THE STRUCTURE AND FORMATION OF MELALEUCA BARK[1]

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ABSTRACT

Samples of melaleuca bark were examined microscopically and their anatomical characteristics were illustrated. The observations revealed that each periderm is composed of layers of radially elongated thin-wall nonsuberized cells alternating radially with a flattened layer of suberized cells bearing casparian strips. Several periderms are formed during each growing season. These periderms alternate with the secondary phloem tissue, which contains fibers.

Keywords: Bark, anatomy, cell structure, periderm, phloem.

The melaleuca tree (*Melaleuca quinquenervia* (Cav.) Blake) is native from eastern Australia through Malaysia and Burma (Little 1953). It has been described under various names by many botanists *M. leucadendron* Linn.; *M. viridiflora* Gaertn.; *M. saligna* Blume; *M. minor* Sm.; *M. cajaputi* Roxb.; *M. cajaputi leucadendra* Rusby (Morton 1966). This species has spread over much of southern Florida since its first introduction from Australia in 1906 (Meskimen 1962). Because of its rapid growth as well as its reputed resistance to disease, fire, and insect attack, this species has been selected as one of the most promising candidates for biomass production in Florida (Smith and Dowd 1981). Melaleuca has thick, multilayered bark that comprises approximately 15–20% of its stem volume.

Although the wood structure of many tree species has been examined, little effort has been given to the structure of the bark. Reports on bark structure, particularly the outer bark or rhytidome, are lacking for most tree species. The bark structure of melaleuca has not been clearly described. Recent attention to the utilization of forest biomass, in the form of whole-tree chips, for energy and chemicals has promoted some interest in the study of bark characteristics. The objective of this study was to observe, and describe the structural elements of melaleuca bark and to discuss its formation and development in the hope of increasing the understanding and improved utilization of this tree species.

MATERIALS AND METHODS

Bark samples used in this study were from: 1) newly formed twigs, 2) young branches, and 3) small trunks. These samples were taken from trees during the
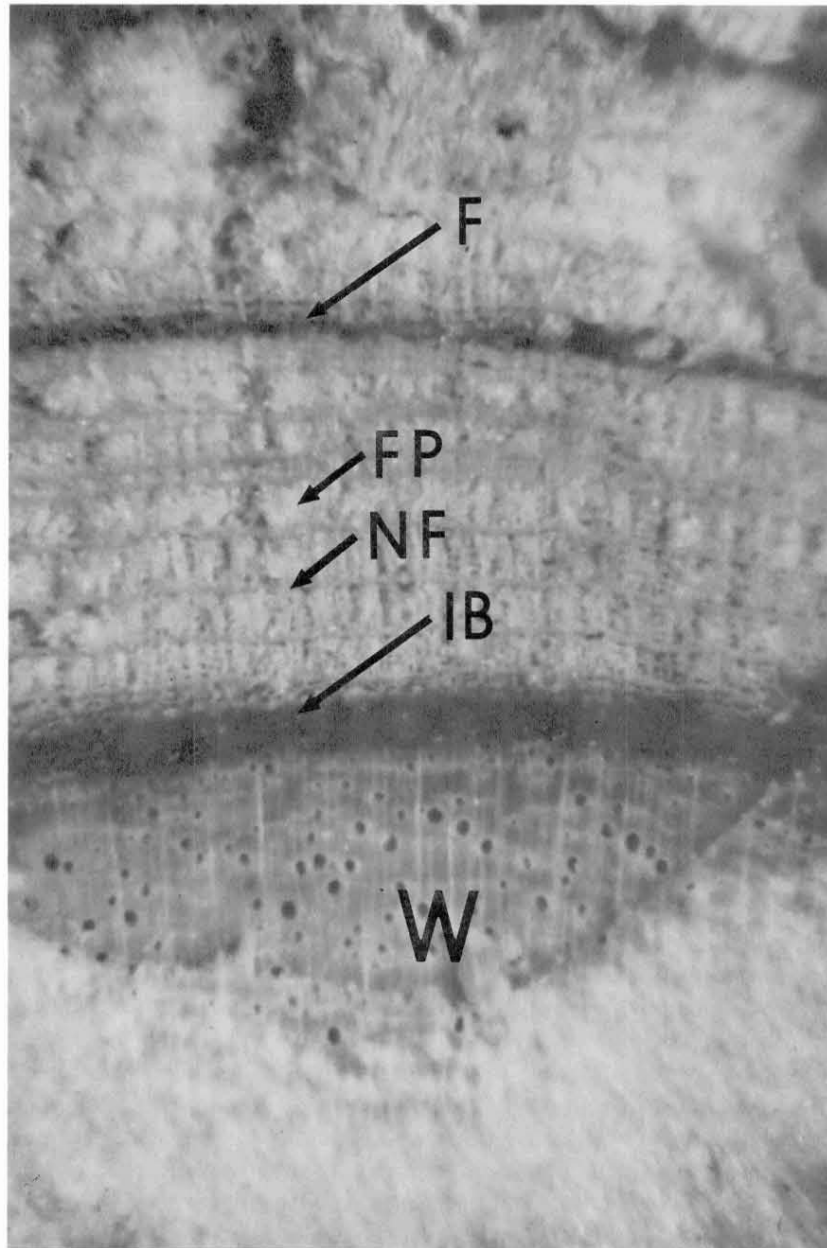

FIG. 1.   The gross structure, cross section, of melaleuca bark. Wood (W), inner bark (IB), nonfibrous sheet (NF), flaky and powdery layer (FP), fibrous layer (F).

growing season in the forms of cylinders and discs. Observations were made on the transverse surfaces of twig cylinders, small bark cubes, microtome sections, and macerated cells.

