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OBSERVATIONS ON THE BIOLOGY AND PHYSIOLOGICAL ANATOMY OF SOME INDIAN HALOPHYTES

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Introduction.

The plants dealt with in this paper constitute the vegetation of the sea-shore. They fall naturally into the two main oecological groups, recognized by Warming (15), *viz.*: (*a*) Littoral Swamp Forest (Mangrove) and (*b*) Psammophilous Halophytes.

Of the two groups, the sand formation seems to have received scant attention. Warming (16) and others have dealt with the sand formations of the West, mainly from the oecological standpoint, with very little information on the anatomy of the plants concerned. The Littoral Swamp Forest has received more attention. Schimper (12, 13), Karsten (9, 10), Goebel (4, 5) and Warming (17) have contributed much towards the understanding of the mangrove formation. But the works referred to, while containing much that was new to science, are in the form of memoirs, dealing mainly with the biology of the plants with rather meagre information regarding their anatomy. As far as the present writer is aware, apart from the information given in such works and passing references to some particular organ of some of the plants, no systematic or sustained effort has been made to study in detail the internal structure of the coast vegetation.

It is the intention of the present writer to supplement in these pages our present knowledge of the halophytes by recording whatever additional information he has acquired as to their biological peculiarities and especially to present in greater detail, than has been done heretofore, the anatomy of the plants in question with special reference to the influence of the environment. In this connection instances are recorded of changes (both morphological and anatomical) which the plants undergo with reference to their habitat, such as: growing in salt or fresh water and on ordinary soil or on the sands of the sea-shore.

Method.

In all, 25 plants, typical of the sea-shore, have been examined from which some have been selected to illustrate the peculiar anatomical characteristics. The plants are roughly divided into two groups: Part I dealing with the plants living typically in the salt swamp and Part II with those growing upon the sandy shore. Several of the perennial psammophilous halophytes were observed during the dry and the rainy seasons in order to note any change that may be induced by the access of fresh water. In order to note the effect of a different environment, a few halophytes were taken from their natural habitat and grown under mesophytic conditions. The biological descriptions, especially of Part II, are illustrated by photographs showing some marked peculiarity of the plants or some change induced in them by a different environment. The anatomical descriptions are illustrated by photomicrographs and camera lucida sketches. In order to get at the average development of some common characteristic tissue, micrometric measurements are recorded in each case. Various characteristics, such as, the thickness of the leaf lamina, the total number of stomata per unit area, the distribution of stomata between the upper and the lower leaf surfaces, etc., were investigated in each plant examined. In every case the anatomy of the stem, leaf and root is given; while, in the case of viviparous plants, the internal structure of the seedling is also added. The cell inclusions noted in the description were tested microchemically. For the purpose of anatomical examination fresh, or alcohol- or formalin-preserved material was used. In most cases hand sections have been found to be more convenient. In the paraffin method, the ordinary fixative proves too strong for the delicate aqueous tissue and in cases where the aerating tissue occurs the penetration of the paraffin is considerably hampered. The plants for the study were gathered from various places in the neighbourhood of Bombay.

Descriptive.

Part I.

Littoral Swamp Forest (Mangrove).

The plants described in this part comprise a number of littoral species, most of them being collectively known as the mangroves. The latter, together with their allies, make up the curious littoral forest known as the mangrove swamp (Fig. 1). Schimper (13) divides the mangrove formations of the world into an eastern and a western area. According to Blatter (1), out of 21 species of the eastern mangrove, 14 occur in the Bombay Presidency. The soil of the salt marsh is mainly soft mud which naturally contains a large percentage of salt, this being particularly great during the intertidal periods when evaporation takes place. The swampy ground impregnated with salt, is thus a physiologically dry substratum which renders absorption difficult. The mangroves overcome this difficulty by developing various xerophytic devices. Schimper (12) was the first to show the remarkable agreement between the leaves of the mangroves and the xerophytes. Since the plants of the salt swamp live in a substratum which is poor in oxygen, special devices for the aerating of their submerged parts are of common occurrence.

Rhizophora mucronata, Lamk. (Rhizophoraceae).

The most important natural order in the mangrove swamp is that of the Rhizophoraceae of which *Rhizophora mucronata*, Lamk. is the "true mangrove". It is a moderate-sized tree which grows typically on the outward and seaward edge of the swamp where the water is decidedly salty and the action of the tide is most strongly felt. As Schimper (13) observes: no tree is better equipped for resisting the movement of the tide on the soft mud as *R. mucronata* and this it does by developing numerous stilt-roots. The same author (13) has observed specimens of the plant growing successfully in undiluted salt water on the coral islands of the Java Sea.

