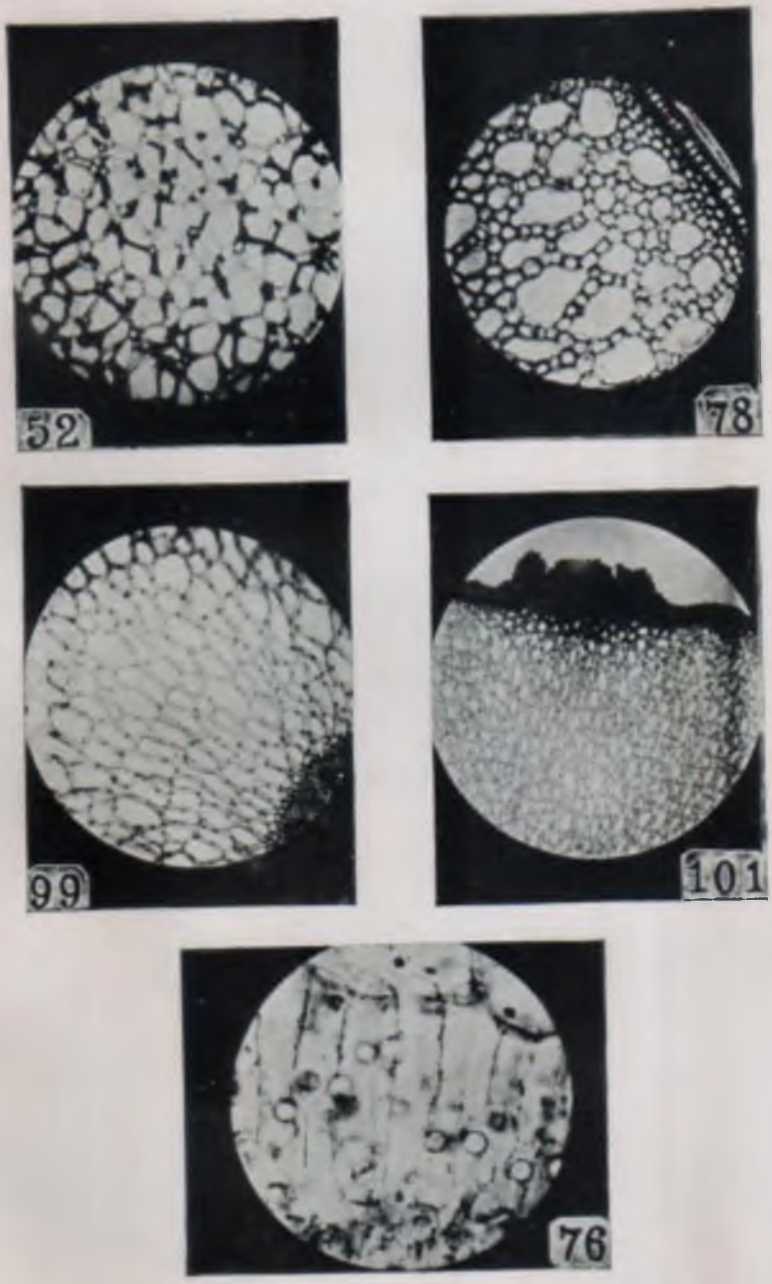
Fig. 99.—Photomicrograph. T. S. terrestrial root showing the lacunar cortex. (× 82).

Fig. 100.—T. S. terrestrial root, showing the lacunar cortex. (× 240).

Fig. 101.—Photomicrograph. T. S. pneumatophore, showing a lenticel and the lacunar cortex. (× 82).

Fig. 102.—T. S. pneumatophore, showing a large supporting cell with thickening ridges. (× 240).