Fresh twigs and bark tissue from the branch or trunk discs were cut into 5-mm-high cylinders and 7-mm cubes. The surfaces to be observed were smoothed
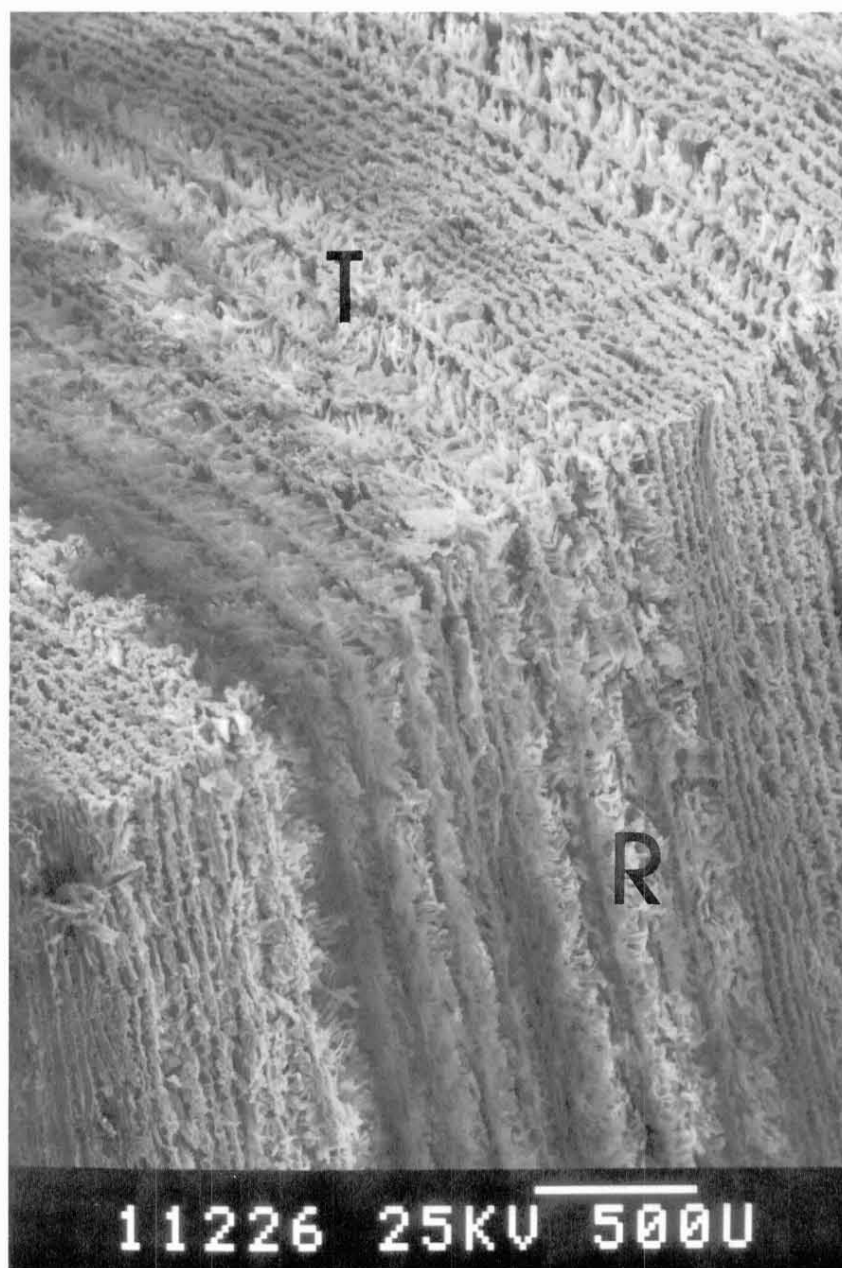
FIG. 2. The multilayered structure of melaleuca periderm. Transverse view (T), radial view (R).

with a handheld, single-edge razor blade—a new blade was used for each cut. These cylinders and cubes were air-dried and then examined with a stereoscopic microscope. The specimens used for the investigations with the scanning electron microscope (SEM) were prepared by coating these cylinders and cubes with gold. Details of SEM technique were similar to those described by McMillin (1977).

Materials used to prepare microtome sections were fixed in FAA (50 ml 95%

FIG. 3.   Transverse (T) and radial (R) view of the basic outer bark components: nonfibrous sheet (NF), flaky and powdery layer (FP), fibrous layer (F).

alcohol, 5 ml glacial acetic acid, 10 ml Formalin, 35 ml water), dehydrated through the TBA (Tertiary Butyl Alcohol) series and then embedded in paraffin. Sections were cut at 10 μ and stained with Safranin and Fast-Green. Suberin and fatty substances were detected by staining the sections with Sudan IV in 1:1 glycerol alcohol, and then destained by 1:1 glycerol alcohol. The macerated cells (mainly fibers) were obtained from the trunk samples. These samples were macerated in Superoxal and then stained with Safranin. The microtome sections and macerated cells were observed with a light microscope.
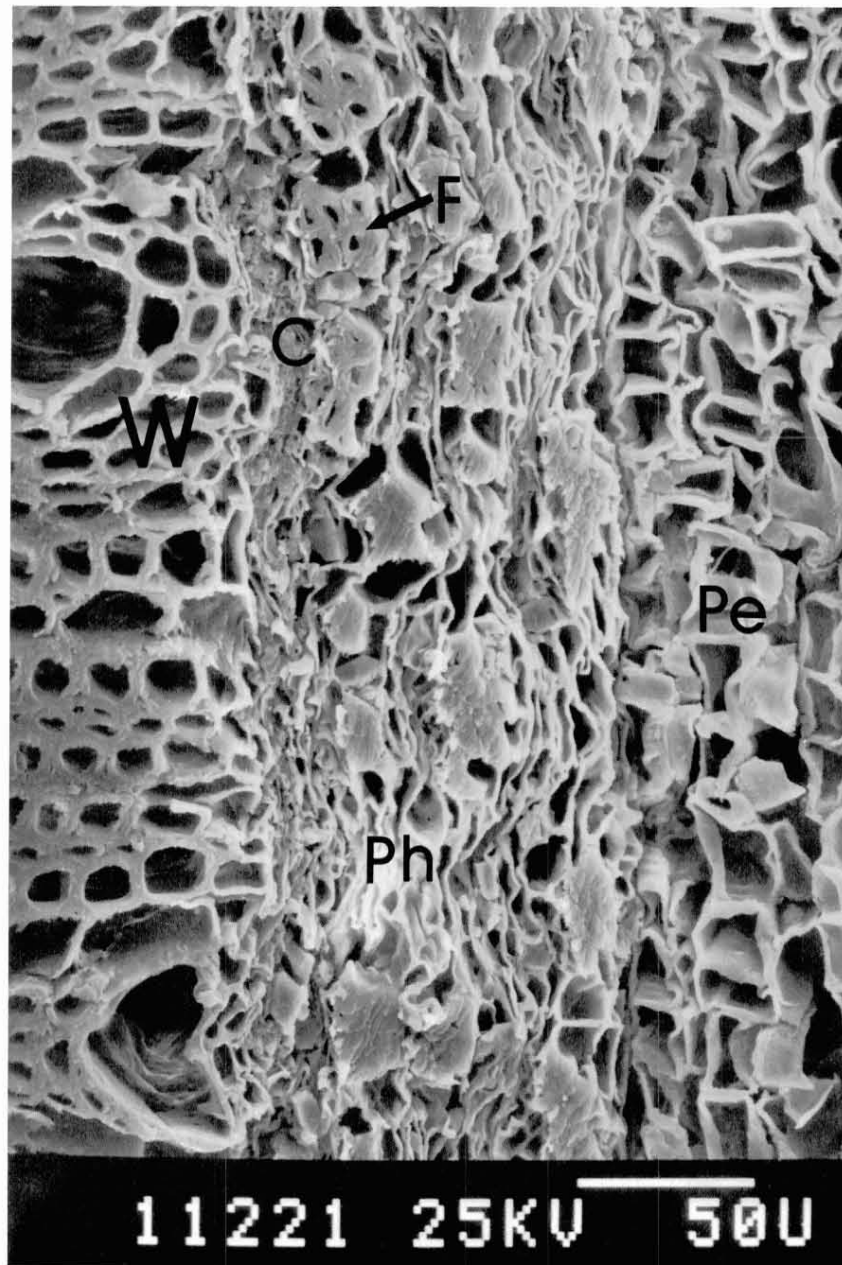
FIG. 4.   The transverse view of inner bark (phloem). Wood (W), cambium (C), fiber (F), thin wall phloem element (Ph), periderm (Pe).