In the young stem the cuticle is very thickly developed (Fig. 2). The epidermal cells are more or less squarish in cross section and hold a substance which appears brownish in preserved material. According to its reaction with ferrous salts this substance is seen to be mainly tannin. Besides the latter, the cells also hold oil. The walls of the cortical cells are pitted. As growth proceeds many of the cortical cells become full of tannin and oil. Aggregate crystals of oxalate of lime occur in vertical rows. The primary cortex of the older part of the stem becomes distinctly lacunar and seems to act as the aerating tissue (Fig. 3). The lacunar cortex is supported by H-shaped internal hairs or spicules with their arms projecting into the lacunae. Warming (17) has observed the occurrence of similar spicules in *R. Mangle*, Linn. and Solereder (14) considers them as a characteristic feature of the whole genus. In *R. mucronata*, the spicules are seen to occur singly in the outer layers of the primary cortex. They are placed vertically and their arms project into the lacunae of the cortex (Fig. 4). The spicules are lignified and evidently act as mechanical supports for the otherwise soft cortex. In the older parts of the stem the innermost layers of the cortex are strengthened by groups of sclereides (Fig. 5). The latter are multiradiate, having a broad central piece and short arms (Fig. 6). The sclereides arise in groups, with their central pieces in close contact and the arms interlocking. These groups arise close together and form a broken ring outside the endodermis. Since the hard bast is feebly developed, its function seems to be taken up by the groups of sclereides which are strongly lignified. The lamina of some of the sclereides hold tannin and oil. The endodermis is distinct and holds starch. The pericycle consists of 3–4 layers among which tannin sacs occur. Pericyclic hard bast consists of very small fibres. The primary medullary rays are 2–3 seriate and the cells hold tannin and oil. The pith is parenchymatous and the side-walls of the cells are pitted. The whole pith is lacunar, being traversed by schizogenously developed cavities. The pith cells hold a little tannin and much oil, the latter appearing as large globules. H-shaped spicules also occur in the pith. In the stem, cork arises subepidermally and consists of phelloid cells with more or less lignified walls. Lenticels are prominently developed on the older parts. The secondary cortex is seen to be mainly differentiated as an aerating tissue. The lacunae are schizogenous in origin and are very prominently developed, especially towards the base of the stem (Fig. 7). Most of the cortical cells appear in cross section to be bluntly stellate, the whole tissue resembling more or less, the "parenchyme etoile" of Duval-Jouve (3). Tannin and oil occur in the secondary cortex.

The inner cortex of the petiole of the leaf resembles that of the stem, being lacunar and strengthened by lignified spicules. The vascular supply of the petiole is seen to be composed of an oval ring of bundles enclosing a medullary zone. The latter is traversed by intercellular spaces and is supported by H-shaped spicular lignified cells. Scattered vascular bundles also occur in the medullary zone. The main stele is sheathed round by a distinct endodermis. Tannin and oil occur in the cortex as well as in the medulla of the petiole.

In the lamina, the cuticle is well developed on both the surfaces. The epidermal cells have thickish and straight lateral walls. The upper epidermal cells are larger and some of them hold a few rod-shaped or cubical crystals of oxalate of lime. The stomata are confined to the lower surface of the leaf (Fig. 8) and are about 100 per sq. mm. They are typically xerophytic in structure, being considerably sunk below the outer surface of the leaf. The outer cuticular ridges are very prominent and are split so as to form a double chamber (8). The inner cuticular ridges are also prominent and are pressed against each other (Fig. 9). The guard cells are surrounded by subsidiary cells whose inner walls are thick. As noted by Schimper (12) the leaf structure is dorsiventral and a 3–4 layered hypodermal aqueous tissue occurs beneath the upper epidermis (Fig. 10). The outer two layers of the aqueous tissue are, as a rule, full of tannin and oil. Crystal-cells, each holding an aggregate crystal of oxalate of lime, occur in the aqueous tissue. In a leaf 0.6 mm. thick, the aqueous tissue occupies 0.2 mm. of the total thickness (11). Schimper (12) observes that the dimension of the aqueous tissue varies in sun and shade, leaves of the same tree, being more in the former and less in the latter. Furthermore, he notes that the old, yellow leaves are thicker and seem to serve as water reservoirs for the younger leaves and this is demonstrated to be a fact by Haberlandt (7). Large, elongated, mucilage cells arise from the inner face of the aqueous tissue on the upper surface and are insinuated between the palisade cells. The palisade tissue consists of 3–4 layers of narrow cells. Secretory cells, holding tannin and oil, are intercalated between the palisade cells. The former resemble the palisade cells in outline but are broader and, at times, longer than the latter. The spongy tissue consists of 9–10 layers of cells, some of which are elongated in the direction parallel to the leaf surface (Fig. 9). Secretory cells, holding tannin and oil, as well as crystal cells occur among the spongy tissue. A hypodermal aqueous tissue also occurs on the under surface of the leaf where it consists of a single layer of cells (Fig. 9) from which large, colourless cells project into the spongy tissue. Solereder (14) remarks: "The mesophyll of Rhizophoraceae contains spicular cells of two shapes. Those in the palisade tissue are more or less distinctly H-shaped, while in the spongy tissue they are star-shaped. Both forms occur in *R. conjugata* and *R. mucronata*". In the leaves of *R. mucronata*, examined by the present writer, it is found that the spicules are mostly confined to a short distance on either side of the midrib. Farther away from the midrib, the stellate hairs become rare or are even absent; while the H-shaped spicules are seen to occur only in relation with the minor veins, being present both on the upper and lower side of each vascular bundle. The minor veins, in cross section, are invested by a sheath of parenchymatous cells. As a rule, the cells towards the upper surface hold tannin and oil. The ground tissue of the midrib is lacunar and possesses star-shaped spicules (Fig. 11). Some of the cells are seen to be stiffened with thickening plates having annular slits. These plates resemble those occurring in the roots of several mangroves to be described later. Such thickening plates are mostly developed on the lower side of the leaf, in the region where the prominent midrib merges into the lamina.

Cooke (2) observes that in *R. mucronata:* "The leaves are dotted with black dots beneath." On the occurrence of such dots Solereder (14) remarks: "In certain species the lower side of the leaves bears numerous brown dots, which are often styled glands in anatomical descriptions. These dots as shown by microscopical examination are not glandular but represent local formations of cork—the so-called cork-warts". In *R. mucronata*, the cork-warts are found to be present on both the surfaces of the leaf, being fewer on the upper and very numerous on the lower surface. The cork cells arise superficially at first, but later, they cut deeper and deeper into the mesophyll. As a rule, the cork-warts on the upper surface are larger than those on the lower and extend deeper, often going right down to the spongy tissue (Fig. 12). At times, due to the rapid development of the cork cells, the epidermis gets ruptured and then the structure comes to resemble a miniature lenticel.

