

*Miscellaneous
Publications*

TALL TIMBERS RESEARCH STATION

The Ecology of
Smoke Particulates and Charcoal Residues
from Forest and Grassland Fires:
A PRELIMINARY ATLAS

E. V. KOMAREK, BETTY B. KOMAREK, AND
THELMA C. CARLYSLE



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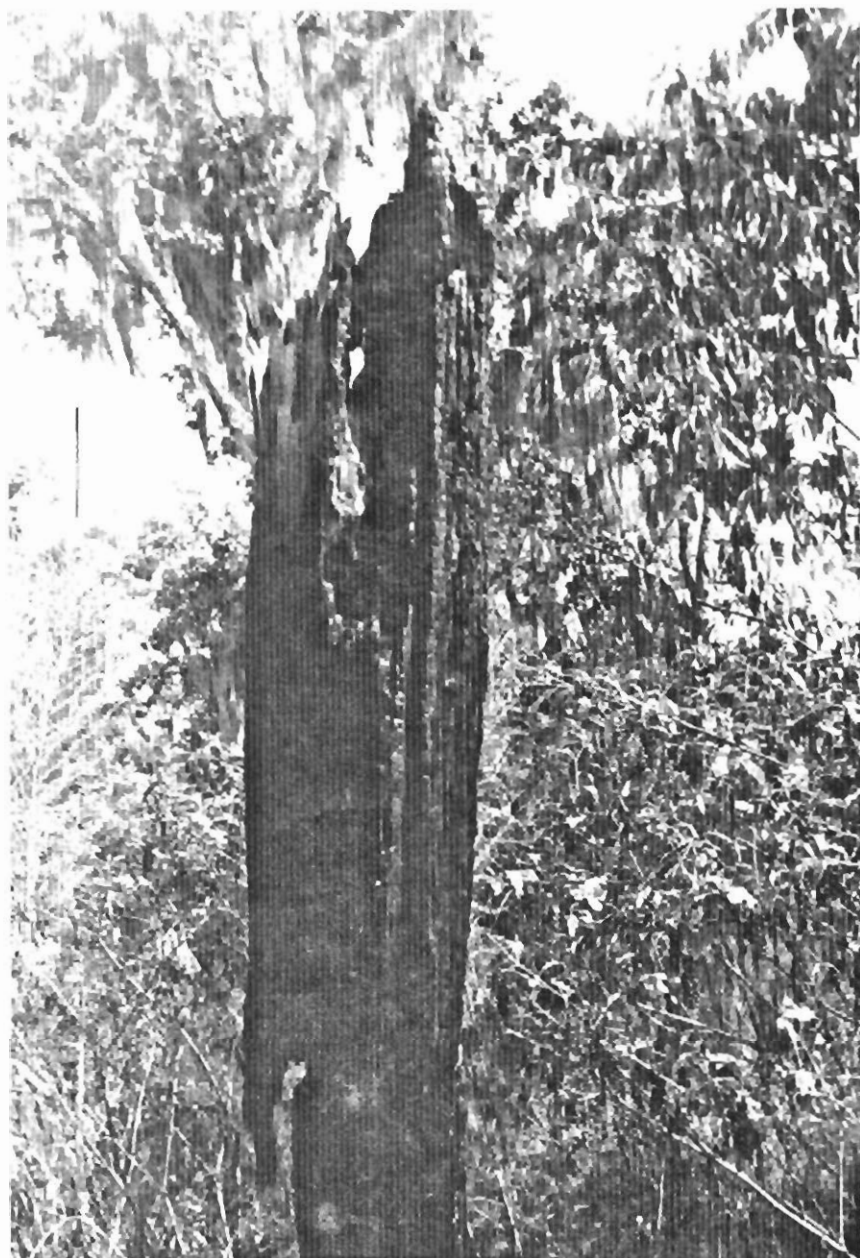
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A Natural Charcoal Filter

**THE ECOLOGY OF
SMOKE PARTICULATES AND CHARCOAL RESIDUES FROM
FOREST AND GRASSLAND FIRES:
A PRELIMINARY ATLAS**

E. V. Komarek*, Betty B. Komarek*, and Thelma C. Carlyle**

INTERPRETIVE SUMMARY—Low intensity forest and grassland fires create airborne particulates and charcoal which act as environmental cleansing agents. The morphological integrity of plant material which remains after burning creates a natural filter with varied porosity.

INTRODUCTION

Smoke from forest and grassland fires as a source of air pollution has recently created much interest. It has been lumped indiscriminately with the pollution from the combustion engine and industry which hangs as a heavy smog over most of our cities. With the increased environmental emphasis on controlling all possible pollution, little distinction has been made between natural and man-made sources. Furthermore, the intricate relationship of fire and the ecology of the atmospheric ecosystem has had very little study and understanding (Komarek, 1970). That the soil ecosystem has many kinds of cleansing mechanisms is well known and an accepted method of garbage disposal is by burying such waste in the soil. River ecosystems likewise have known cleansing mechanisms. Both do a very good job of renewing and cleansing their ecosystems if not constantly over-loaded. However, not as well recognized, except for the washing action of precipitation, is that the atmospheric ecosystem must also have methods of cleansing itself.

At the past Tall Timbers Fire Ecology Conference, March 1973, questions were posed as to the possible role of charcoal particulates from forest and grassland fires as a major cleansing agent (Komarek,

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in press). Charcoal has been known for centuries and used throughout the world by both primitive and modern industrial men for the purifying, filtering, adsorption, etc. of products ranging from water, liquids and air, to wines, metals, sugars and many industrial products. Charcoal, particularly in its activated form, is one of the best absorption materials known.

This preliminary atlas is the result of studies in the collection of various particulates under controlled burning conditions and their micro-photography under a scanning electron microscope. It is hoped that this approach to an understanding of the role that such charcoal particulates might play in the atmospheric ecosystem will stimulate other studies.

Since 1935 the Komareks have had considerable experience in controlled burning, and its ecological effects in relation to wildlife management, silviculture, and agriculture have been of special study. The effects of fires, severe and otherwise, have been observed in Arizona, California, Washington, Montana, Minnesota, Alaska, in many parts of Canada including the Yukon Territory and the Gaspé Peninsula region. More recently fires and fire research were studied in Europe (Scotland, The Netherlands, Sweden) and in various parts of Africa and Australia.

From this extensive fire ecology background certain relevant impressions on particulates have developed:

1. Particulates from forest or grassland fires are quite different from the man-caused particulates of an industry-oriented society.
2. Natural fire particulates vary in size from microscopic to those readily seen with the eye.
3. For the most part, particulates from fires of low or moderate temperatures are larger and more varied than those from intense fires and high temperatures.
4. In severe wildfires much of the material is consumed or turned largely into very fine particles such as ash and soot-like materials. Intense black smoke columns are characteristic of such fires.
5. Controlled burning, in contrast to severe wildfires, is characterized by white, bluish or yellowish smoke because these are conducted under conditions of lower temperatures, wetter fuels, and higher humidities. Under such conditions most of the charcoal and minerals remain on the ground and the possibility of activating the charcoal improved.
6. Controlled fires are much smaller than wildfires and can be conducted under proper atmospheric conditions so that the smoke and particulates can be carried away from populated areas, which removes or lessens the nuisance factor.

Particulates from natural fires were a part of the earth's atmosphere millennia before particulate emissions produced by man (Komarek, 1973).

Lightning has always been a part of the earth's atmosphere and an agent in the ignition of fires since enough combustible material evolved and conditions were right to burn. Coal and coal formation from the Carboniferous to more recent periods are records of extensive fires in the past (Komarek, 1972). Smith, Griffin and Goldberg (1973) have reported recently upon the accumulation of forest fire carbon particulates in marine sediments in the Atlantic and Pacific Oceans over the past 100 million years (excluding the past 5,000 years because of man's activities). They compared, by the use of the scanning electron microscope and infrared spectroscopy, these ancient particulates with those produced by a forest fire in southern California and by accumulations in a wood burning chimney and found them to be similar.

The porous and filter-trap like structures revealed in our preliminary scanning electron micro-photographs gives substance to the theory that carbon particulates from forest and grassland fires might be cleansing agents of the atmosphere as postulated in March, 1973 (Komarek, in press). Then, a series of continuing studies was initiated into the ecology of airborne particulates from such fires and their possible filtering and cleansing properties in the atmosphere, in cooperation with Thelma C. Carlyle, Research Technician, U.S.D.A. Insect Attractants, Behavior, and Basic Biology Research Laboratory, Gainesville, Florida, with the use of this agency's scanning electron microscope. However, it was quickly realized that an understanding of the charcoal and other residues that remain on the ground after forest and grassland fires would have to be acquired. The particulates are only fractions of plant substances which have become airborne. Such particles can vary in size from one micron to 3-4 feet in length, such as the flaming brands of the candle-bark eucalyptus in Australian fires which can cause spot fires as much as 15 miles ahead of the main fire front. They can also vary from complex plant structure residues to such things as elephant dung in Africa, which after burning, will frequently become airborne and start fires ahead of the main fire.

Schaefer (1973, in press) has pointed out the complexities of measurement and of the physical, chemical and electrical properties of airborne particles. He points out the weaknesses in sampling methods of such particles, particularly from forest fires, with standard sampling methods such as the E.P.A.-type high volume sampler. We, likewise, have observed that any method of sampling that concentrates large volumes of air, particularly against any filter arrangement, destroys the larger particulates. They are fragile, and thus their structure is damaged and the particles reduced in size. He points out that because of the visibility problems "... it seems obvious that the most effective smoke pollution control strategy for such fires should utilize techniques that produce particles either smaller than 0.3 micron or larger than 1 micron." That "... it is desirable, if at all possible, to make particles

larger than one micron since gravity would accelerate their removal from the atmosphere. This would utilize the coldest, slowest, wettest fire that it is possible to burn."

In the Southeast as well as in the ponderosa pine forests of the West, just this kind of controlled burn is desirable for silvicultural and wildlife purposes. For this reason we have limited our investigation to particulates one micron or larger and have studied their structure and aerodynamic behavior. In our experimental controlled burns for wildlife and silvicultural purposes we have noted that the particles are larger with head fires than with back fires. This will be investigated in more detail in the winter and spring of 1973-1974 when large scale controlled burning operations will be conducted in northern Florida and southern Georgia by game plantations, State and Federal forest and park agencies, and large pulp companies, for forest, wildlife, and agricultural purposes.

ACKNOWLEDGEMENTS

We are indebted to Dr. D. L. Chambers, Director of the Insects Attractants, Behavior, and Basic Biology Research Laboratory, Agricultural Research Service, U.S.D.A. for the excellent cooperation received in this study. We appreciate the continued interest and encouragement from Dr. Philip S. Callahan of the above laboratory and of Dr. W. H. Whitcomb, Professor of Entomology, University of Florida. Our thanks go to Roy Komarek, Editor, Tall Timbers Research Station for interest and editorial assistance, and to Mrs. Harriett Knowles, Tall Timbers Research Station for typing the manuscript.

METHODS

A cursory study of forest and grassland fires revealed a wide range of varied complex structures, many of which appeared to be ideally organized to act as adsorbent charcoal filter-like traps for air pollutants. This approach to a study of air particulates from such fires showed great possibilities and a start was made on an atlas of micro-photographs. That the particulates are an integral part of fire ecology cannot be disputed.

The particulates from any forest or grassland fire are of great variety because of the number of plant species involved and because of variations due to the differences in combustion processes under different intensities of fires. The first step had to be a sorting out and identification of particulates, charcoal and ash.

1. Material of known plant species (leaves, stems, twigs) that had lain on the ground for at least 2 months or more was selected. This was burned on the ground in small samples, the charred material and

ash was put into petri dishes and taken to the laboratory for examination. Because the material was so fragile a technique developed by Carlyle for insect work was used. Pieces of double-coated adhesive tape were cut into small pieces and placed on standard microscope cover slides. The material to be examined was carefully placed on the tacky surface. Then the cover slide was mounted to a standard scanning electron microscope stub, "out-gassed" and coated with gold.