RESULTS AND DISCUSSION

The gross characteristics of outer bark

The term "bark" as used in this report refers to all tissues produced outside the vascular cambium. It consists of two portions—the inner bark (living phloem)
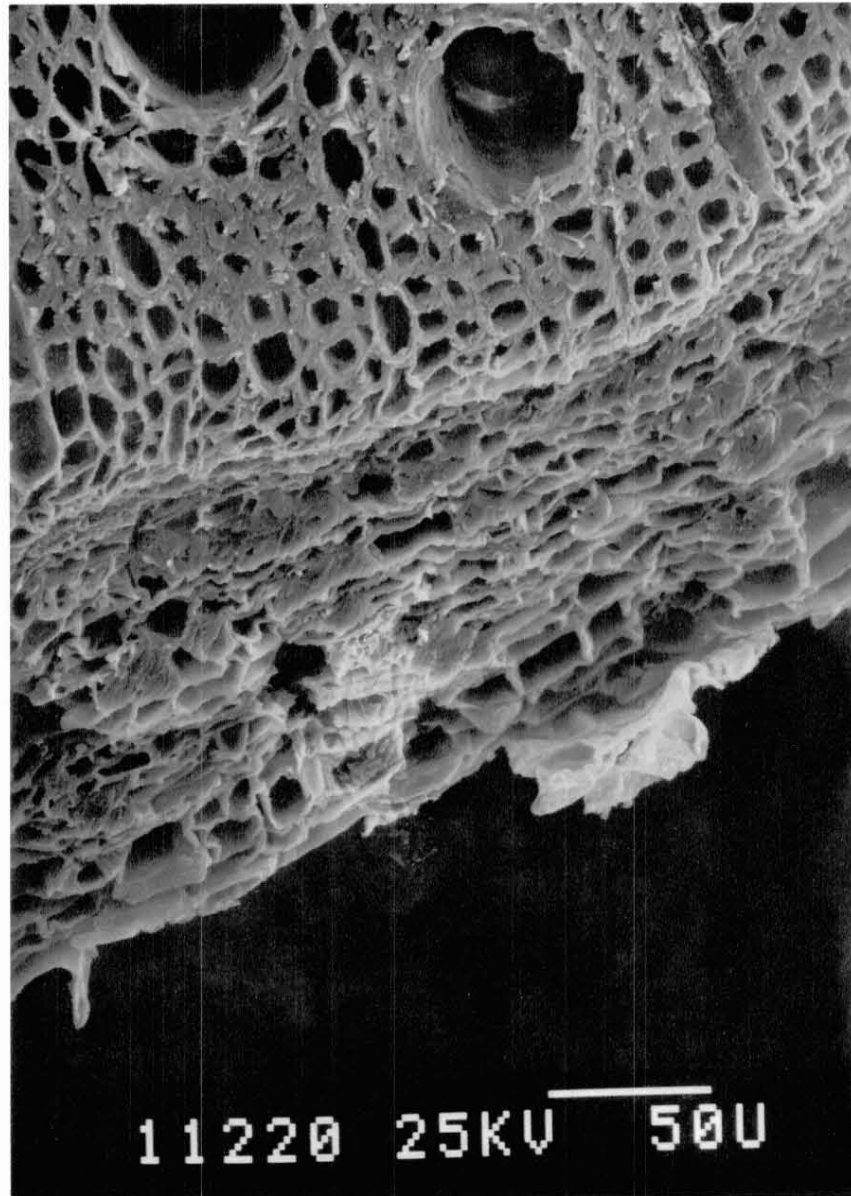
FIG. 5.   The transverse view of a young twig.