The anatomical examination of the aerial and subterranean portions of the stilt-roots shows characteristic differences. In the terrestrial root, the stele is contracted. The outer pith cells are thick-walled, pitted and lignified and form, together with the xylem elements, a strong, central zone of mechanical tissue. Tannin and oil occur in the pith. Secretory cells also occur in the pericycle and, in cross section, appear to form arcs over the phloem groups. The most characteristic feature of the terrestrial root is the primary cortex (Fig. 13). Warming (17) has studied the structure of the root of *R. Mangle*, Linn. The primary cortex of *R. mucronata*, resembles that of *R. Mangle* in general structure. The cortex is broad and lacunar, being modified mainly as the aerating tissue. The cortical cells are of two kinds. Most of them are stretched radially and are connected tangentially with one another by short, lateral arms. These more or less stellate cells (*t*) are mostly clear and are provided with peculiar thickening ridges (Fig. 14). The latter (*r*) are feebly lignified and, in radial longitudinal section, are seen to form a coherent tissue Warming (17), from his study of *R. Mangle*, is of opinion that such ridges are devices against side pressure. Here and there, at the junctions of the thin-walled cells, occur the cells of the second type. The latter are narrow, tubular cells (*s*) which are elongated vertically. These are secretory cells and are full of tannin and oil. The lacunar cortex is further supported by multiradiate, lignified sclereides (Fig. 15). Cork develops superficially and consists of more or less lignified, phelloid cells.

The primary cortex of the epigeous part of the stilt-root differs considerably, in dimension and structure, from that of the part buried in the mud. A comparison of the photomicrographs (magnified equally) of the primary cortex of the terrestrial (Fig. 13) and aerial part (Fig. 16) brings out the characteristic differences. The cortex in the epigeous parts is much reduced, both the cortical cells and the lacunae being small. The cortical cells are all similar and present a roundish polygonal outline in cross section. The typical thickening ridges of the terrestrial root are absent in the aerial part. Tannin and oil are present in many cells. H-shaped spicules are strongly lignified and are more numerously developed in the aerial part of the root. The stele is comparatively very broad. The secretory cells in the pericycle are more numerous. The inner faces of the xylem groups are strengthened by strands of strongly lignified sclerenchyma. The pith is broad and holds secretory cells and spicules. The outer surface of the epigeous part is covered by lenticels. All these characteristics show that the epigeous part of the root is well adapted to an aerial existence.

Schimper (12, 13) and Karsten (9) have described the viviparous fruits and the mode of germination of *Rhizophora*. The seedlings of *R. mucronata* (Fig. 17) are washed ashore during the monsoon. The outer layer of the mature fruit is covered by cork. Tannin and oil are present in the fruit, the former being more concentrated in the outer layers. The cotyledons are composed of thin-walled parenchyma with intercellular spaces. Some of the cells hold tannin and oil, while others have starch. The long green, club-shaped hypocotyl is smooth and thickly coated with wax. The outer green surface of the young hypocotyl bears a few scattered brown dots which resemble the cork-warts of the leaf. As growth proceeds each dot develops into a lenticel (Fig. 18). As the outer surface of the green hypocotyl is astomatic, the lenticels seem to facilitate the exchange of gases for the assimilatory tissues. Besides, as Haberlandt (6) has shown, since little water vapour escapes through the lenticels, they may also serve to reduce transpiration. As long as the viviparous fruit is attached to the tree, the lenticels remain few and small, but after falling to the ground they increase considerably in size and number, thus facilitating the exchange of gases for the roots buried in the mud. The cuticle of the hypocotyl is well developed and the epidermal cells hold tannin and oil. As the girth of the hypocotyl increases, the epidermal cells seem to multiply by the formation of secondary division walls. The cortex is parenchymatous, its outer cells holding chloroplasts with included starch. Tannin and oil are present in the hypodermis and in the inner cortex. After germination the cortex becomes distinctly lacunar, especially towards the basal part of the hypocotyl which is washed by the rising tide. A characteristic feature of the cortex is the more or less spherical masses of stone cells. The latter occur in a circle a little within the outer surface of the hypocotyl and are so large as to be distinctly visible to the naked eye as white dots. While the hypocotyl is still attached to the parent tree, the masses of stone cells remain in an undifferentiated state (Fig. 18), each being composed of more or less thin-walled polygonal cells some of which hold tannin and oil. But soon after germination, they get fully differentiated and strongly lignified. Thus the stone cells, by their peripheral position, act as the mechanical tissue of the hypocotyl, evidently protecting the latter against the bending strains caused mainly by the rising tide. Besides the stone cells, isolated lignified, multiradiate sclereides also occur in the cortex. The pith resembles that of the stem and the cells hold tannin, oil or starch. Lignified sclereides also occur in the pith.

In the epicotyl, the cortex and the pith are lacunar, the latter more so than the former. In the pith, starch and oil are present but tannin is feebly developed. Aggregate crystals of oxalate of lime are more numerous in the cortex and the pith of the epicotyl than in those of the mature stem.

Ceriops candolleana, Arn. (Rhizophoraceae).

Ceriops candolleana, Arn. is a glabrous shrub which grows well out in the swamp usually occurring behind the growth of *Rhizophora mucronata,* Lamk.

In the stem, the cuticle is very thickly developed (Fig. 19) and the protective function of the cuticle is augmented by a coating of wax. In the young parts, the epidermal cells are clear but in the older parts they hold tannin and oil. Some of the epidermal cells show secondary division walls which run at right angles to the outer surface of the stem. Stomata do not occur on the stem. The hypodermis consists of closely-packed polygonal cells which, in the young part, hold chloroplasts with included starch. The rest of the cortex is lacunar, having schizogenously formed air spaces (Fig. 20). The inner cortical cells hold starch. Slender, vertically elongated secretory cells, holding tannin and oil, occur throughout the cortex. Aggregate crystals are present and are more numerous in the inner cortex where the crystal cells are arranged in vertical rows. A 3–4 layered pericycle holds crystal cells and secretory cells. Isolated groups of pericyclic fibres are present. The primary rays are well developed, being 3–6 seriate and have a tendency to dilate in the cambial region. The ray cells hold tannin and oil or a few starch grains. The pith is broad and the outer cells are pitted and lignified. Secretory cells and crystal cells, similar to those of the cortex, occur in the pith. The phellogen arises in the last layer of the hypodermis. The cork is of the spongy type and consists of phelloid cells with more or less lignified walls. Lenticels occur on the older parts. The secondary cortex, at maturity, develops schizogenous cavities. Some of the cortical cells are stiffened by peculiar thickening plates with slit-shaped pits. Tannin is most abundant in the secondary cortex.