Fig. 103.—Photograph, showing the various stages of the seedling.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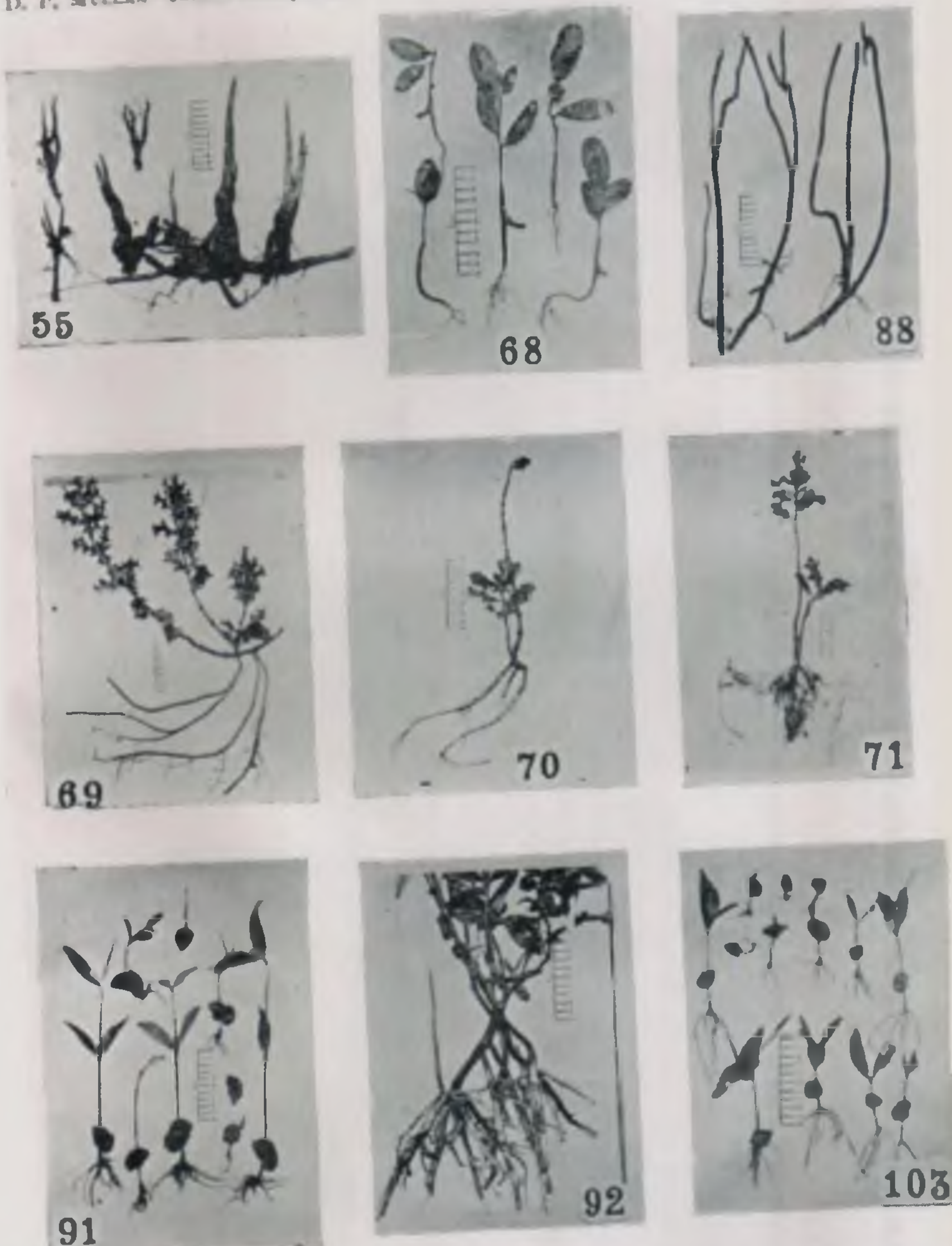