and the outer bark. The innermost periderm separates the two zones. The dead tissue outside the periderm of melaleuca bark is laminated: 1) thin nonfibrous sheets, 2) fine scalelike flakes or creamy powder between these sheets, and 3) layers of dark brown, coarse fibers that are present about every 2–4 mm in the outer bark. The outer bark can be very easily pulled apart at these dark brown layers. The tissue between these dark brown layers can also be pulled apart at flaky or powdery layers with ease. The gross structure of melaleuca bark is shown in Figs. 1, 2, and 3.
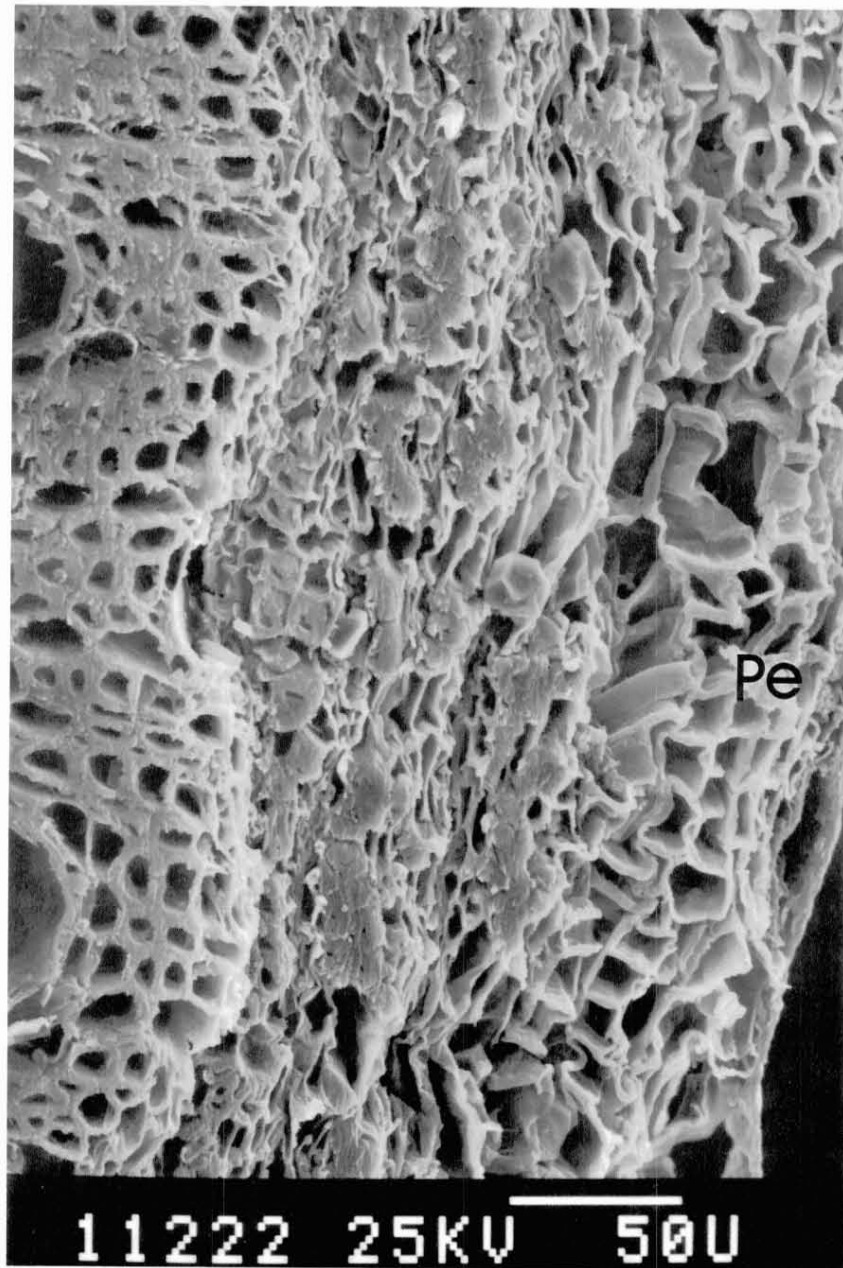
FIG. 6.   The transverse view of a twig bearing the first periderm (Pe).

The minute structure

The inner bark (phloem).—The principal tissues and cells described for hard-wood phloem are: 1) sieve tube elements and companion cells; 2) parenchyma cells; and 3) fibers (Martin and Crist 1970). In cross section, the sieve tube elements of melaleuca phloem are usually not distinguishable from the surrounding paren-
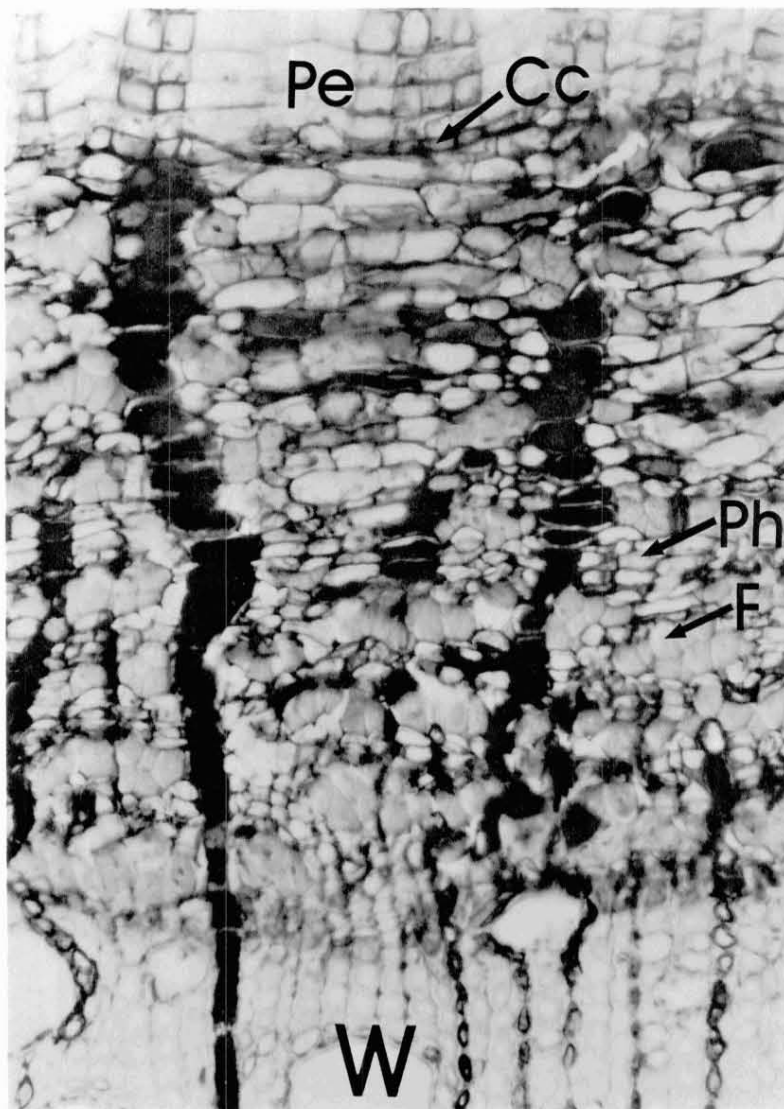
FIG. 7.   Cross section of melaleuca phloem and its adjacent tissues. Wood (W), fiber (F), thin wall phloem element (Ph), cork cambium (Cc), periderm (Pe), ×150.

chyma cells because they are both thin walled (Figs. 4 and 7). The amount of these thin wall cells is highly variable. Parenchyma of melaleuca phloem is ar-ranged in two systems: longitudinal and horizontal (rays). Fibers have remarkably thick walls (Fig. 4). They may be scattered (Fig. 5) or may appear so abundant that the sieve elements and parenchyma cells occur as small groups surrounded by fibers (Fig. 6).