In the petiole of the leaf, the cuticle is well developed. The hypodermis acts as the photosynthetic tissue, while the rest of the cortex is lacunar. Tannin and oil occur in the cortex, being most abundant in the hypodermis. The vascular supply consists of a ring of bundles with a single medullary bundle. In the lamina, the cuticle is prominently developed on the upper surface. Tannin occurs in some of the epidermal cells. The stomata are small and depressed (Fig. 21). They are confined to the lower surface of the leaf, being about 100 per sq. mm. As Holtermann (8) has noted, the outer cuticular ridges are split into two (Fig. 22). Schimper (12) has noted a two-layered hypodermal aqueous tissue beneath the upper epidermis (Fig. 23). At the margin of the leaf, which is directed to the sky, the hypodermis has a tendency to become three-layered. The cells of the hypodermis are not clear but are, as a rule, full of tannin and oil. A few chloroplasts with included starch also occur in the hypodermal cells which are thus seen to take some part in the photosynthetic activity. The lower epidermis is also followed by a single-layered hypodermis (Fig. 22) holding tannin and oil and a few chloroplasts. The leaf lamina is about 0.6 mm. thick, the aqueous tissue occupying about 0.07 mm. of the total thickness (11). The palisade tissue consists of two layers of short, narrow cells among which elongated secretory cells (holding tannin and oil) are insinuated (Fig. 23). Crystal cells (with aggregate crystals of oxalate of lime) arise at short intervals in a row towards the inner face of the palisade tissue. The cells composing the outer layer of the spongy tissue are elongated like the palisade cells (Fig. 22), thus giving the leaf a more or less centric structure. The rest of the spongy tissue is typical. Distinct starch sheaths invest the main as well as the minor veins. Enlarged terminal storage-tracheides occur in the mesophyll (12).

The main roots of *C. candolleana* are stout and radiate out from the lower part of the stem, acting more or less like prop-roots (Fig. 24); while the roots which are buried deeper in the mud are slender. A cross section of one of the slender roots shows a contracted stele in the centre. Secretory cells, with tannin and oil, are present in the secondary phloem and in the pericycle The primary rays also hold tannin and oil. The outer pith cells are thick-walled, pitted and lignified, while in the lateral roots the entire pith gets lignified. The most characteristic tissue of the root is the cortex (Fig. 25) which is lacunar and resembles in general structure that of *R. mucronata*. Thus the primary cortex is composed of two types of cells (Fig. 26): the major part consisting of radially stretched, clear cells which are provided with annular thickening ridges. The latter forms a pretty coherent skeleton (Fig. 27). At the junction of the radially stretched cells come smaller cells (either singly or in pairs) which hold tannin. These secretory cells are tubular and run vertically in the cortex (Figs. 26, 27). The air spaces of the lacunar cortex are schizogenous in origin. The multiradiate sclereides of *R. mucronata* are absent in the primary cortex of *C. candolleana*. Cork arises superficially and consists of phelloid cells with more or less lignified walls.

The internal structure of the stout, prop-like roots differs in several respects from that of the slender roots described above. The stele of the main roots is broad and both the xylem and the hard bast are strongly lignified. The cortex is broad and the lacunae are distinctly visible to the naked eye. The thickening ridges are lignified throughout. The most striking difference occurs in the pith. In the slender roots, the pith is composed of roundish polygonal cells with small intercellular spaces. In the stout roots, the outer 1–2 layers are composed of polygonal cells with pitted and lignified walls. But the inner pith consists of clear, radially stretched cells with thickening ridges and secretory cells placed at their junctions (Fig. 28). The ridges are very prominently developed in this region and are lignified. The lacunae are wide and are radially arranged around each secretory cell. Thus in the stout, prop-like roots, the cortex as well as the pith are adapted to act as the aerating tissue.

Vivipary of *C. candolleana* is studied by Karsten (9). The outermost layer of the fruit is heavily coated with wax which is deposited in the form of flakes. Masses of strongly lignified stone cells occur around the inner side of the fruit. The hypocotyl (Fig. 29) is green when young, but turns reddish-brown as it elongates. The cuticle is very thickly developed (about 0.3 mm. in thickness) and shows oblique striations (Fig. 30). The epidermal cells, in cross section, appear as narrow cells which are elongated at right angles to the outer surface of the hypocotyl. The cells show secondary division walls. The epidermal cells hold tannin and a little oil. The hypodermis and the outer cortex act as the photosynthetic tissue. Later on, the cells get full of tannin and oil, hence the change of colour of the hypocotyl from green to reddish-brown. The mature hypocotyl shows a lacunar cortex which is full of tannin and oil. The pith also becomes lacunar and holds starch, as well as tannin and oil.

Bruguiera caryophylloides, Blume. (Rhizophoraceae).

Bruguiera caryophylloides, Blume is the smallest and, according to some, probably the rarest species of the genus. It is noted to occur in the southern parts of the Presidency (2) but a few plants were found growing in a creek to the north of Bombay.