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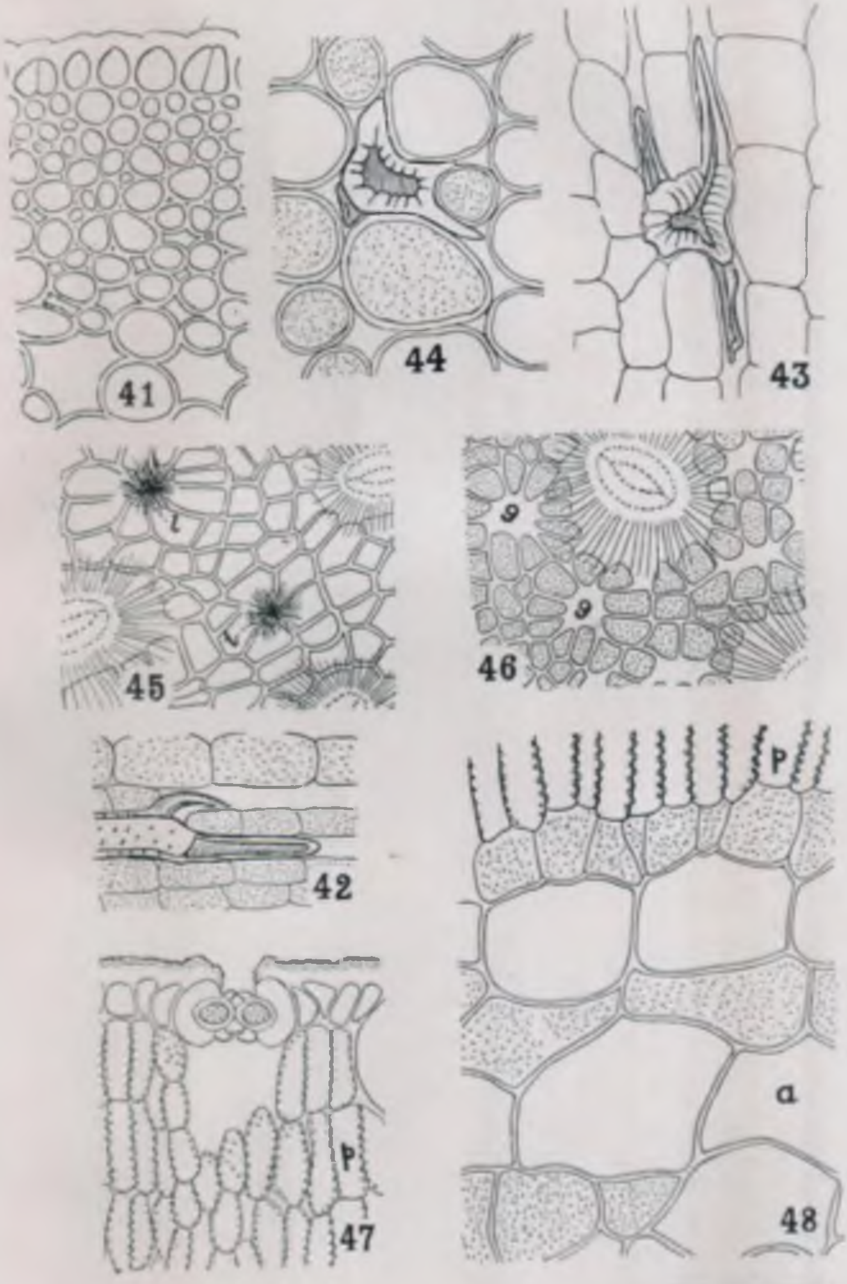
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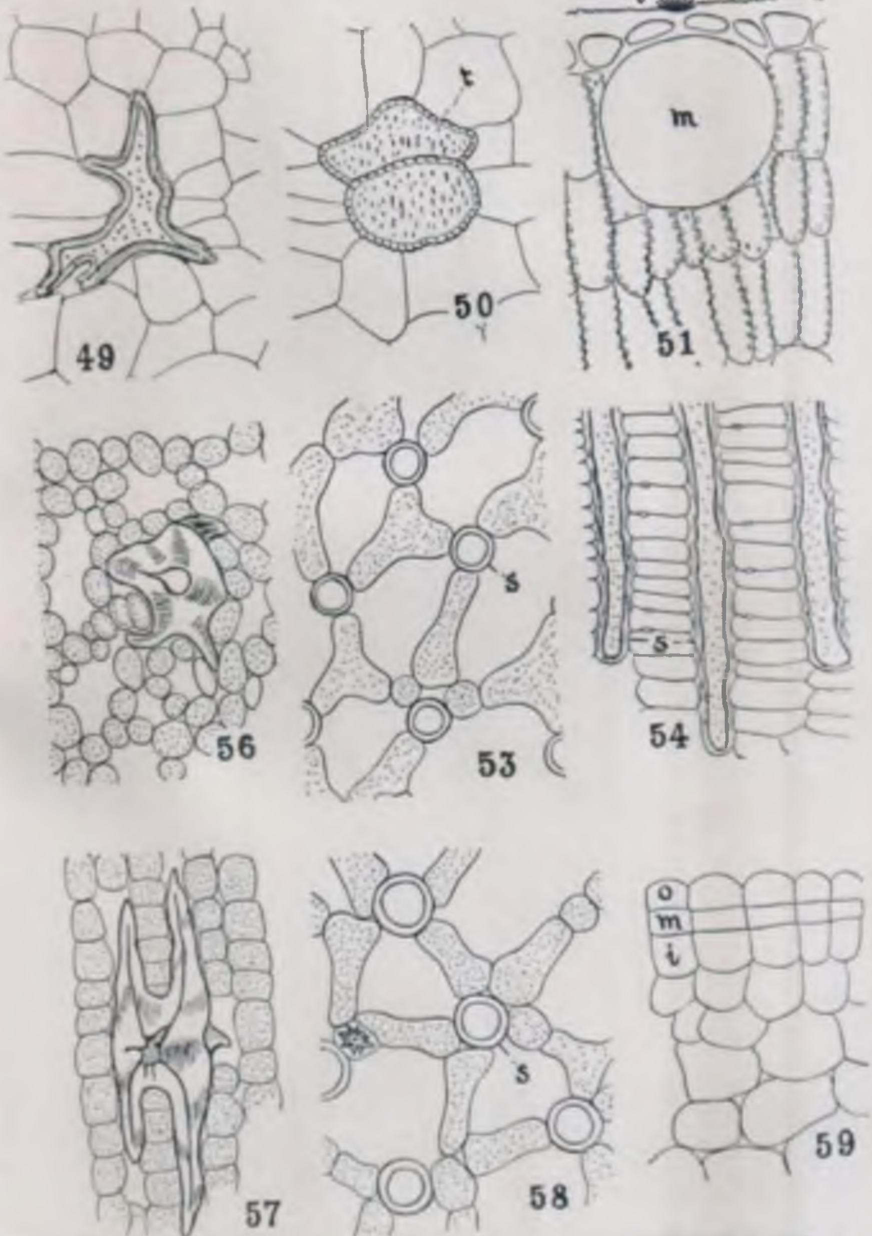