   The outer bark (periderm and dead tissues outside the periderm).—A periderm is composed of three tissues: phellogen, phellem, and phelloderm (Martin and Crist 1970). The phellogen (cork cambium) is the layer of cells that forms phellem
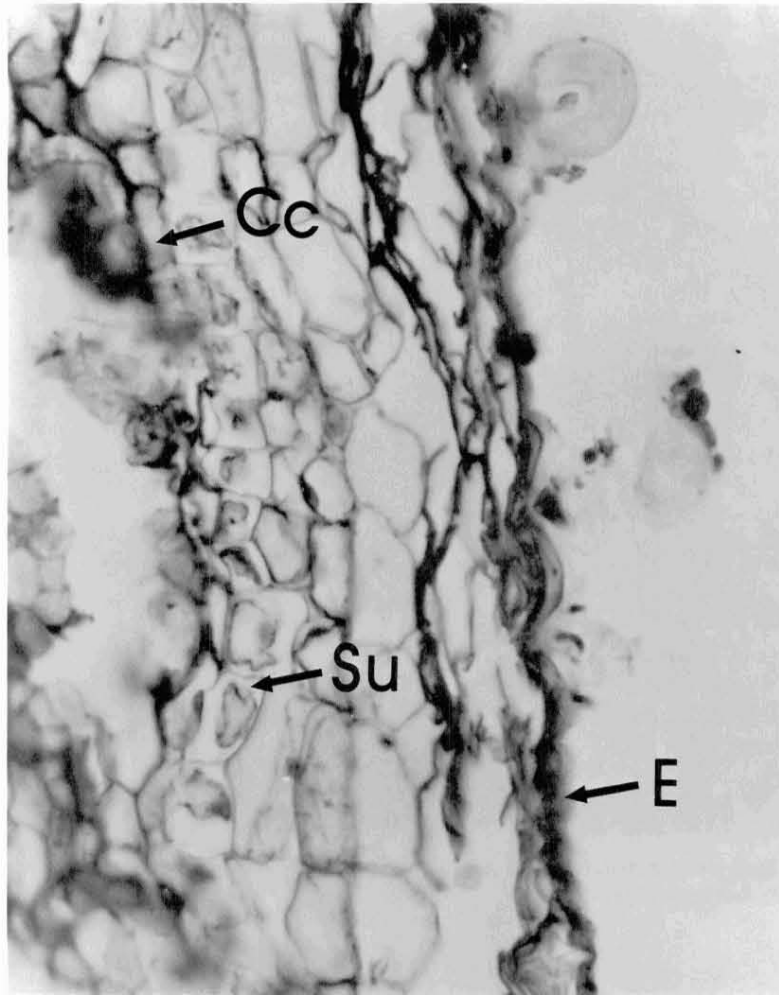
FIG. 8.   Transection through the first periderm of a young branch. Cork cambium (Cc), suberized layer (Su), epidermis (E), ×315.

(cork) toward the outside and phelloderm on the inside. The first phellogen or some early phellogens originate from cortical cells, but in older bark they arise from parenchyma of the nonfunctional phloem—secondary phloem.

The first periderm of a melaleuca young branch is found in the inner cortex, as deep as the 10th cortical layer, almost immediately external to the living phloem (Figs. 7, 8). As the cell layers of the first periderm become about 12 cells thick, the second phellogen starts to form in the secondary phloem (Fig. 9). Three to four subsequent periderms are formed during the first growing year (Fig. 10). Each of these subsequent periderms originates from the secondary phloem that is being formed constantly from the vascular cambium. Thus, the subsequent periderms alternate with the secondary phloem layers (Fig. 10). The secondary phloem is composed of three main tissues: thick-walled fibers (Fig. 11), ray cells, and thin-
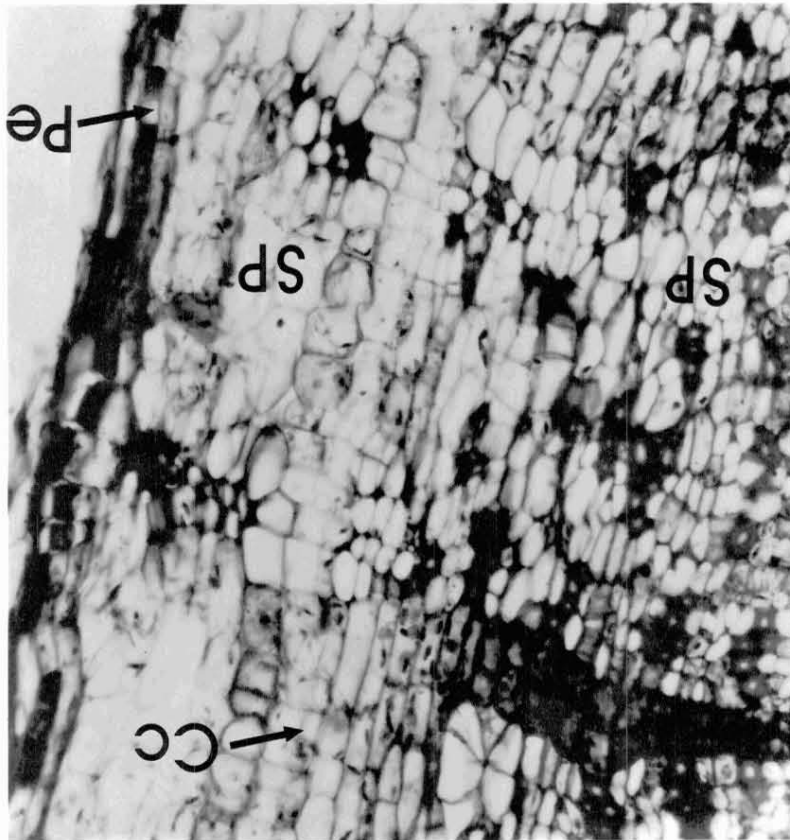
walled phloem elements. Both rays and thin-walled phloem elements disintegrate at later stages.