In surface view, the epidermal cells of the stem appear of various shapes, while in cross section (Fig. 31), they appear more or less conical. The peculiar shape of the cells is due to the thickening of the lateral walls, it being greater towards the outer than towards the inner end of the cell. The cuticle is thickly developed and the external walls of the cells arch outwards. The young parts of the stem are grooved. The hypodermis consists of 5–6 layers of polygonal cells with thick and pitted walls. In the young parts, it holds a few chloroplasts with included starch. Tannin and oil are present in most cells. The rest of the cortex is parenchymatous and is lacunar (Fig. 32). The lacunae are schizogenous in origin and increase in size and number in the older parts of the stem. Secretory cells, holding tannin and oil, occur throughout the cortex and are arranged in vertical rows. Aggregate crystals of calcium oxalate are mainly to be found in the inner cortex. Pericyclic hard bast occurs as single fibres or in isolated groups. Crystal cells and secretory cells also occur in the pericycle. Vertically elongated, tubular, secretory cells occur in the secondary bast. The primary medullary rays are well developed and the ray cells are thick-walled and prominently pitted. Some of the ray cells hold tannin and oil, while those in the cambial region hold starch. The pith is prominently pitted and holds aggregate crystals and secretory cells disposed in vertical rows. Cork arises superficially and is of the spongy type, being composed of phelloid cells with more or less lignified walls. The secondary cortex is very lacunar and consists of more or less bluntly stellate cells (Fig. 33). Groups of strongly lignified stone cells support the outer margin of the lacunar cortex, some of the groups forming tangentially elongated arcs of mechanical tissue. Tannin is abundantly developed in this region.

The petiole repeats the general structure of the stem. The hypodermis is pitted and holds tannin. The outer cortex acts as the photosynthetic tissue, while the inner one is lacunar. Secretory cells holding tannin occur in the soft bast. The medullary rays are well developed and hold tannin and oil. In the lamina, the cuticle is moderately developed on the upper surface and the epidermal cells hold oil. Stomata are wholly confined to the under surface of the leaf (Fig. 34) and are about 150 per sq. mm. The stomata are surrounded by subsidiary cells which are characterised by the presence of large globules of oil. The structure of the stoma in *B. caryophylloides* is less strikingly xerophilous than in the two members of the Rhizophoraceae treated previously. The stomata are not prominently depressed. Holtermann (8) observes that in *B. gymnorhiza* the outer cuticular ridges are split into two. In *B. caryophylloides*, however, the outer ridges are not split and the front cavity consists of a single chamber (Fig. 35). Cork-warts occur on the lower surface of the leaf.

The leaf structure is bifacial. Schimper (12) has noted the occurrence of a hypodermal aqueous tissue. The aqueous tissue is restricted to a single sub-epidermal layer on the upper side of the leaf (Fig. 36). Oil as well as large, aggregate crystals of oxalate of lime occur in some of the hypodermal cells (Fig. 36). The lamina is 0.48–0.6 mm. thick (being thicker towards the mid-rib), the hypodermis occupying nearly 0.06 mm. of the total thickness (11). On the lower surface, the hypodermal aqueous tissue consists of small, clear cells (Fig. 35). The palisade tissue is 3–4 layers deep. A prominent feature of the palisade cells is the presence of oil which usually occurs as a single large globule in each cell (Fig. 36). Starch is more abundant in the inner palisade layers. The spongy tissue also holds oil and consists of 10–12 layers of loose cells. Crystal cells occur mainly between the palisade and the spongy tissues. Secretory cells, holding tannin and oil, are present in the soft bast of the main as well as of the minor veins. Bast fibres support the veins on both the surfaces. Enlarged terminal tracheides occur in the mesophyll (12).

Schimper (12) has studied the root structure of *B. caryophylloides.* The cortex is thick and rich in lacunae. The cortical lacunae are both of schizogenous and lysigenous origin. The main cavities are visible to the naked eye and are arranged radially around the stele (Fig. 37). Annular thickening ridges, similar to those in the two previous plants, support the lacunar cortex. The outer layers of the cortex hold tannin and oil. Large aggregate crystals occur in the neighbourhood of the endodermis whose radial walls are thick and lignified. Pericyclic secretory cells, holding tannin, are arranged in the form of arcs on the outer faces of the phloem groups. The stele is contracted and the pith is pitted and lignified. Cork develops superficially and consists of phelloid cells with more or less lignified walls. Schimper (12) has noted knee-like structures in the roots of *B. gymnorhiza* and *B. caryophylloides,* which he believes perform the same function as the pneumatophores of some mangroves. The present writer was not successful in coming across any knee-roots in the couple of specimens that came under his observation.

Vivipary in *Bruguiera* is studied by Karsten (9). The epidermis of the fruit resembles that of the stem having unequally thickened lateral walls. The cuticle is thick and heavily coated with wax. Starch grains and oil occur in the fruit, the latter most abundantly. Tannin occurs in the inner layers of the fruit. Large lignified stone cells support the inner side of the fruit. The hypocotyl of the seedling is green when young, its outer surface bearing shallow vertical grooves (Fig. 38). The cuticle is thick and coated with wax (Fig. 39). The epidermis of the hypocotyl resembles that of the stem and the cells hold tannin. The hypodermis holds chloroplasts and starch. The rest of the cortex is lacunar and consists of large, radially elongated cells with schizogenous cavities (Fig. 40). The inner cortex is full of large starch grains. Pericyclic secretory cells hold tannin and oil. Pith is parenchymatous and is full of starch.

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Explanation of Plates.

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

Fig. 1.—A mangrove formation near Bombay.

Rhizophora mucronata, Lamk.

Fig. 2.—T. S. stem : *e*, epidermis ; *h*, hypodermis. (× 500).

Fig. 3.—T. S. stem, showing the lacunar cortex. *t*, tannin and oil globules. (× 500).

Fig. 4.—L. S. stem, showing cortical cells with an H-shaped spicule. (× 500).