2. Our next procedure was to build the test fires in the open on an aluminum tray which was placed upon a 3 by 4 foot galvanized metal sheet that had been well burned to remove the galvanizing. This in turn was placed upon a metal barrel so that the fires were 4 feet above the ground (Fig. 7). In this way various air currents, artificially produced as well as natural, could be observed more easily and particulates could be obtained under various conditions. The resulting char and ash that was not airborne remained in the tray. Various materials were examined by the methods already described. However, by this time Carlyle had remarked about the ease with which excellent micro-photographs were being made. She then experimentally examined a piece of charred red oak twig without any gold coating and obtained remarkably clear photos (Figs. 33, 34, 35, 36). However, she soon learned that if the charcoal material was left exposed in the airconditioned laboratory it absorbed sufficient moisture to inhibit good scanning.

In this respect it is interesting to note that Sir Humphrey Davis in 1800 developed the first electric arc by using charcoal electrodes because of its conductivity. Also, it is of interest that because of the affinity of charcoal for gold and silver, charcoal is used in the separation processes of mining and refining these metals. Thus, charcoal particulates are ideal materials for scanning for they are conductive throughout and if "out-gassed" so they contain little if any moisture, can be used without gold coating. Gold coating in turn makes the production of excellent micro-photographs much easier.

The white ash particulates were difficult to work with. Even after gold coating the porosity and fragile nature of white ash made it difficult and, in most cases, impossible to obtain good photographs because of the lack of conductivity. Even in charcoal materials charge lines would develop wherever any white ash adhered to the charcoal.

3. Material for examination, as well as for investigation of aerodynamics of particulates, was obtained from controlled burns of field size. One example (Figs. 1, 3, 5) was a controlled burn, August 17, 1973, 2-6 p.m., steady wind speed of about 5-7 miles per hour from the northeast with occasional gusts and change of direction with wind out of the northwest reaching up to 10 or more miles per hour. Part of the tract was a mixed bahia grass and broomsedge old pasture with considerable brush species of hardwoods. The upper end was

a small section of mature longleaf pine, brush choked with several hardwood species. The area had not been grazed for over 5 years and had not been burned for 2 years. It was noted in this fire as well as others that the white ash particulates apparently are not as aerodynamic and tend to fall back on the ground short distances from the fire. Small charcoal particulates were observed over one-half mile from this fire. By placing sheets of clear adhesive with tacky side up at various distances from the fire, good collections of particulates were obtained. Charcoal, ash, and partially charred plant materials were also collected from the ground surface for study of their structure and other characteristics in relation to the ecology of the soil surface, the soil, and the atmosphere.

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A PRELIMINARY ATLAS

Low intensity forest and grassland fires create a great diversity of airborne particulates and charcoal. The variation of temperatures, caused by many factors such as wind, humidity, moisture content and kind of fuel, develop an increased diversity upon the morphological integrity of plant material. This airborne material or the residues that remain on the surface vary from carbonized material to minerals, white ash, tars and gases. We have found that many of these can be determined as to genera of plant material. However, because of the varying temperatures and the variety of plant material being burned in any single fire only a portion can be identified easily. Figures 107 through 122 show a few of the materials collected on one 8½" by 11" tacky, clear adhesive plastic sheet from one fire. Some were easily identified by comparison from materials from test burns. Others could not be so identified, at least at present.

The following selected micro-photographs show some of the diversity found in the particulate matter and residual surface charcoal from low intensity forest and grassland fires.



Fig. 1. Control burn in bahia grass and broomsedge. Aug. 19, 1973. Birdsong Plantation, Grady Co., Georgia.



Fig. 2. Charred and ashed stems and leaves of above grasses in above burn.

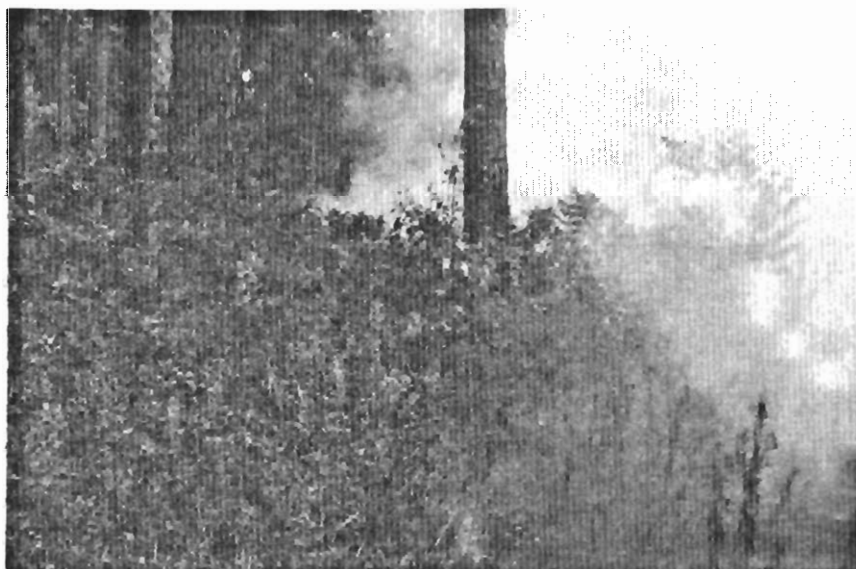


Fig. 3. Control burn in longleaf pine and brush at same time as Figs. 1 and 2.



Fig. 4. Charred and ashed pine needles and twigs in above burn.



Fig. 5. Particulates becoming airborne above flames in burns of Figs. 1-4.

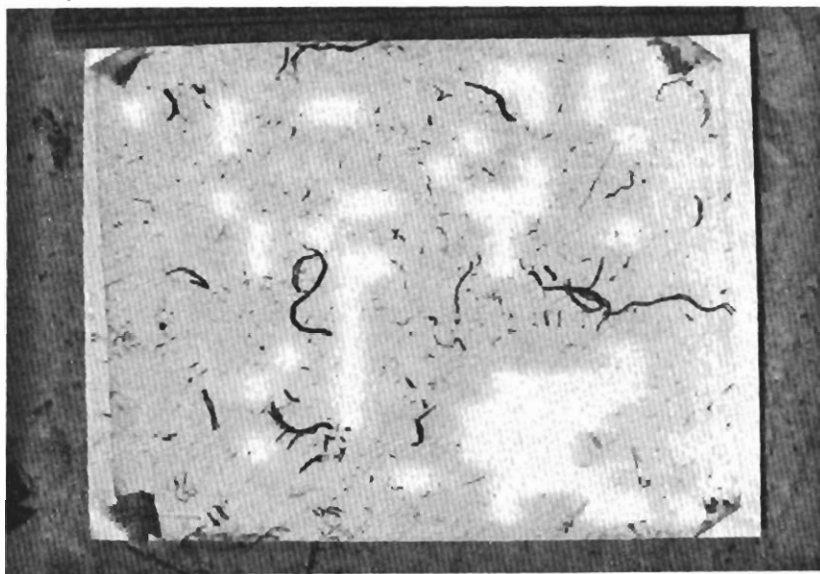


Fig. 6. Particulates trapped on plastic tacky sheets 1500 feet from fire, Figs. 1-4.



Fig. 7. Test fire on burning platform.



Fig. 8. Burned snag. Longleaf pine tree killed by lightning 1968 and burned into black snag by control burning. The charcoal covering was 2" thick in places.

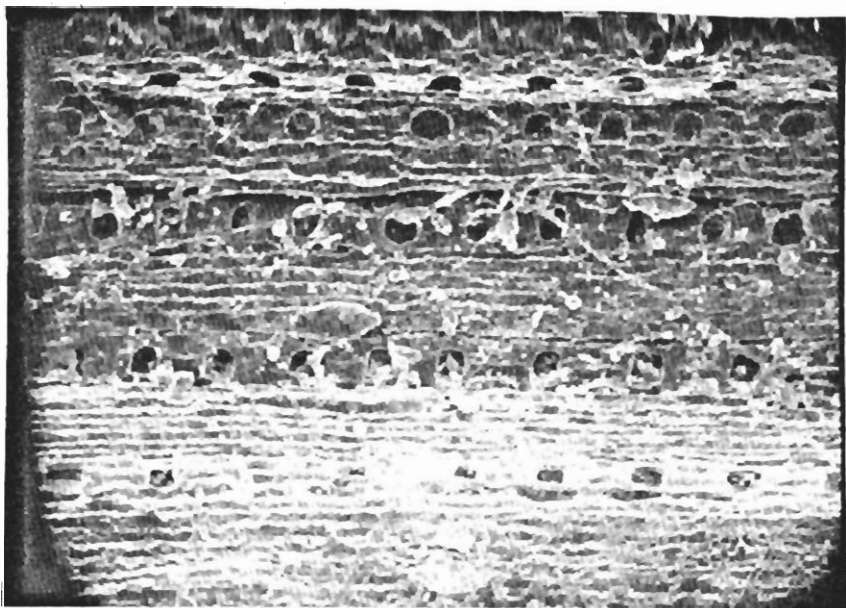


Fig. 9. Black, charred slash pine needle from wildfire, Gainesville, Fla. about June 1973. Ventral side, black char. 200X.

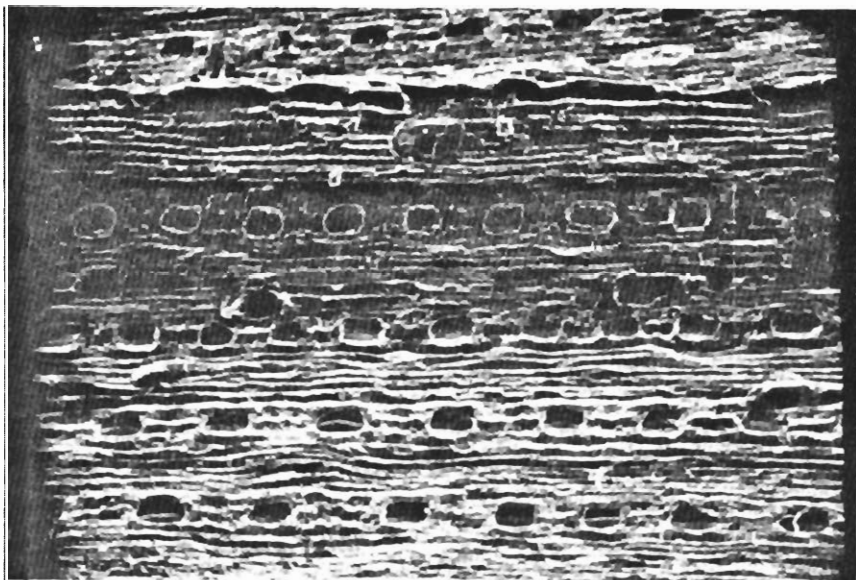


Fig. 10. Black, charred slash pine needle from test burn, July 26, 1973. 200X. Compare with Fig. 9.

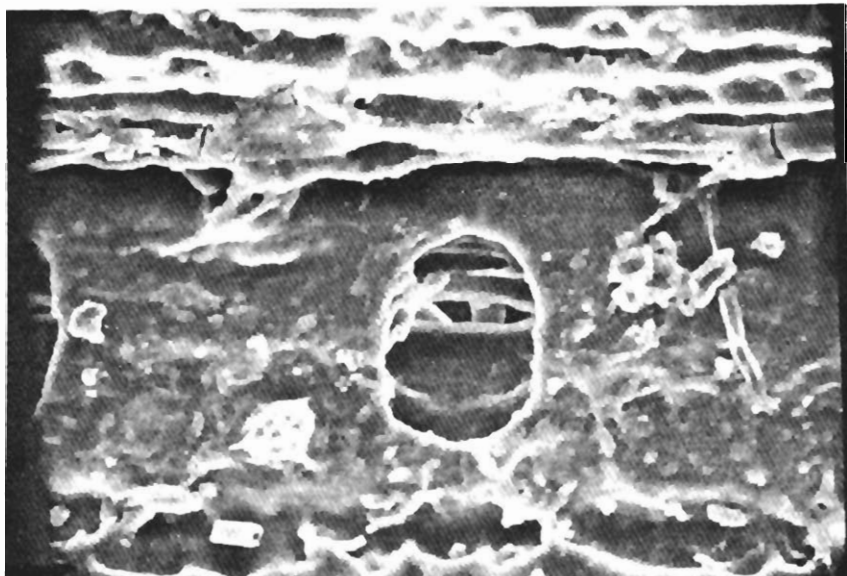


Fig. 11. Black charred slash pine needle from wildfire, Gainesville, Fla., about June 1973. Dorsal side, black char with some white ash. 1055X.