Melaleuca periderm has a relatively wide phellem produced from the phellogen. The phelloderm, however, may be only one cell deep in some periderm and no indication of any phelloderm in others (Figs. 12 and 13). During the formation of phellem, the phellogen gives rise to a layer of suberized cells alternating with a layer of nonsuberized cells. The nonsuberized cells then become elongated radially soon after they are separated from the phellogen, except for those formed in the first periderm (compare Fig. 13 with Fig. 8). The suberized cells remain as a radially flattened layer and are characterized by the presence of casparian strips on their anticlinal (both transverse and radial) walls (Fig. 14). In most cases, the first derivatives of the initial phellogen appear to be the suberized cells bearing conspicuous casparian strips (Fig. 8). In addition to bearing casparian strips, the suberized cells appear to be wrinkled. The wrinkled pattern can be clearly identified in the tangential section (Fig. 15), and becomes obscure in the periderms near the stem surface.
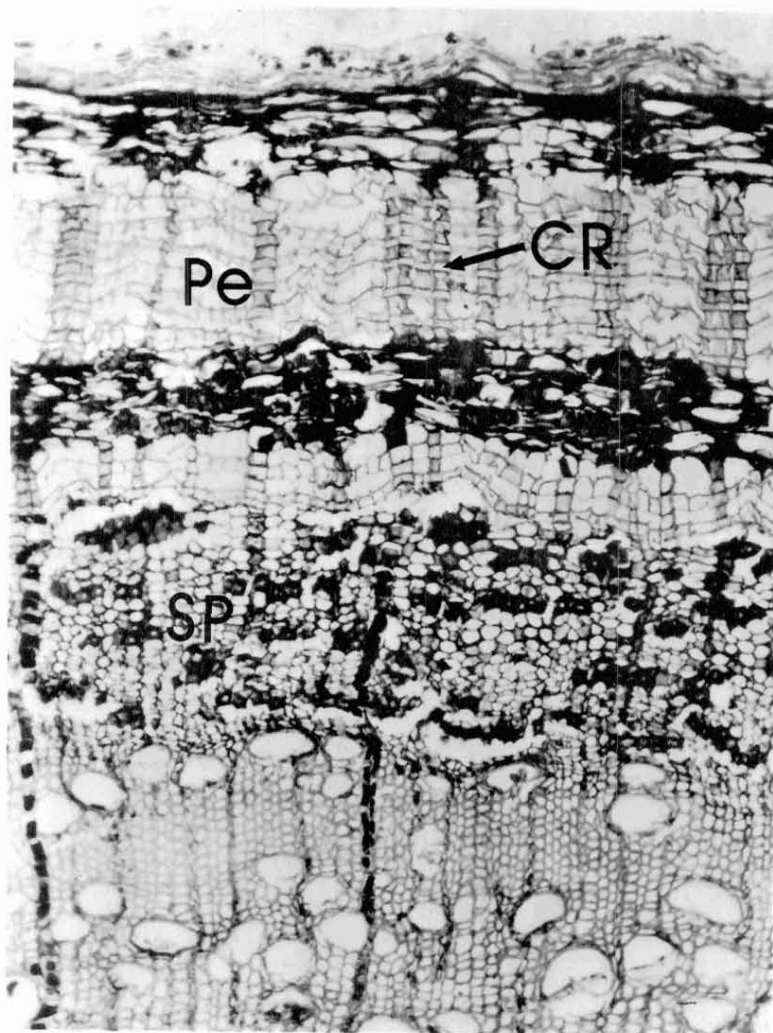

Fig. 9. Early development of the second layer of periderm from cork cambium (Cc). Secondary phloem (SP), first layer of periderm (Pe). ×150.

FIG. 10. Cross section of the bark bearing three layers of periderm (Pe). Secondary phloem (SP), cork ray (CR), ×80.

In the tangential view, the suberized layer has a structure very similar to storied cambium (Fig. 16). It consists of rather vertically elongated cells (comparable to the fusiform initials) and has both uniseriate and multiseriate raylike cells. It is believed that the nonsuberized layer has similar structure but it is difficult to see. The vertically elongated cells in the nonsuberized layer expand and disintegrate first as the branch continues to increase in circumference. The disintegration of raylike cells in the nonsuberized layer may follow. The cell walls of the suberized cells are firmly attached to each other anticlinally; they do not separate from each other in the macerating reagents such as Superoxal, Jeffrey's, or Franklin's solution.

FIG. 11.   The macerated fiber cells from secondary phloem, ×315.

As the branch grows bigger, its outer bark bears numerous layers of subsequent periderms. The outer periderms appear to be spongy in texture. They consist of alternating layers of cells: one cell layer of suberized cells, and several layers of cells with partly disintegrated nonsuberized cells (Fig. 16). This one-after-the-other pattern becomes obscure in the bigger branches and trunk. The suberized cells in these outer periderms remain compactly arranged with casparian strips,
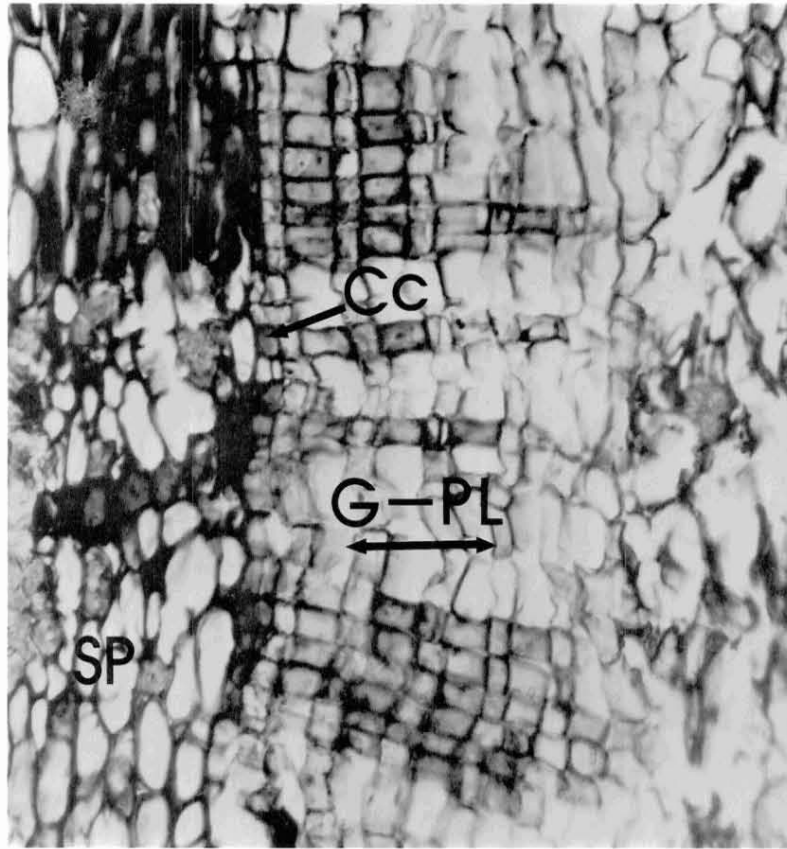
FIG. 12.   Transection of growing phellems (G-PL). Cork cambium (Cc), secondary phloem (SP), ×170.

but only cork ray cells may remain undestroyed in the nonsuberized layers. In most cases, four to five radially attached nonsuberized cork ray cells are present between two successive suberized cell layers. The stem of *M. quinquenervia* normally produces three to four periderms in one year. Once the preceding phellogen ceases to divide, a subsequent phellogen is formed in the secondary phloem. The phellogen has been observed to divide more than ten times.