Fig. 5.—T. S. stem : a group of sclereides in the inner cortex. *n*, endodermis. (× 500).

Fig. 6.—Multiradiate sclereides from the inner cortex of the stem. (× 500).

Fig. 7.—T. S. stem, showing the lacunar secondary cortex. (× 240).

Fig. 8.—Lower epidermis of the leaf, with depressed stomata (focussed at a lower level). (× 500).

Fig. 9.—T. S. leaf : *o*, outer and *i*, inner cuticular ridges of the stoma ; *h*, hypodermis ; *s*, spongy tissue, (× 500).

Fig. 10.—T. S. leaf : *c*, culticle ; *a*, aqueous tissue ; *m*, mucilage cells ; *p*, palisade cells. (× 500).

Fig. 11.—T. S. leaf, showing a sclereide in the lacunar ground tissue of the midrib. (× 500).

Fig. 12.—T. S. leaf. Photomicrograph showing a cork-wart on the upper surface. (× 82).

Fig. 13.—T. S. terrestrial root. Photomicrograph, showing the lacunar primary cortex. (× 82).

Fig. 14.—T. S. terrestrial root, showing the cortical cells. Explanation in the text. (× 240).

Fig. 15.—Same as above, with a multiradiate sclereide. (× 240).

Fig. 16.—T. S. epigeous root. Photomicrograph, showing the primary cortex. (× 82).

Fig. 17.—Photograph, showing the viviparous fruits and the seedlings.

Fig. 18.—T. S. hypocotyl. Photomicrograph, showing a lenticel and groups of stone cells in the hypodermis. (× 60).

Ceriops candolleana, Arn.

Fig. 19.—T. S. stem: showing the cuticle, epidermis and hypodermis (× 500).

Fig. 20.—T. S. stem, showing the inner lacunar cortex (× 500).

Fig. 21.—Lower epidermis of the leaf, with a depressed stoma (× 500).

Fig. 22.—T. S. stem: *t*, stoma; *h*, hypodermis; *s*, spongy tissue (× 500).

Fig. 23.—T. S. leaf: *e*, upper epidermis; *h*, hypodermis; *p*, palisade cells; *s*, secretory cell. (× 500).

Fig. 24.—Photograph, showing the root system.

Fig. 25.—T. S. root. Photomicrograph, showing the cortical aerating tissue. (× 82).

Fig. 26.—T. S. root, showing the lacunar cortex. (× 240).

Fig. 27.—Radial L. S. root, showing the strengthening tissue formed by the ridges. *s*, secretory cell with tannin and oil. (× 500).

Fig. 28.—T. S. root. showing the lacunar pith. (× 240).

Fig. 29.—Photograph, showing the viviparous fruits.

Fig. 30.—T. S. hypocotyl; *c*, cuticle; *e*, epidermis; *h*, hypodermis. (× 500).

Bruguiera caryophylloides, Blume.

Fig. 31.—T. S. stem: *c*, cuticle: *e*, epidermis; *h*, hypodermis. (× 500).

Fig. 32.—T. S. stem, showing the lacunar cortex. (× 500).

Fig. 33.—T. S. stem, showing the secondary cortex. (× 240).

Fig. 34.—Lower epidermis of the leaf with depressed stomata. (× 500).

Fig. 35.—T. S. leaf: *t*, stoma; *h*, hypodermis; *s*, spongy tissue; *o*, oil globule. (× 500).

Fig. 36.—T. S. leaf: *e*, upper epidermis; *h*, hypodermis; *p*, palisade cells; *o*, oil globule. (× 500).

Fig. 37.—T. S. root. Photomicrograph, showing the arrangement of air-spaces in the primary cortex. (× 26).

Fig. 38.—Photograph, showing the viviparous fruits and the seedlings.

Fig. 39.—T. S. hypocotyl: *c*, cuticle; *e*, epidermis: *h*, hypodermis. (× 240).

Fig. 40.—T. S. hypocotyl, showing the inner lacunar cortex. (× 240).