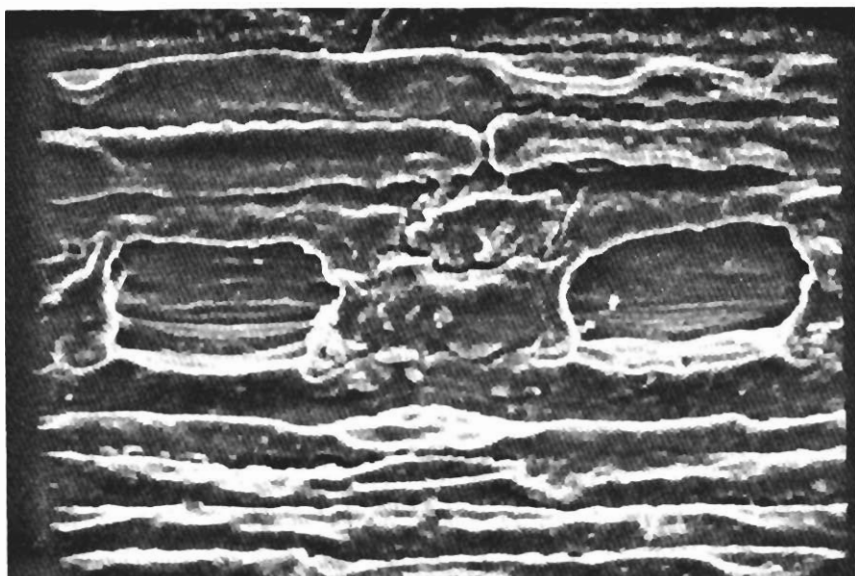


Fig. 12. Black charred slash pine needle from test burn, July 26, 1973. 1000X. Compare with Fig. 10.



Fig. 13. Slash pine bark, charred. Dorsal view. From wildfire, Gainesville, Fla. 200X.



Fig. 14. Slash pine bark, charred, dorsal view, from test burn. 200X.

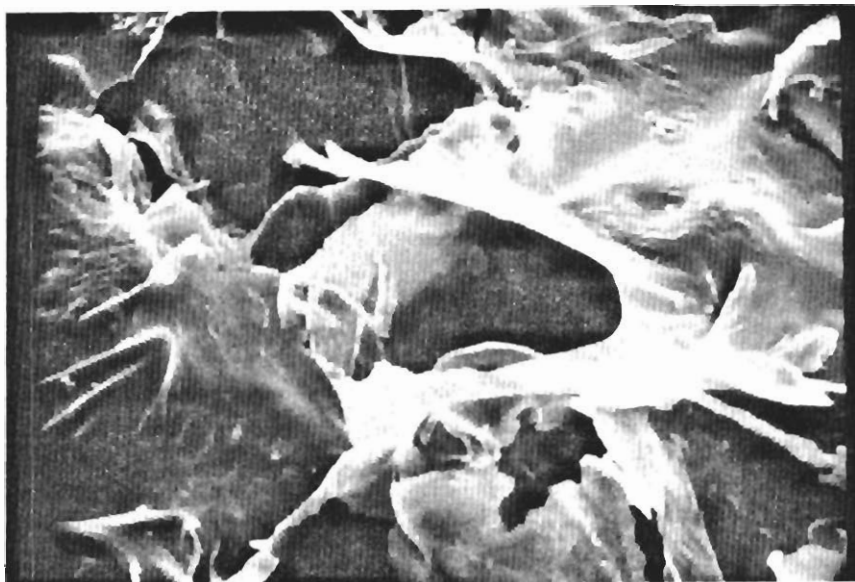


Fig. 15. Slash pine bark, charred, dorsal view. Same as Fig. 13. From wildfire, Gainesville, Fla. 1010X.

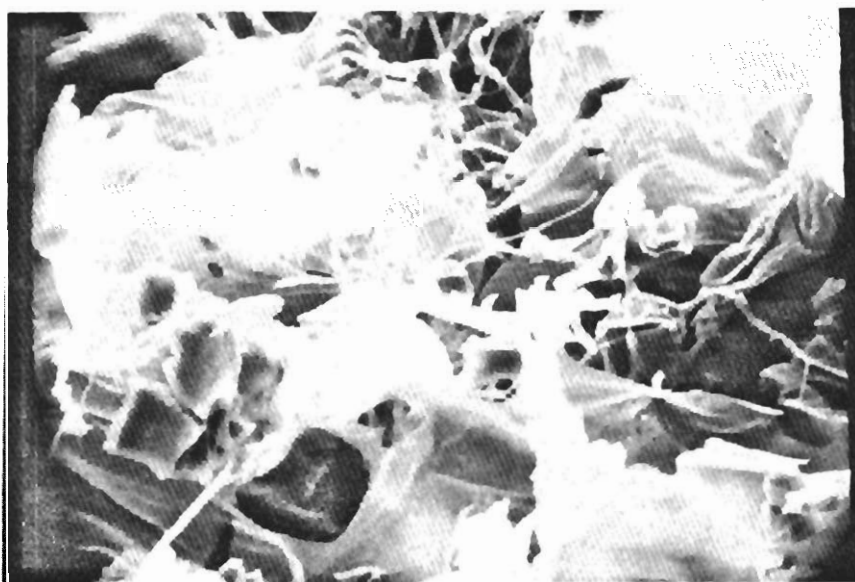


Fig. 16. Slash pine bark, charred, dorsal view. From test burn. Same as Fig. 14. 1050X.

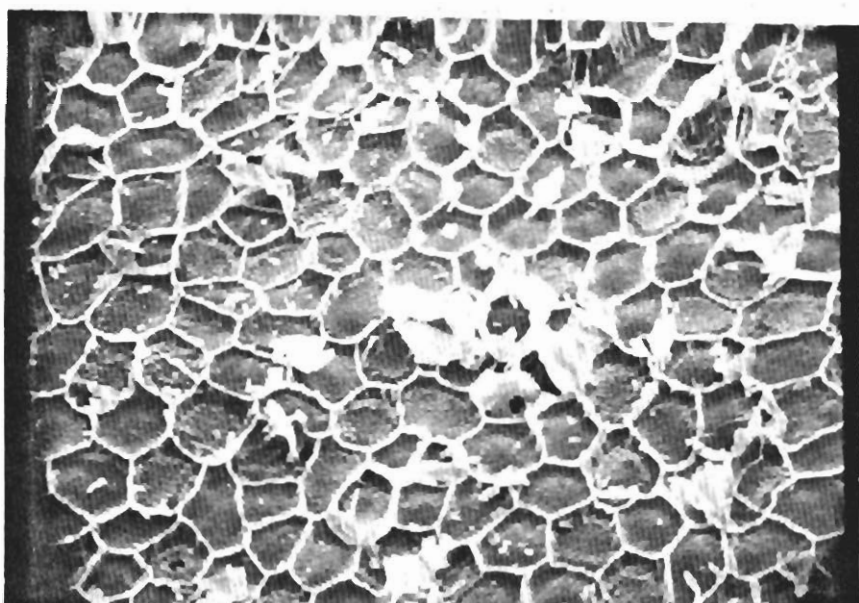


Fig. 17. Slash pine bark, charred, ventral view. From wildfire, Gainesville, Fla. 220X.

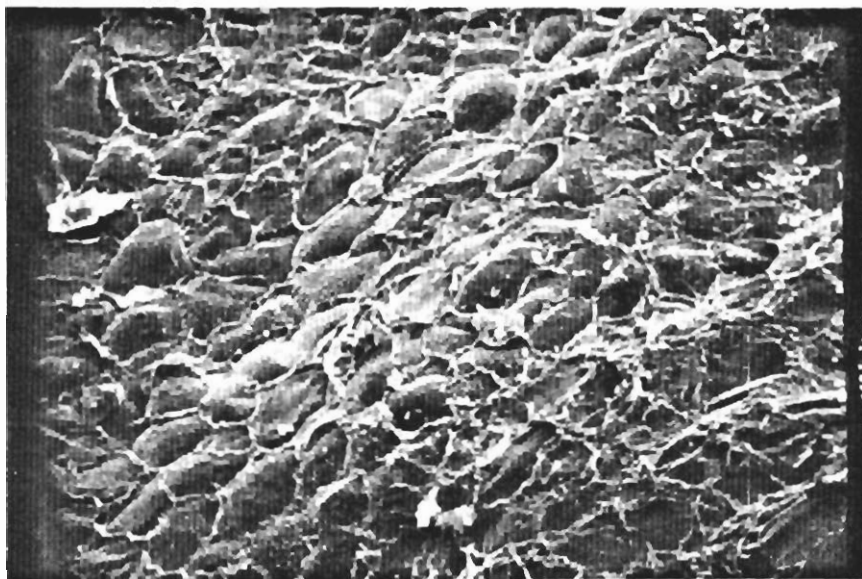


Fig. 18. Slash pine bark, charred, ventral view. From test burn. 200X.

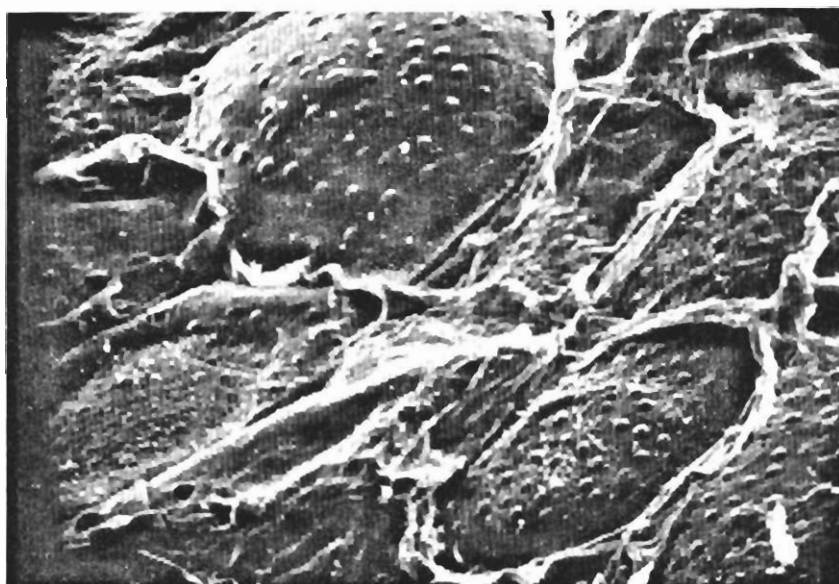


Fig. 19. Slash pine bark, charred, same as Fig. 17 but mag. 855X.