Heterogeneous phellem or cork has been found in some species of Myrtaceae (Esau 1977; Metcalfe and Chalk 1950), yet cork exhibiting a structure comparable to that of *M. quinquenervia* has not been previously seen. Except for the initial periderm, all the subsequent periderms constantly originate from the secondary phloem in this species. The formation of one-after-another periderm in the secondary phloem makes the rhytidome a significant part of the melaleuca stem. Though some restricted overlapping strata of the sequent periderms can be seen, most of them occur parallel to each other. Numerous layers of the subsequent periderms alternating with parallel-seated dead secondary phloems remain on the stem surface for a rather long time. The formation of a large amount of intercellular
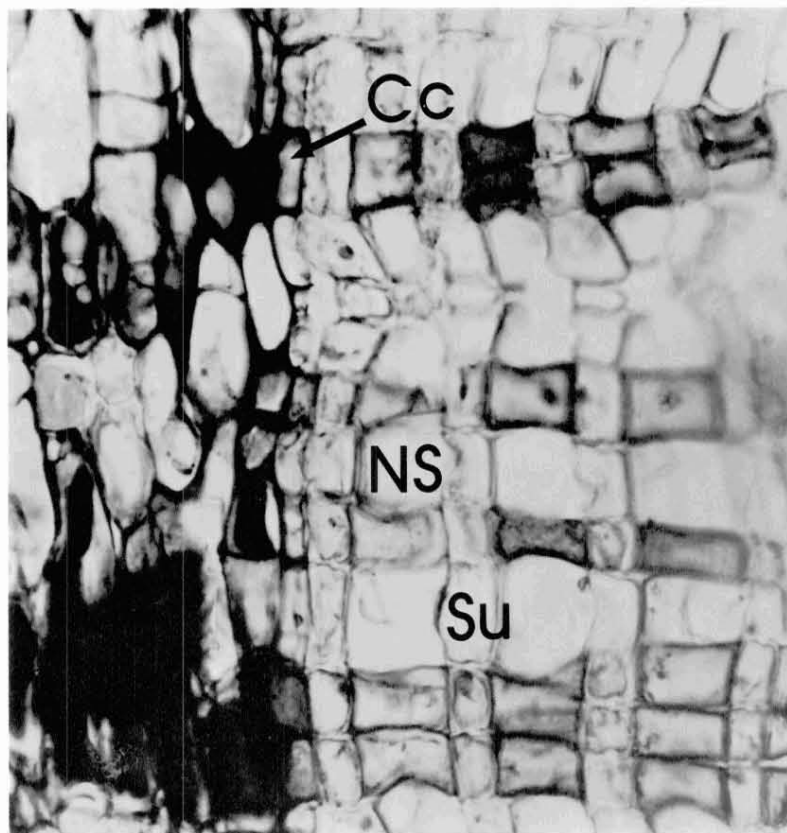
FIG. 13. Growing phellems showing the arrangement of suberized cell layer (Su) and nonsuberized cell layer (NS). Cork cambium (Cc), ×350.

spaces by the destruction of the nonsuberized expanding cell layers makes the mature cork highly compressible and spongy in texture.

Casparian strips are constantly visible in the cork of this species. The presence of a casparian strip may prevent the suberized cells from separating from each other because it can connect a cell wall more tightly with the walls of its neighboring cells. Hence, the formation of the casparian strip and the wrinkled cell walls during the development of suberized-cell layers may explain why these suberized layers are so strong and remain intact for a long time. The presence of large numbers of these intact suberized cells in the melaleuca cork may also explain why the bark of this tree species has a high ether solubility—16% (Wang and Huffman 1982) and an exceptionally high heat of combustion—25,791 kj/kg (Wang et al. 1981).

CONCLUSIONS

The multilayered structure of the outer bark of M. quinquenervia is formed by the alternation of disintegrated phloem layers with the periderms, which are
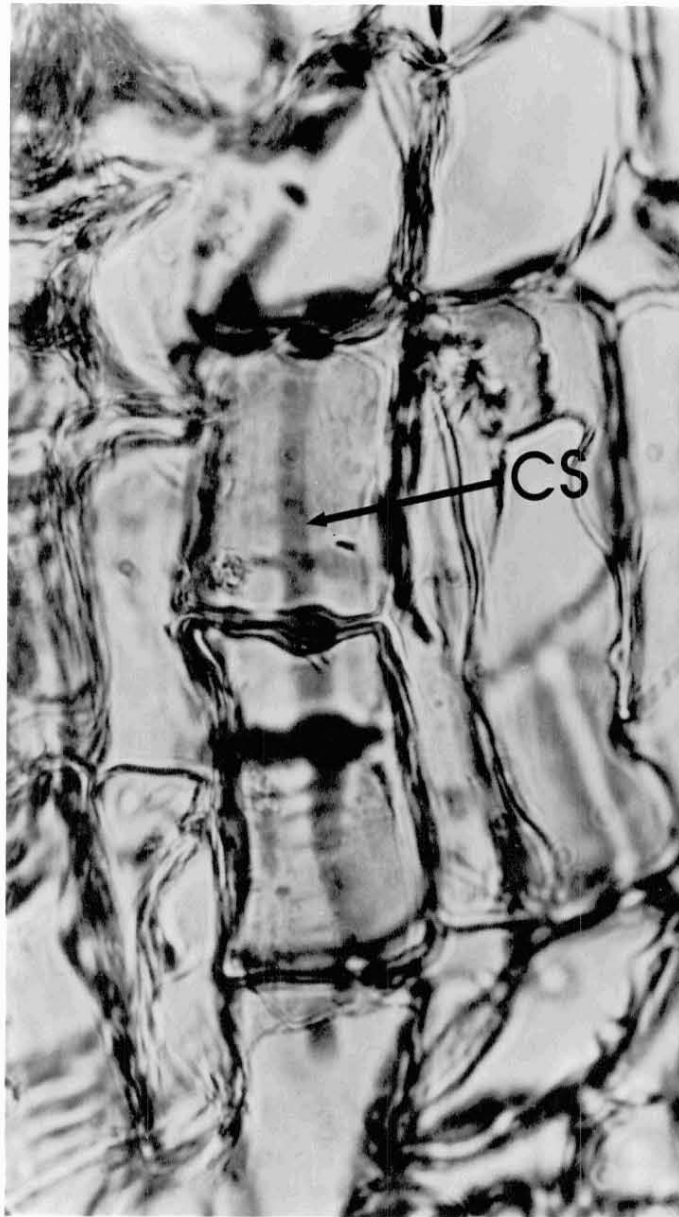
FIG. 14.   The suberized cells bearing casparian strips (CS), ×900.