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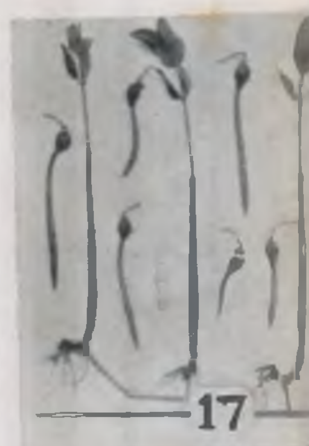
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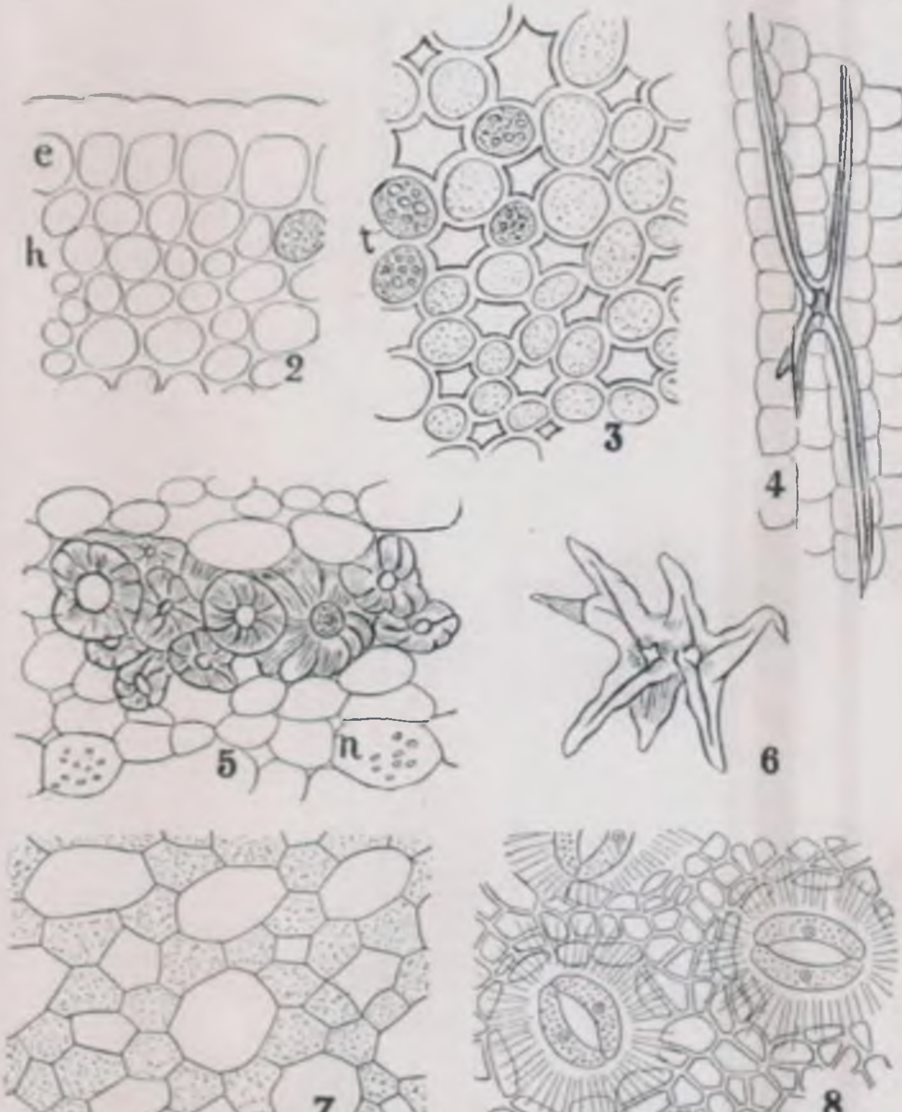
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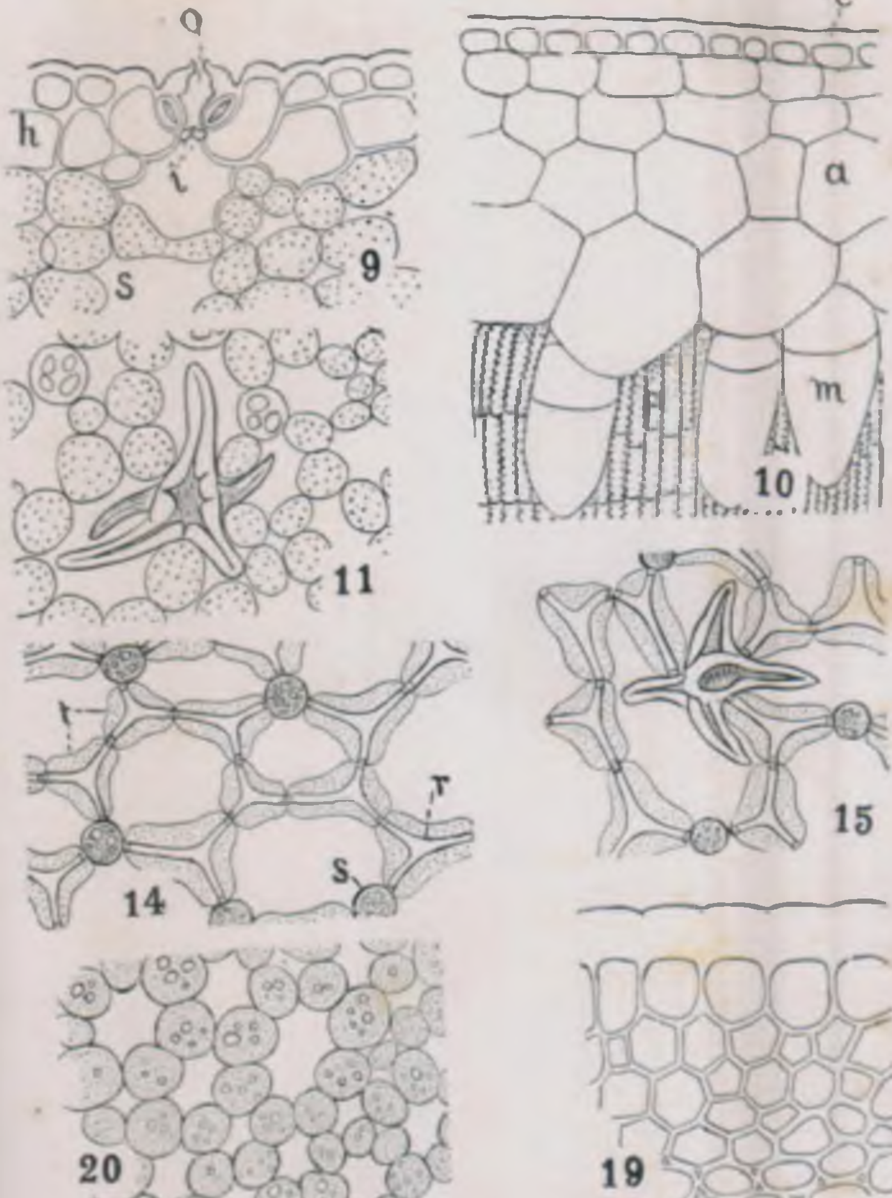
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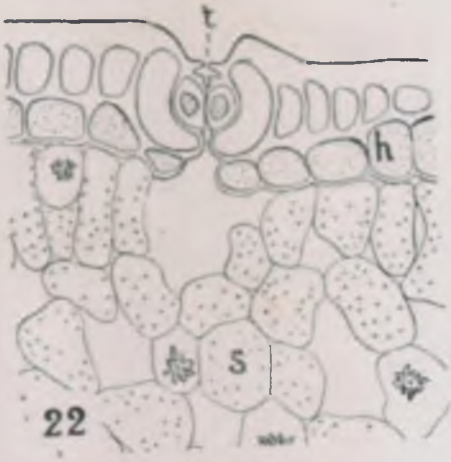