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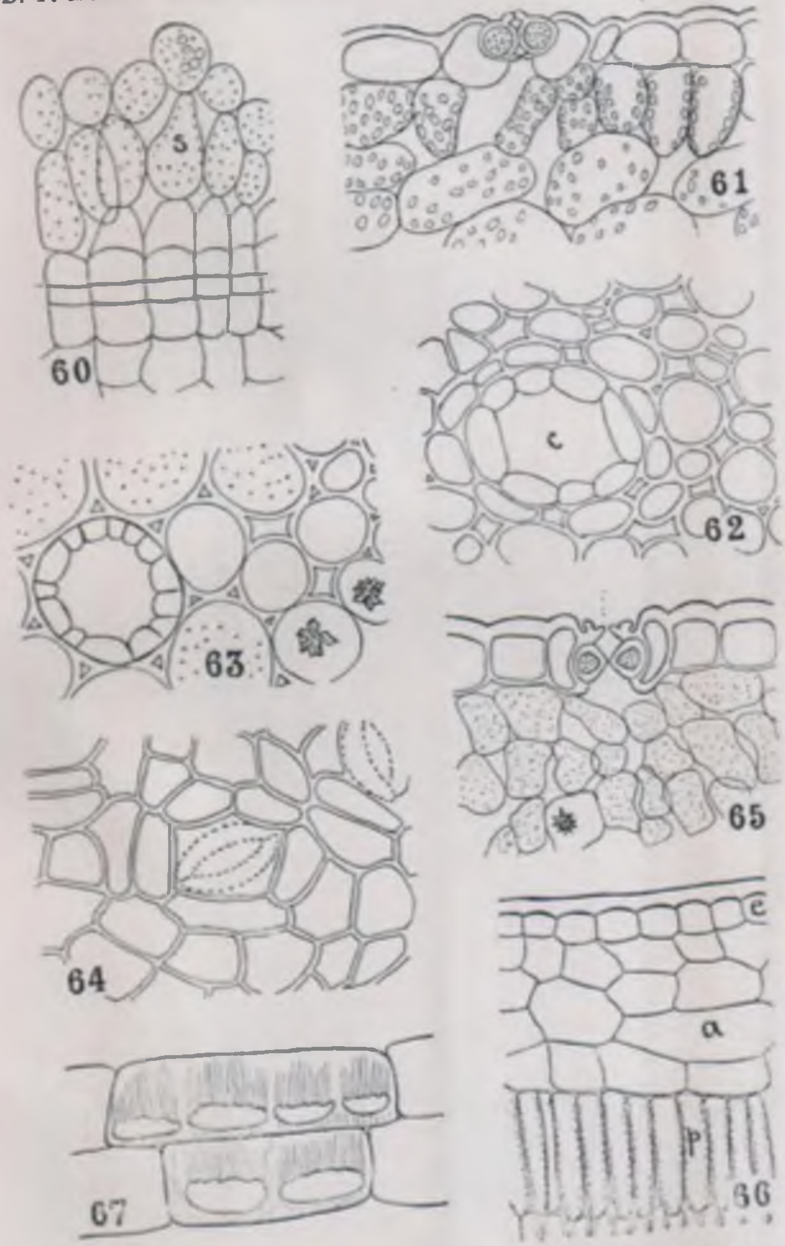
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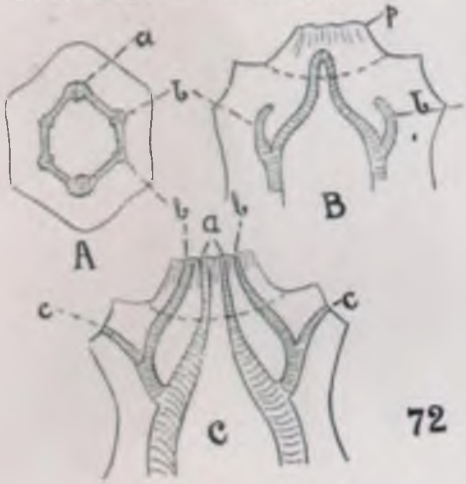