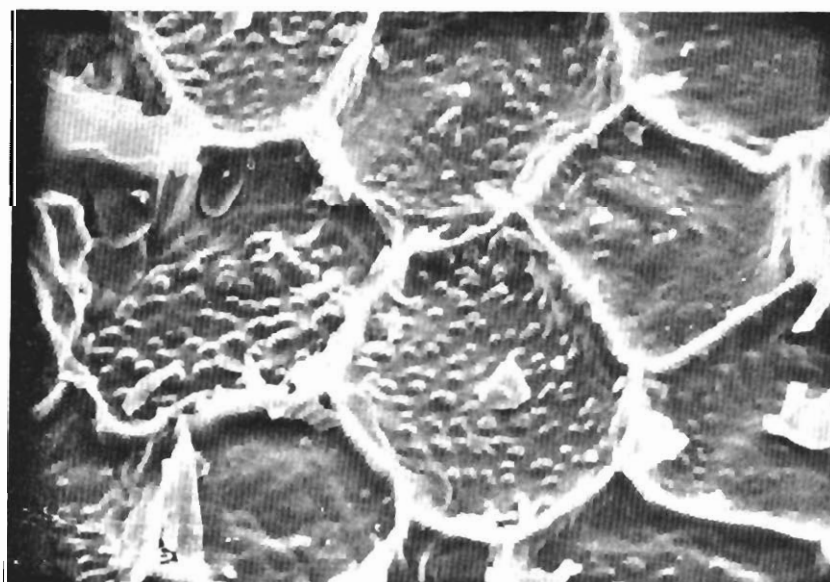


Fig. 20. Slash pine bark, charred, same as Fig. 18 but mag. 1000X.

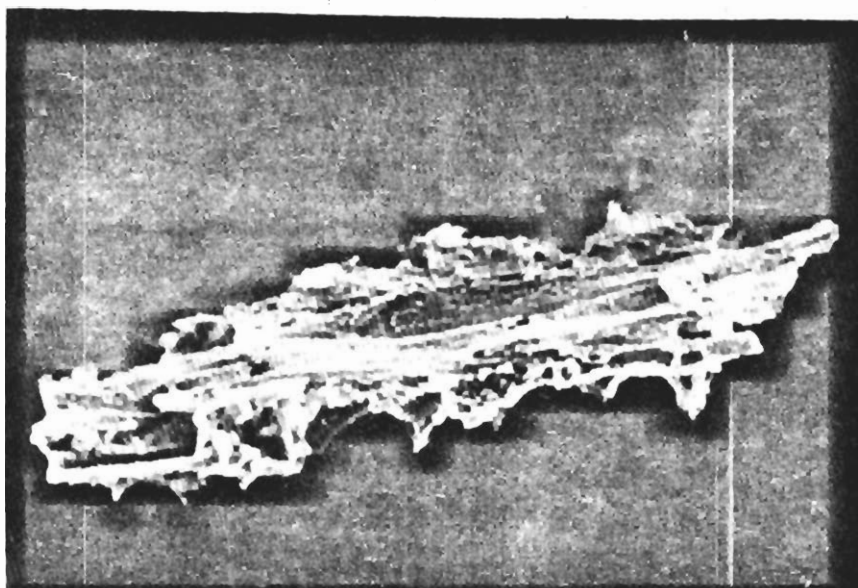


Fig. 21. Longleaf pine needle, airborne particulate from test burn. Black char with some white ash. Note porous structure. 675X.

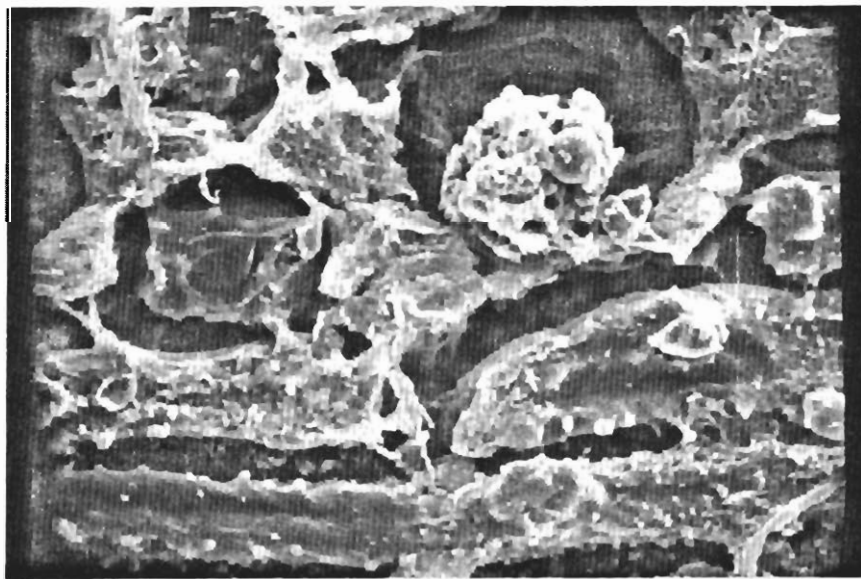


Fig. 22. Black charred longleaf pine needle airborne particulate with white ash in test burn. Dorsal view. 1060X.

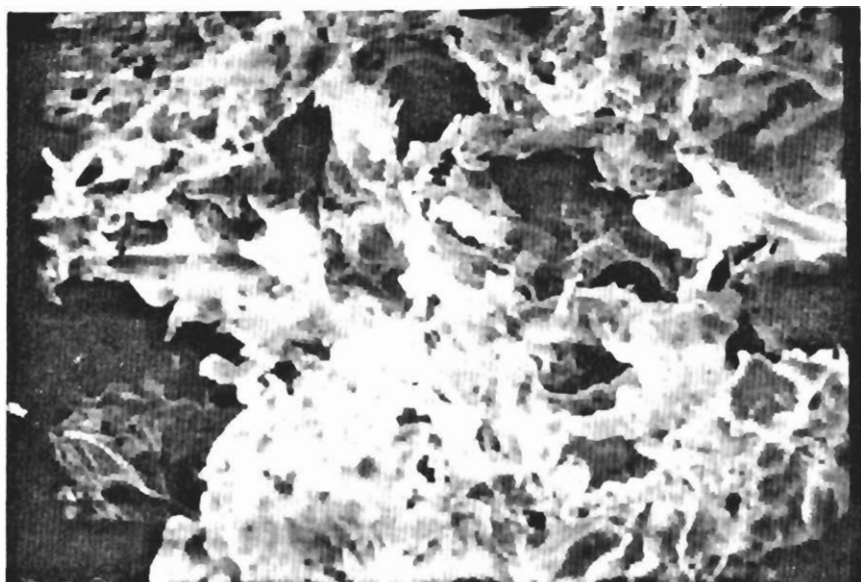


Fig. 23. Longleaf pine needle airborne particulate charred in test burn. Dorsal view. 1000X.

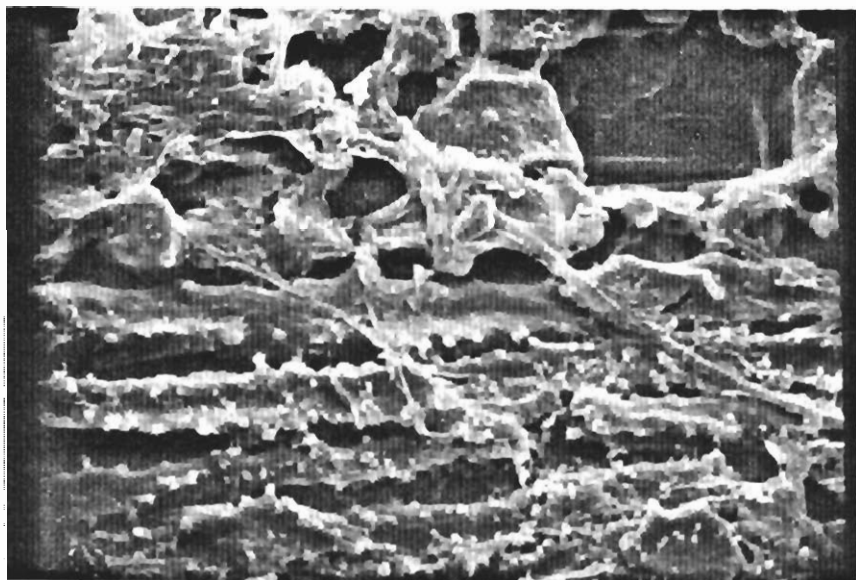


Fig. 24. Longleaf pine needle charred airborne particulate in test burn. Ventral view. 1000X.

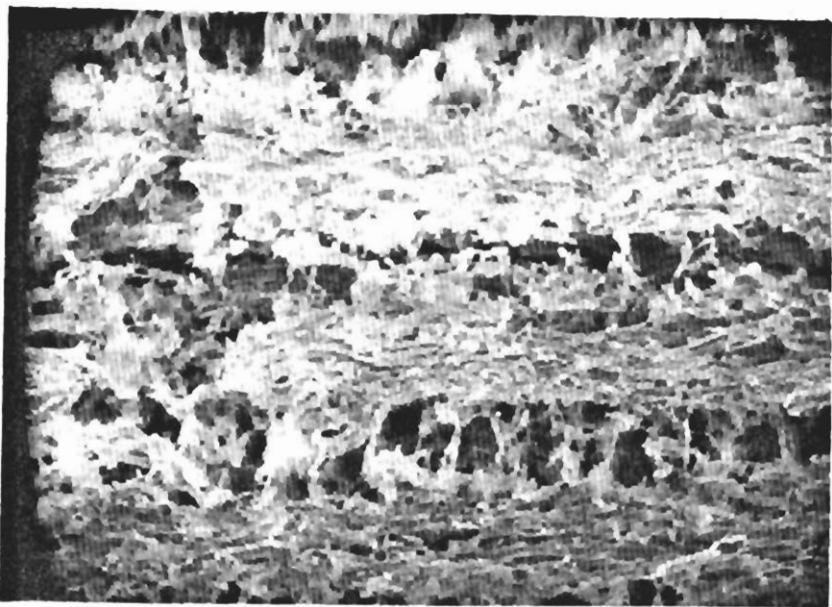


Fig. 25. Longleaf pine needle charred and partly ashed in test burn. Dorsal view. 210X.

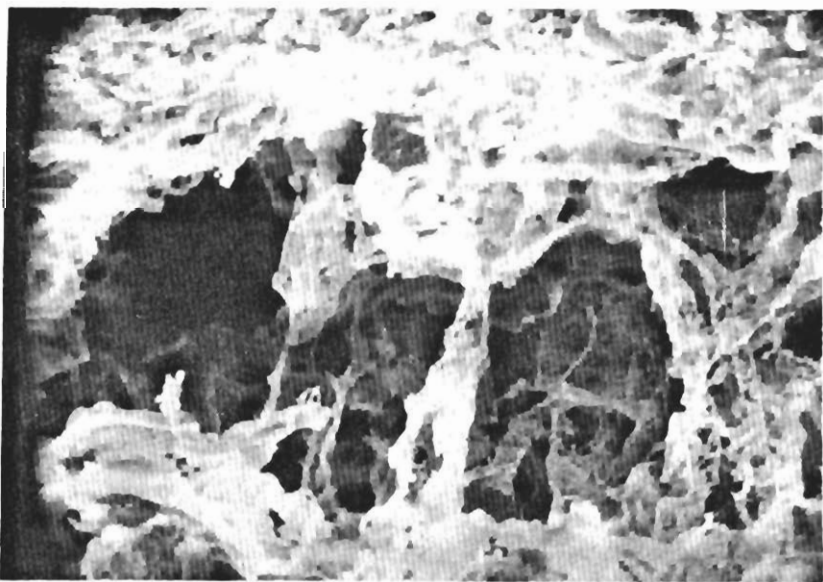


Fig. 26. Longleaf pine needle. Same as above but mag. 1000X.



Fig. 27. Edge view of longleaf pine bark scale from regularly control burned forest. Black char. 220X.