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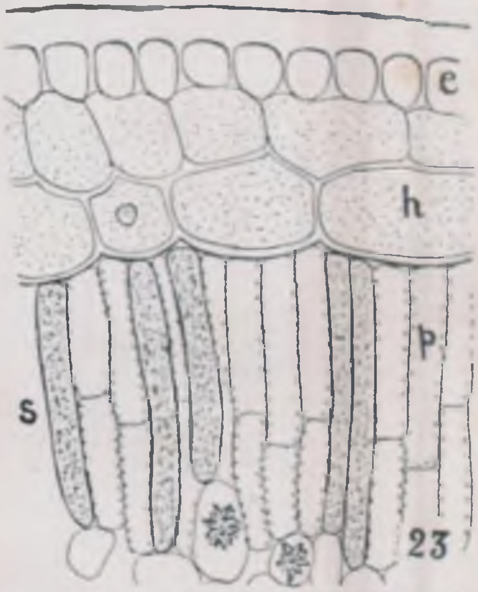

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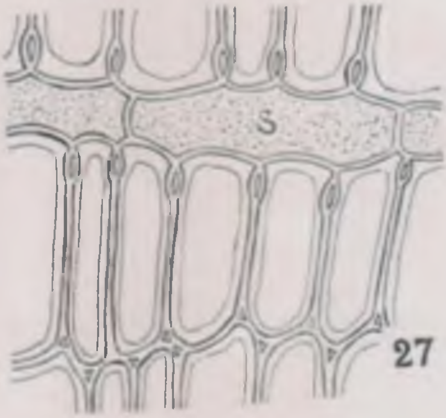

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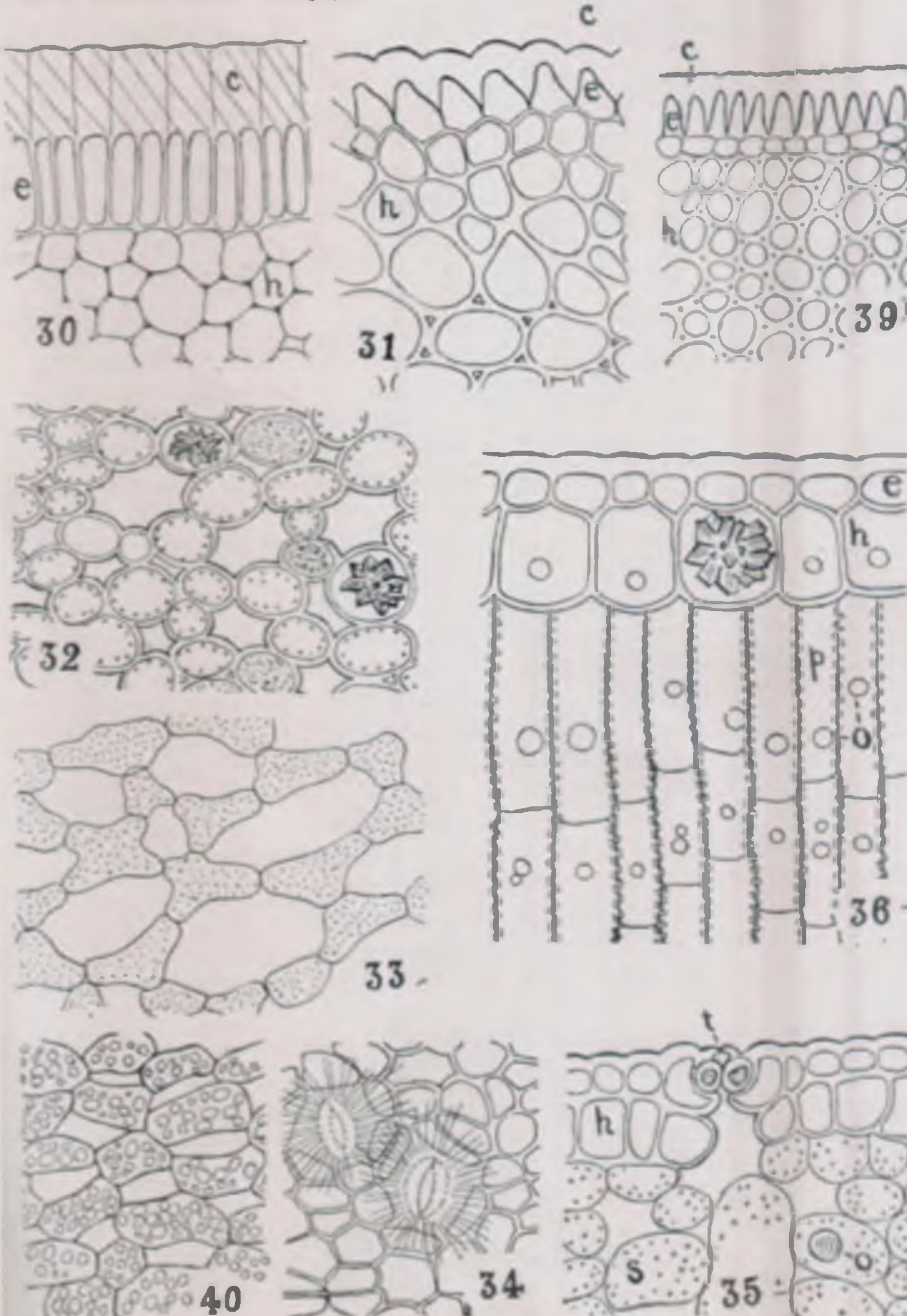
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