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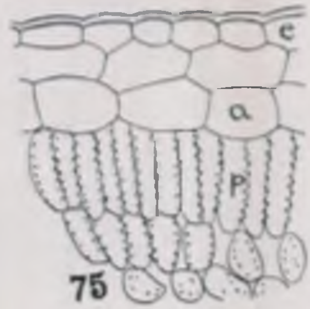

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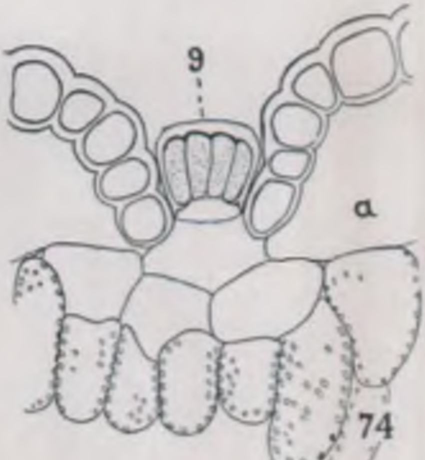

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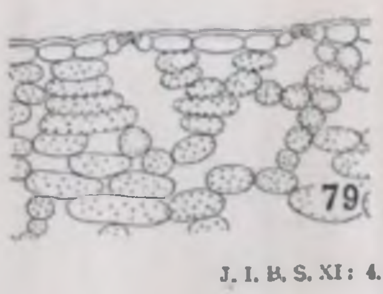
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