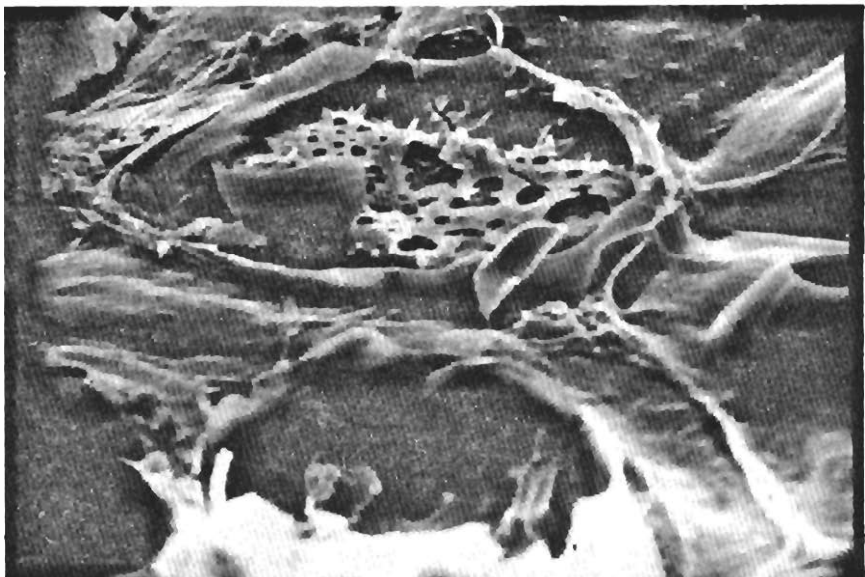


Fig. 28. Longleaf pine bark scale surface from regularly control burned forest. (Same bark as Fig. 19.) Black char. 900X.

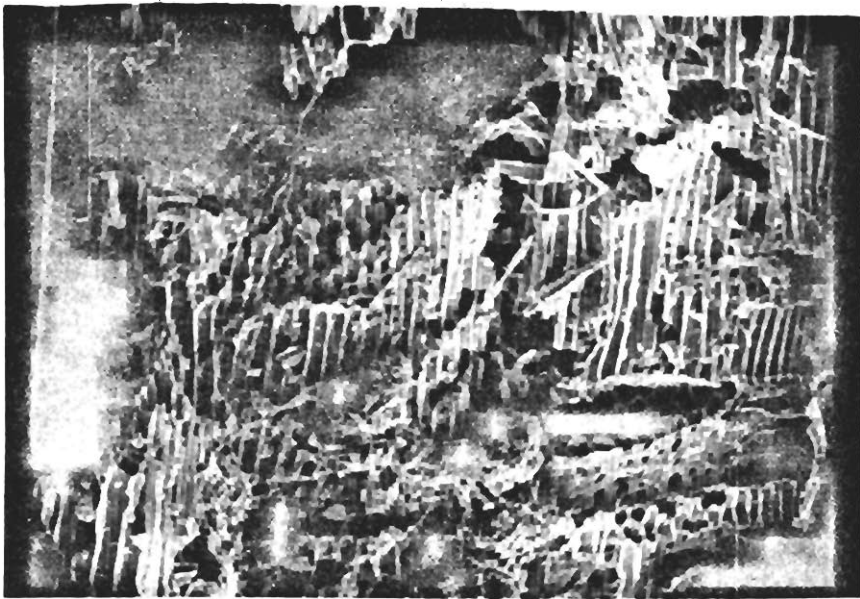


Fig. 29. Charred black twig from small longleaf pine tree in test burn. Broken area caused by forceps but shows internal structure. 200X.

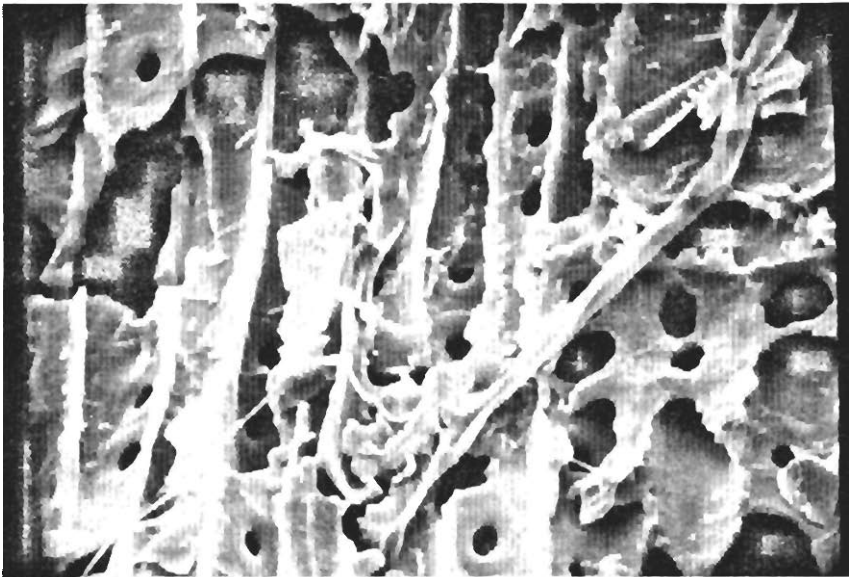


Fig. 30. Higher magnification of Fig. 29. Black charred longleaf pine twig. 1000X.

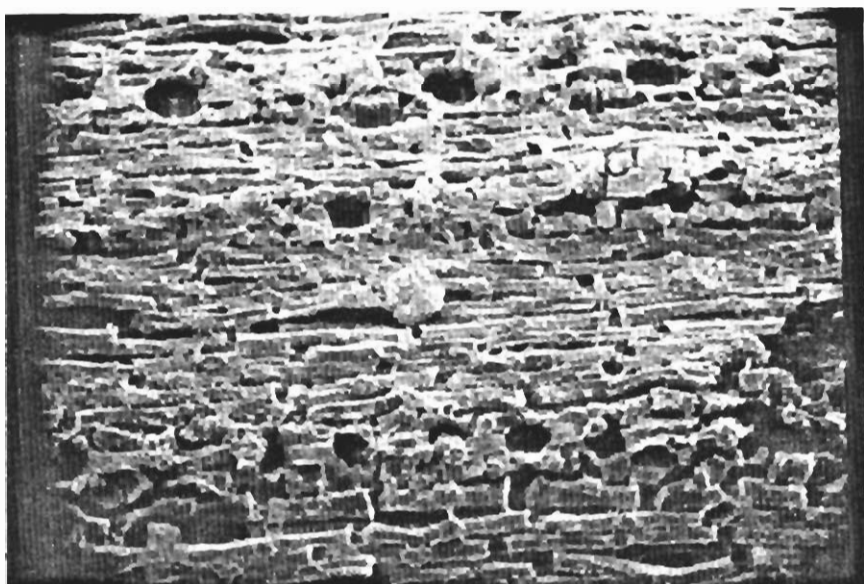


Fig. 31. Longleaf pine needle charred in test burn. Ventral view. Black char. 200X.

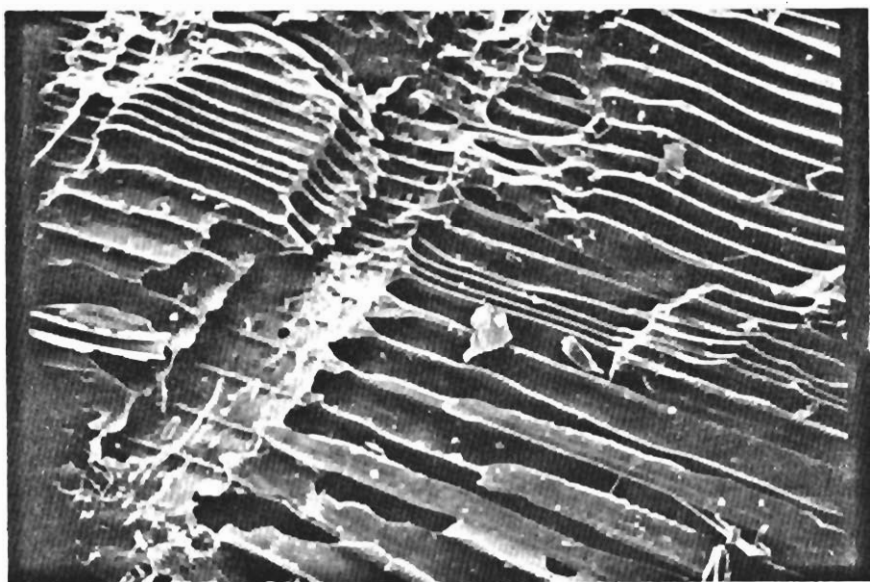


Fig. 32. Longleaf pine charred snag from Fig. 8, showing internal porous structure. Black char from regular control burns.

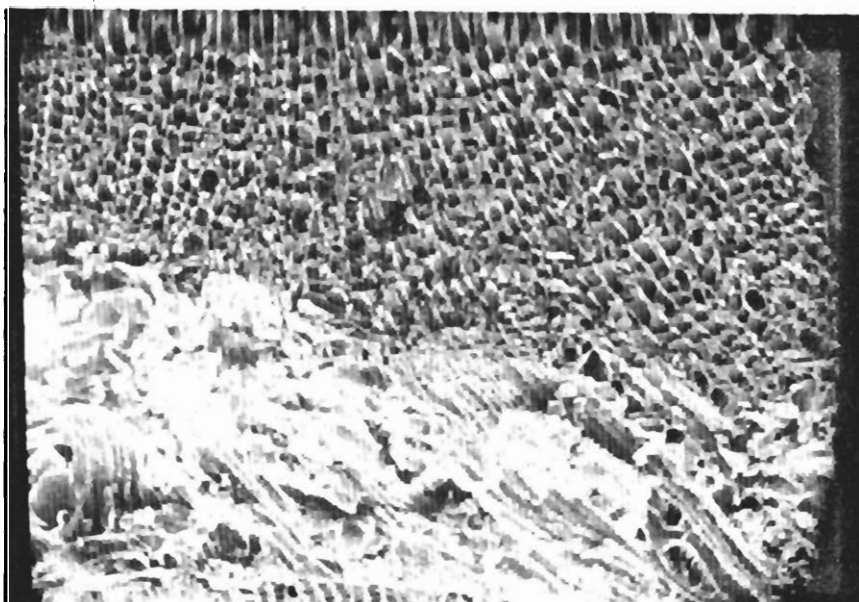


Fig. 33. Charred longleaf pine twig from test burn, but not coated with gold and scanned without treatment. 105X.

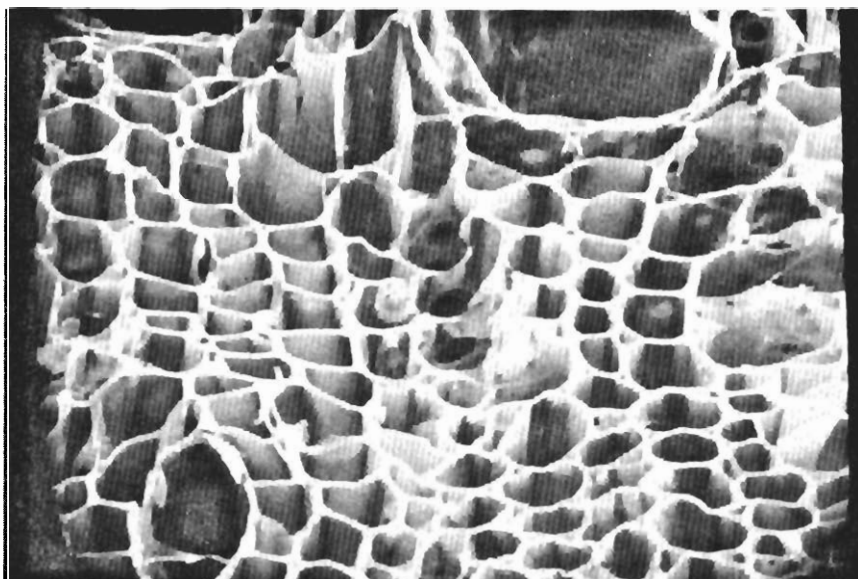


Fig. 34. Same as Fig. 33 but at magnification of 520X.



Fig. 35. Longleaf pine twig. Black charred and coated with gold in regular procedure.