constructed by alternating one layer of suberized cells with several layers of partially destroyed nonsuberized cells. Based on the observations conducted in this study, it appears that: 1) the thin nonfibrous sheets are the layers of suberized cells; 2) the fine scalelike flakes and creamy powder are the destroyed nonsuberized cell-wall fragments and the intact nonsuberized ray cells respectively; 3) layers of
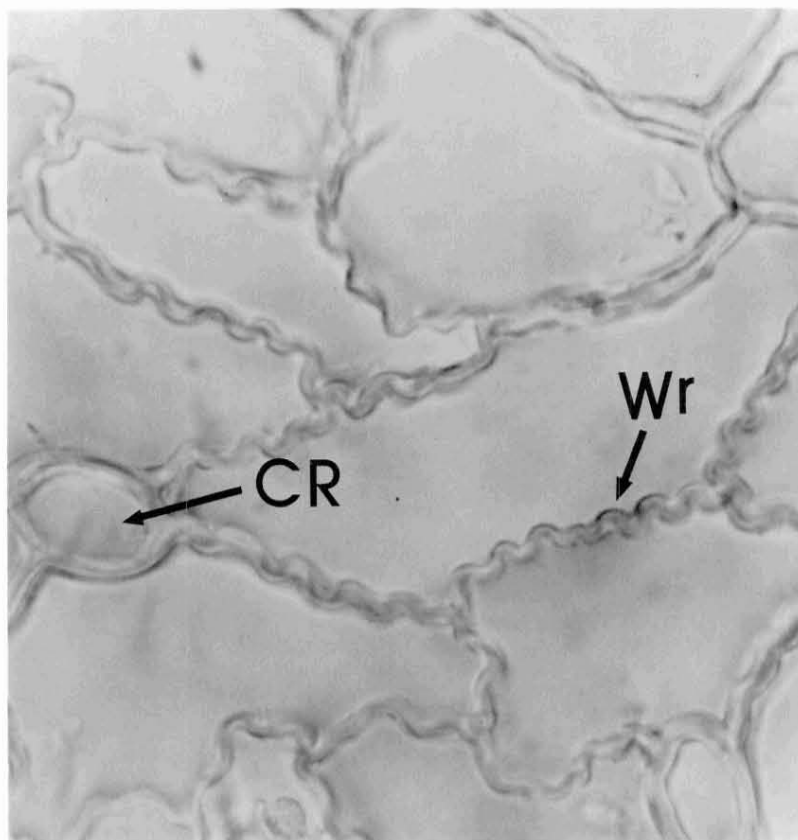
FIG. 15.   Tangential view of suberized cells showing the wrinkled cell walls (Wr). Cork ray (CR), ×900.

dark brown, coarse brittle fibers are the phloem fibers that remain intact after the disintegration of secondary phloem layers.

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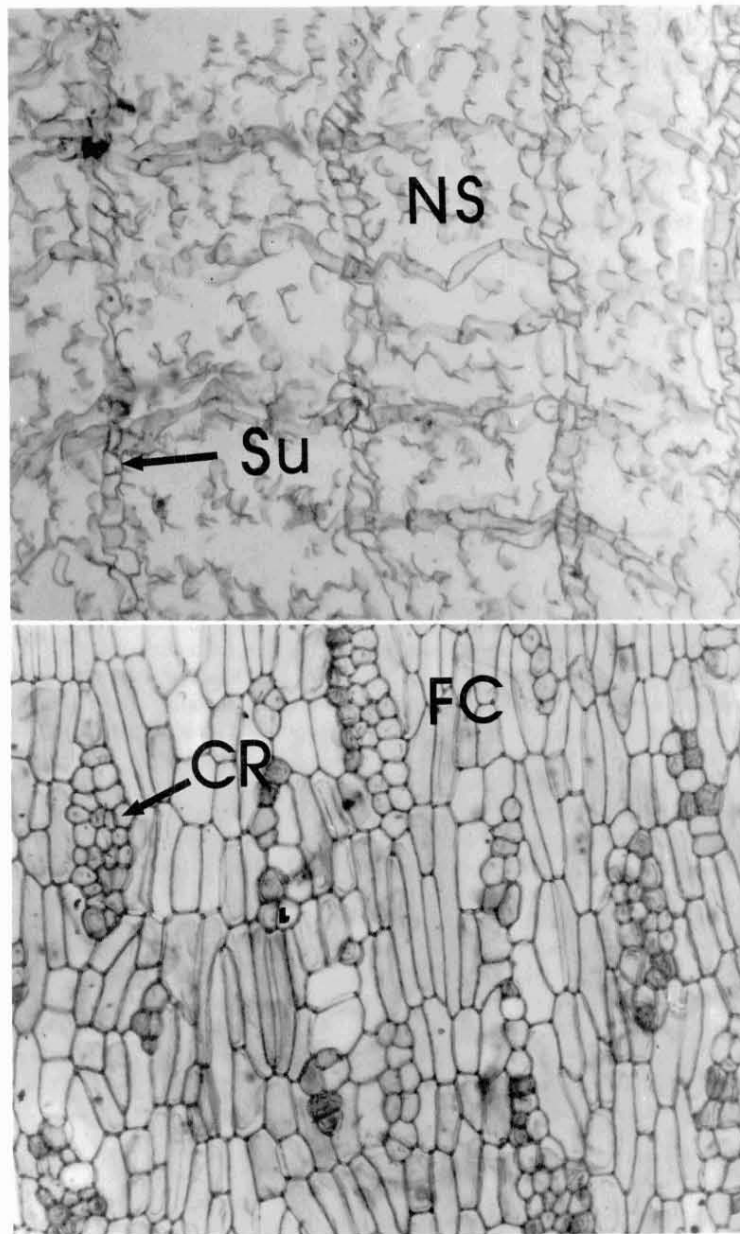
FIG. 16.   The structure of outer periderm. Top—the transverse view of the suberized layers (Su) and disintegrated nonsuberized layers (NS), ×88. Bottom—the tangential view of suberized layer showing fusiform type cells (FC) and ray type cells (CR), ×88.