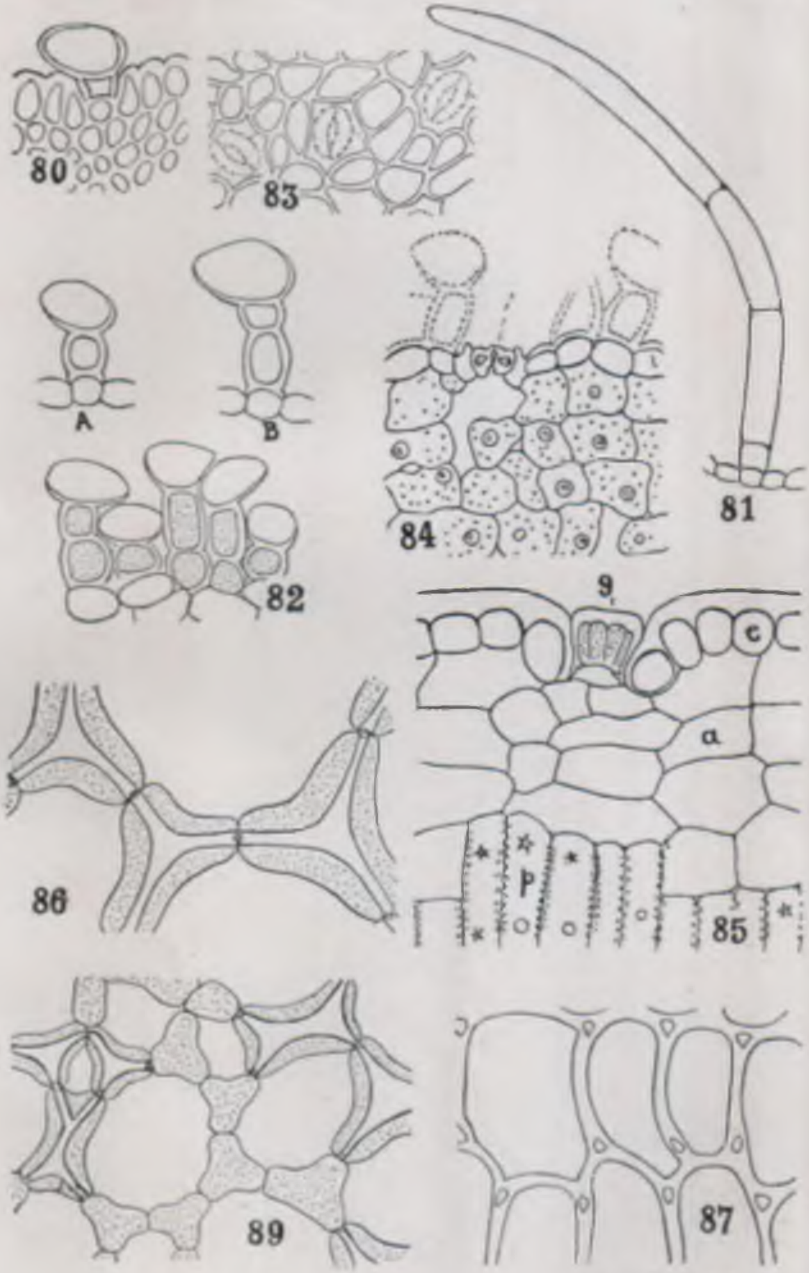
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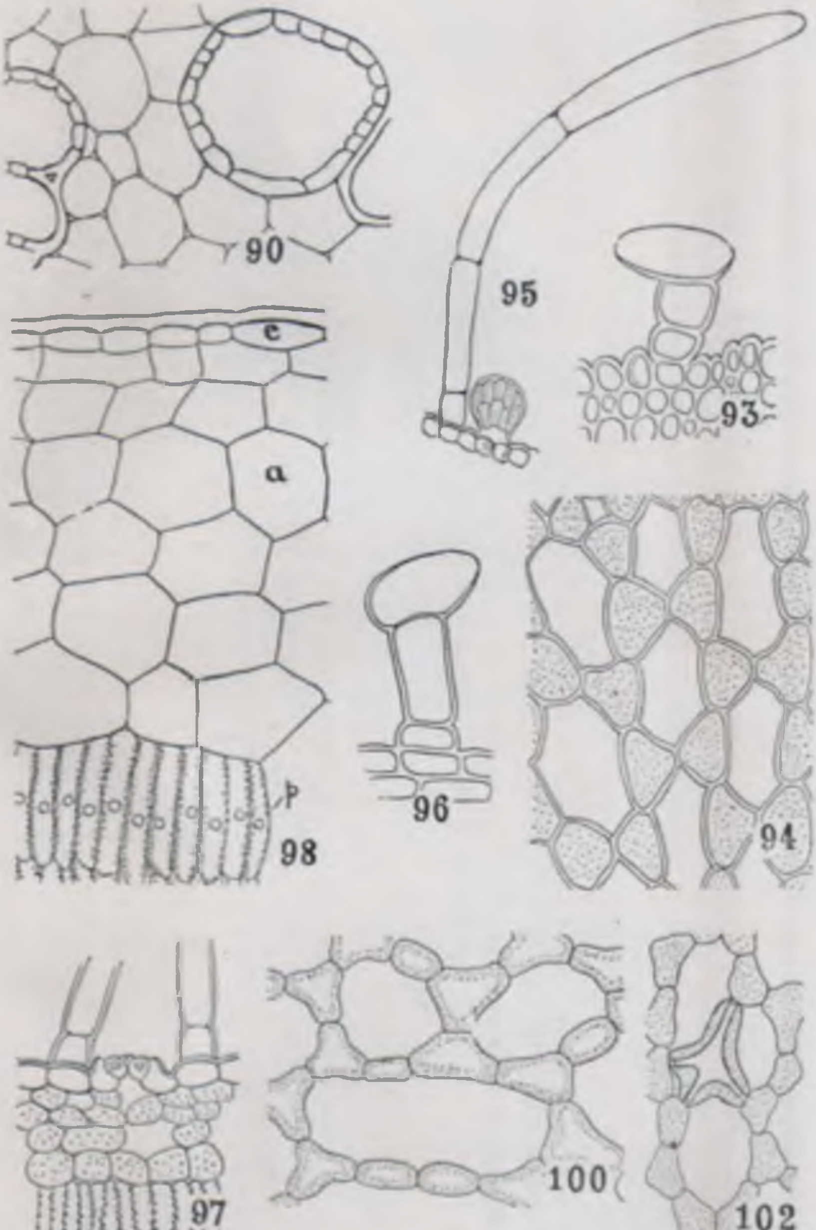
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