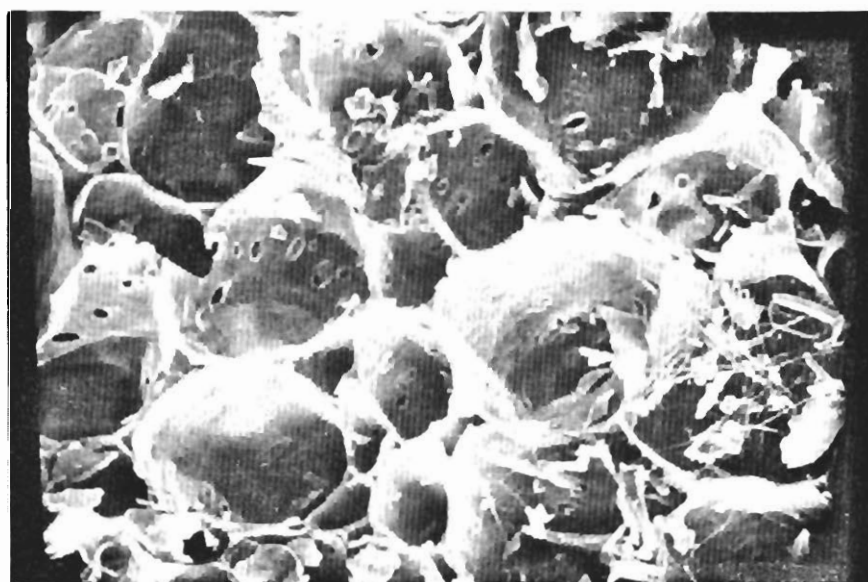


Fig. 36. Longleaf pine twig, charred, but not coated for scanning.

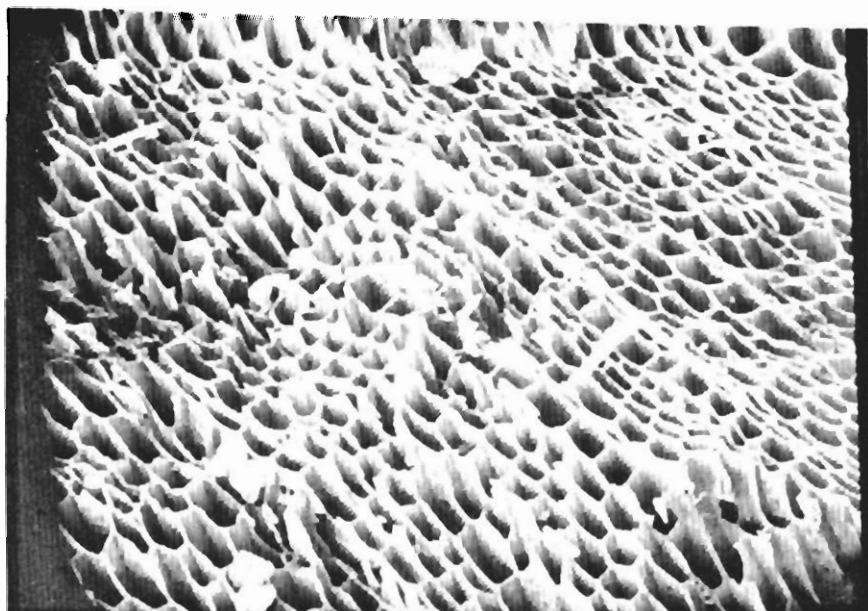


Fig. 37. Longleaf pine snag charred from repeated control burns. 130X.

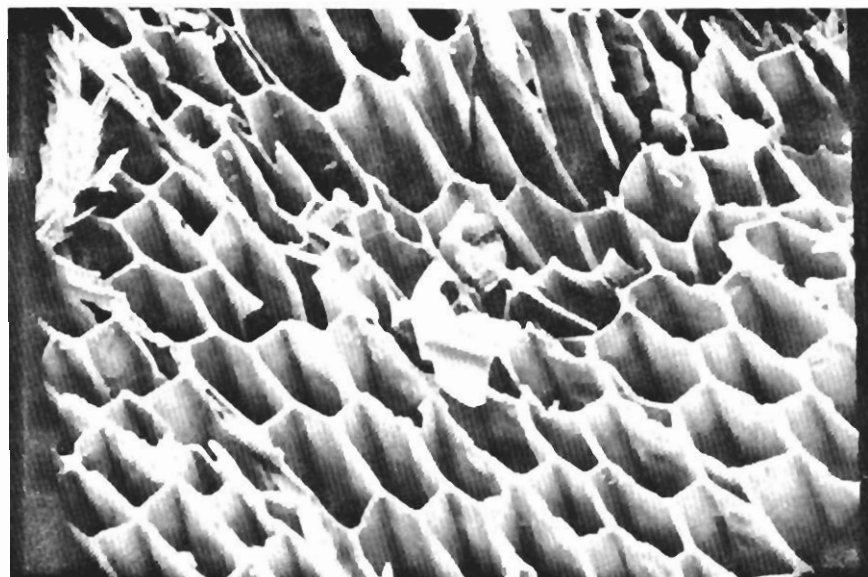


Fig. 38. Same as Fig. 37 but magnification of 255X.

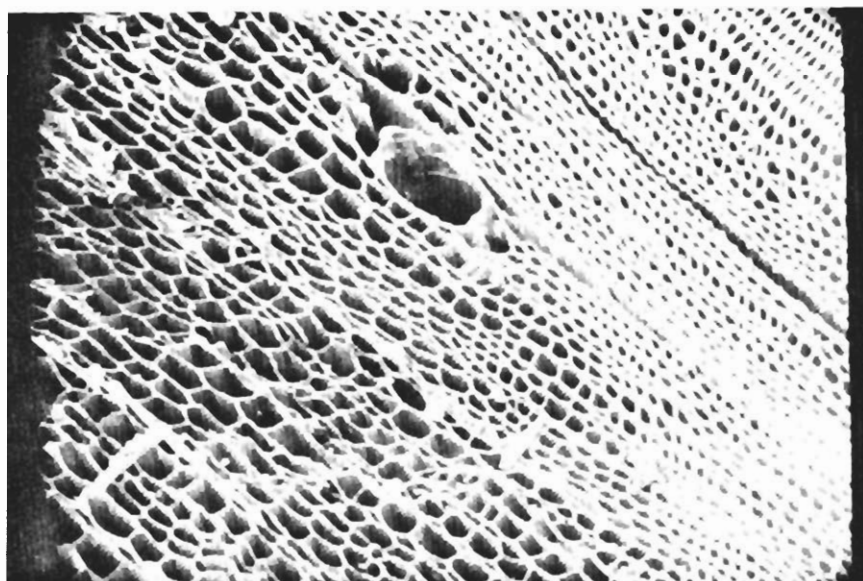


Fig. 39. Longleaf pine snag charred from repeated control burns. 130X.

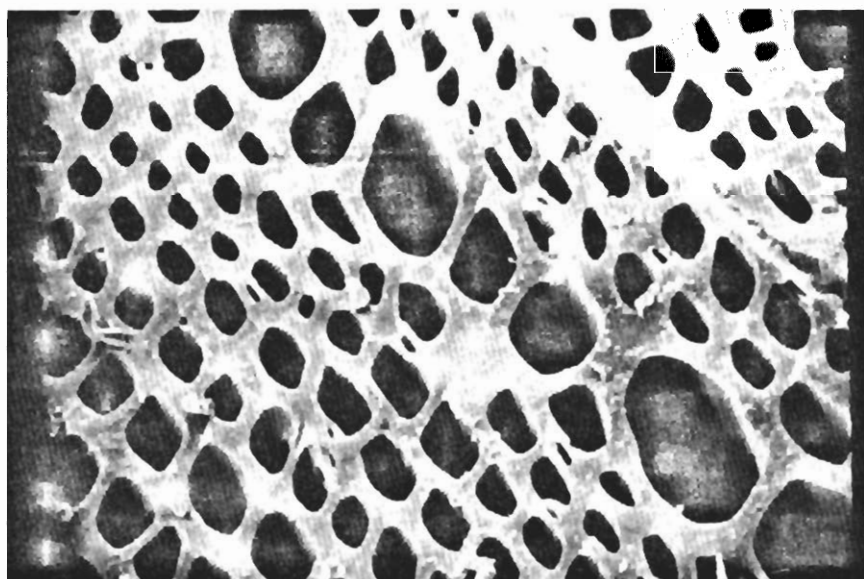


Fig. 40. Same as Fig. 37 but magnification of 650X.

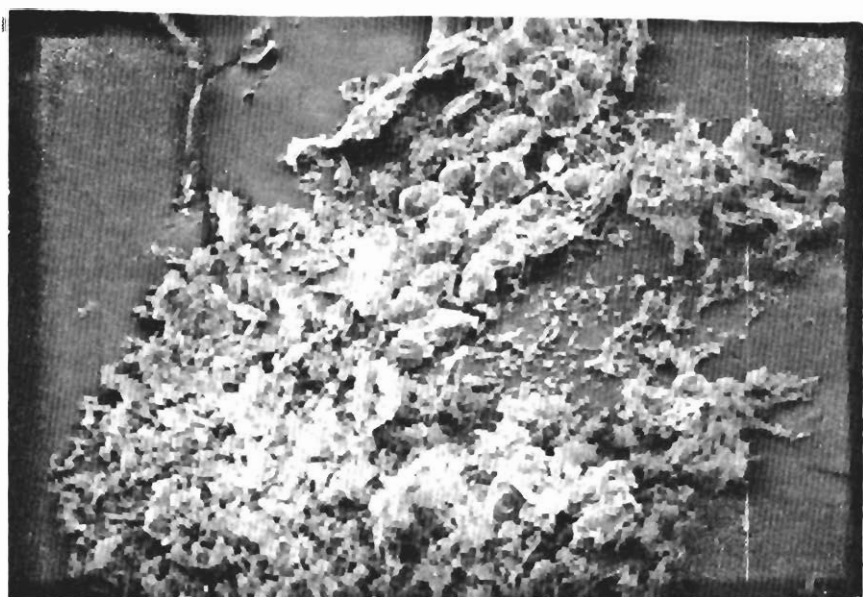


Fig. 41. Spruce pine bark airborne particulate from test burn. Partly white ash. 160X.

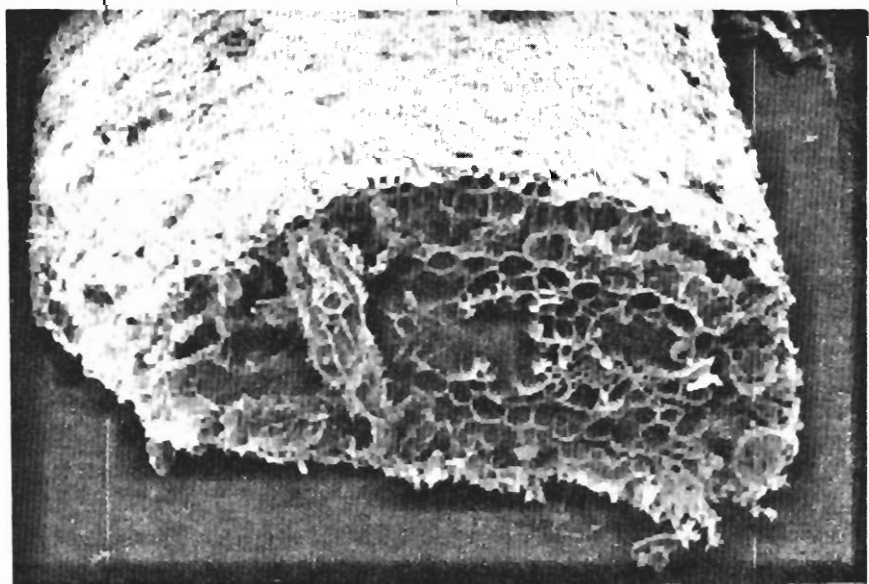


Fig. 42. Cross section of spruce pine charred needle. Black char. 162X.



Fig. 43. Stomata (?) from spruce pine bark particulate, Fig. 33. 1600X.

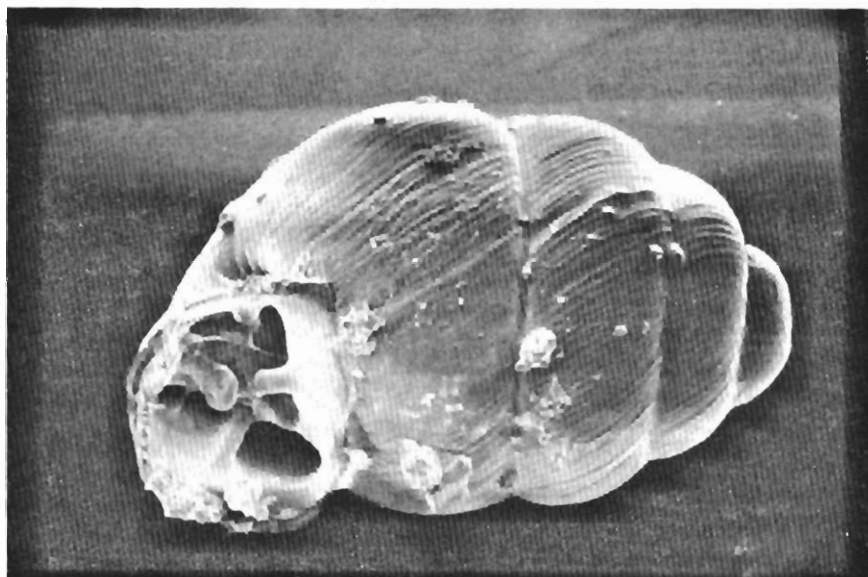


Fig. 44. Snail (Pupillidae) came out of spruce pine bark in test burn and was charred black. 48X.

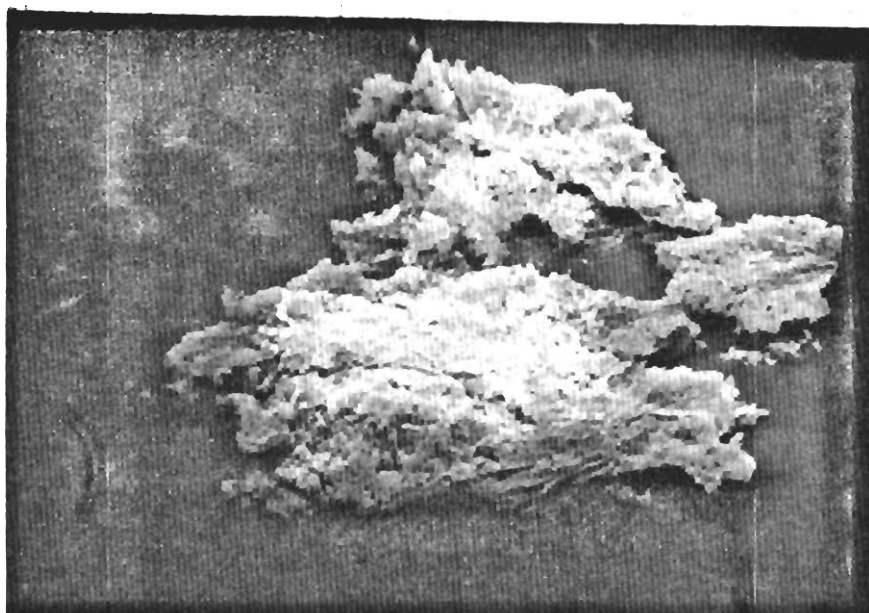


Fig. 45. Red oak particulate from test burn. 107X.



Fig. 46. Red oak particulate same as Fig. 45. 1075X.

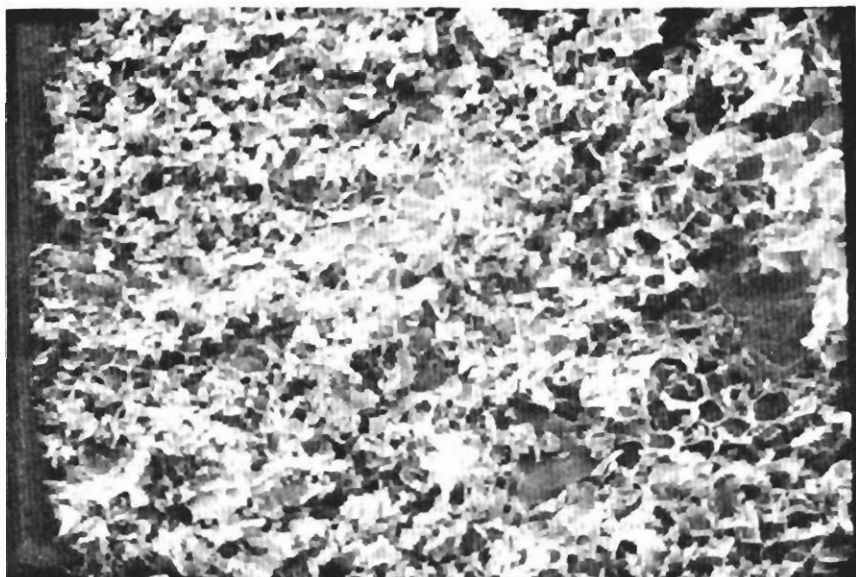


Fig. 47. Red oak bark charred in test burn. Ventral view. 115X.



Fig. 48. Red oak bark charred, same as Fig. 47. 640X.



Fig. 49. Red oak charred twig from test burn. 23X.

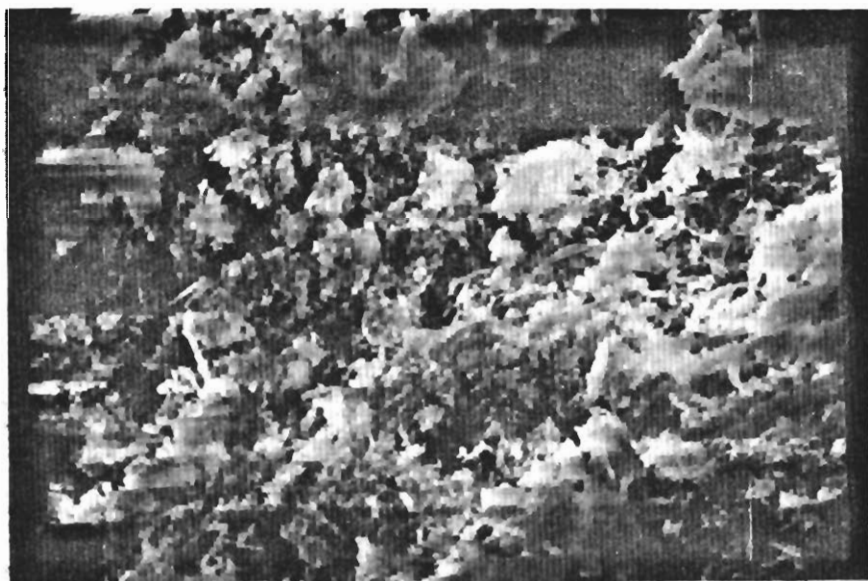


Fig. 50. Red oak charred twig from test burn. Same as Fig. 49. White ashed section. 580X.

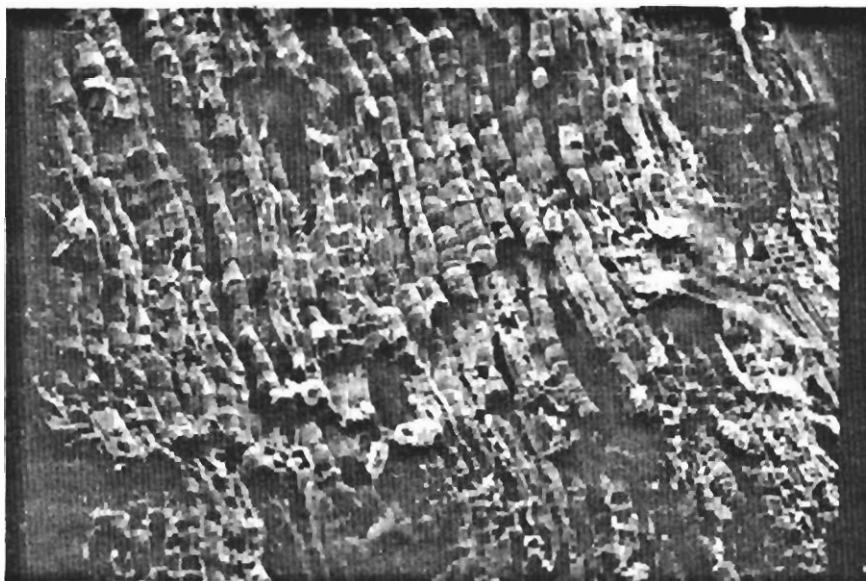


Fig. 51. Red oak charred twig from test burn. Same as Fig. 49 but from black charred section. 110X.

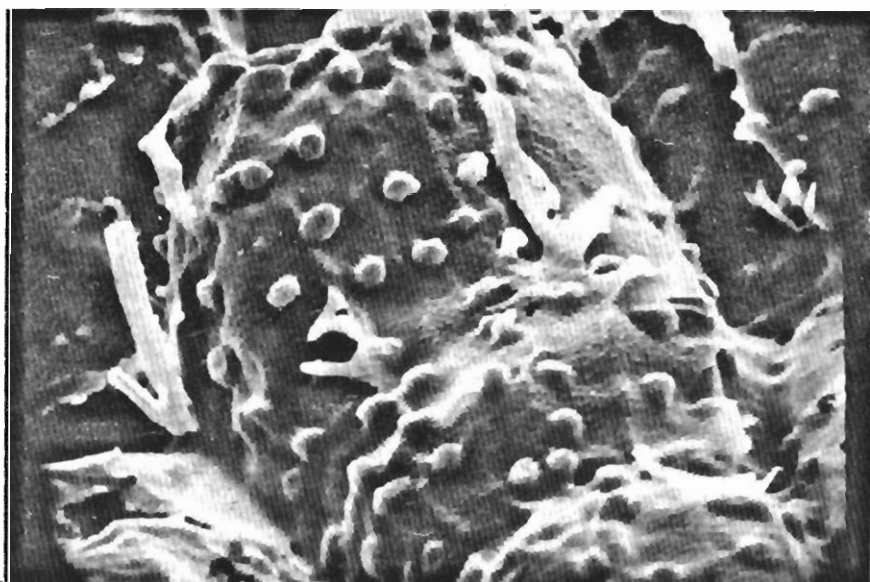


Fig. 52. Red oak charred twig. Same as Fig. 51. 2200X.



Fig. 53. Red oak black charcoal section from bark. Test burn. 26X.

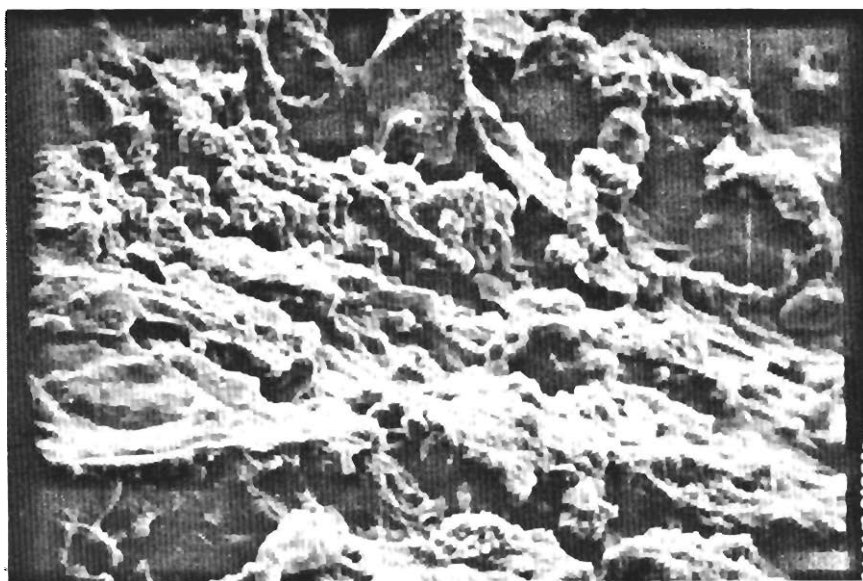


Fig. 54. Red oak charcoal. Same as Fig. 53. 1240X.

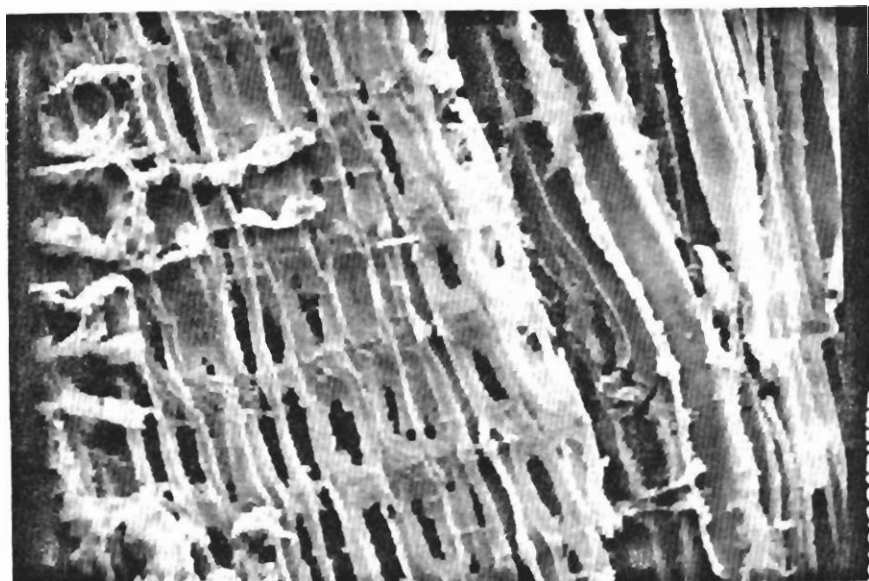


Fig. 55. Red oak charcoal. Same as Fig. 53 but another section. 1110X.

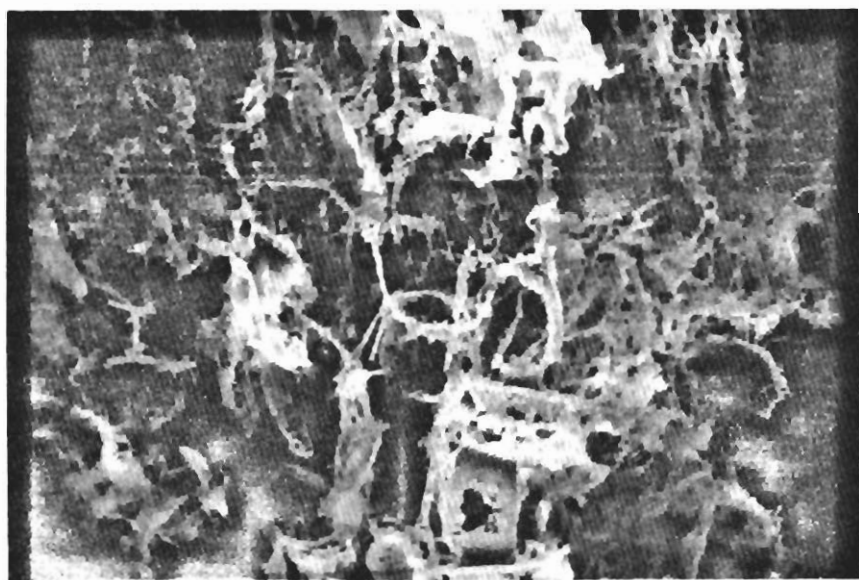


Fig. 56. Red oak charcoal. Same as Fig. 53 but another section. White ashed. 625X.

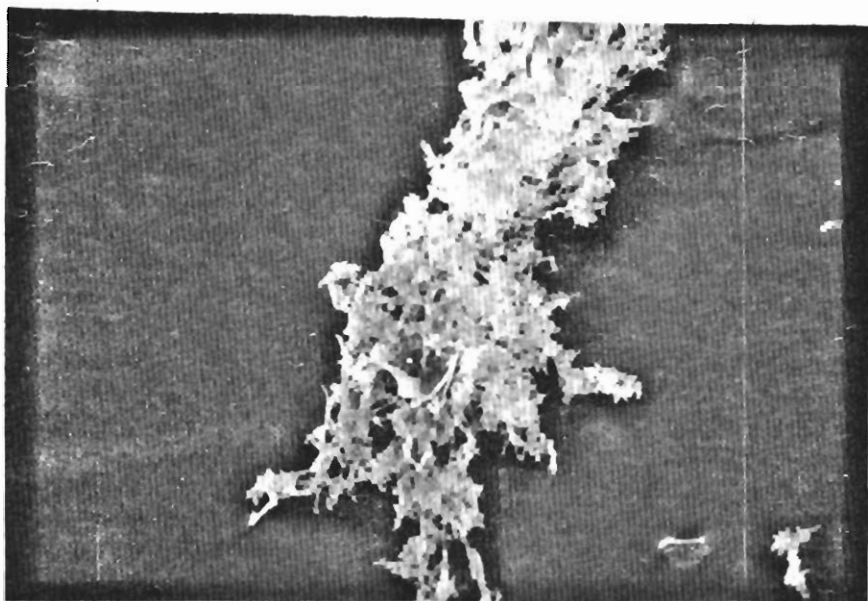


Fig. 57. Water oak airborne particulate from test burn. 280X.

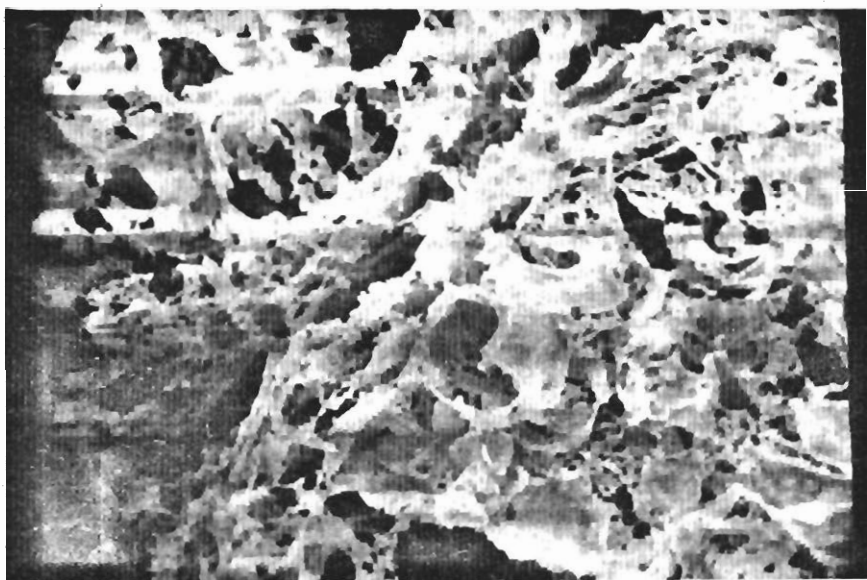


Fig. 58. Water oak. Same as Fig. 57. 950X.

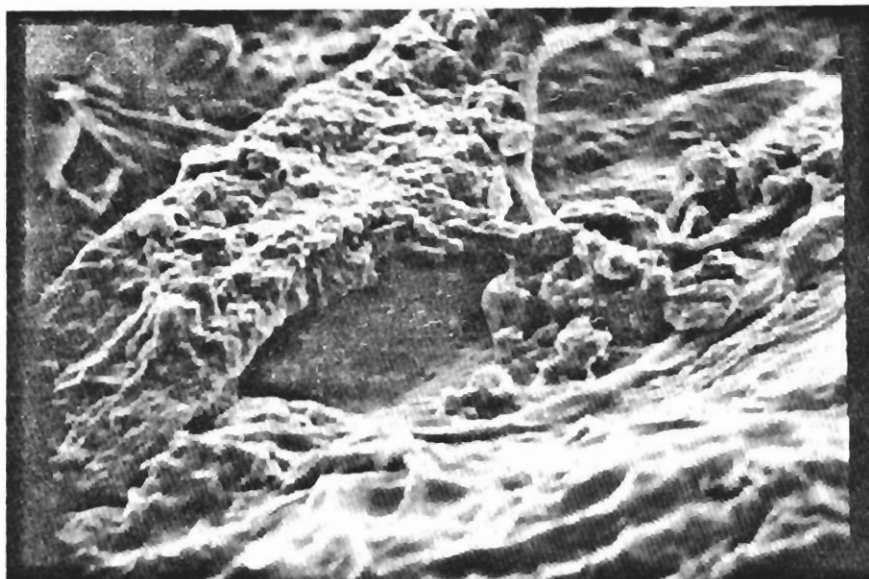


Fig. 59. Water oak. Black charred particulate. 1120X.

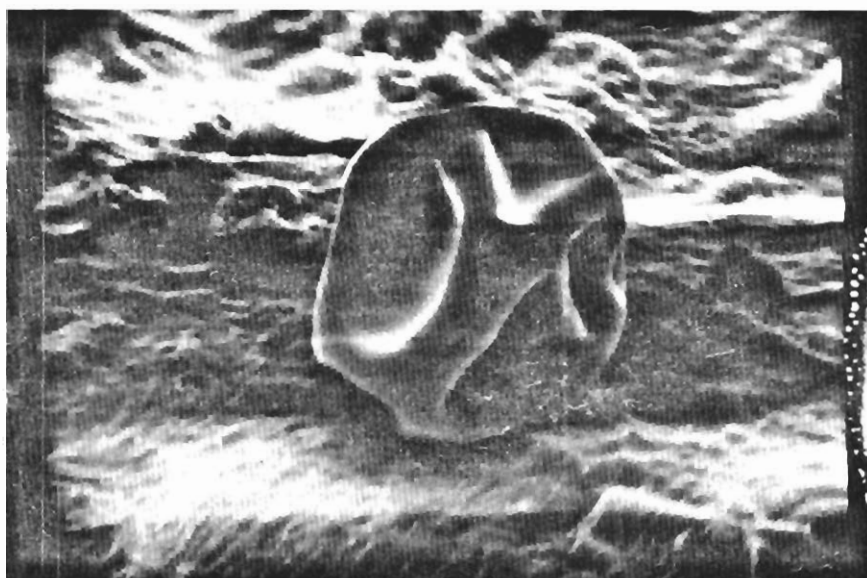


Fig. 60. Water oak, from Fig. 57. 2240X.



Fig. 61. Magnolia leaf. Large particulate from test burn. 55X.

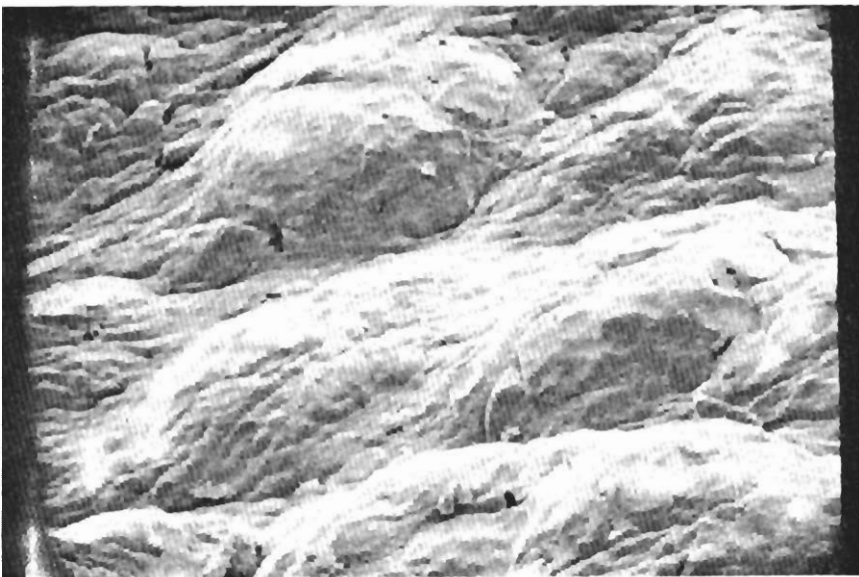


Fig. 62. Magnolia leaf. Detail from lower right corner of Fig. 61. 480X.

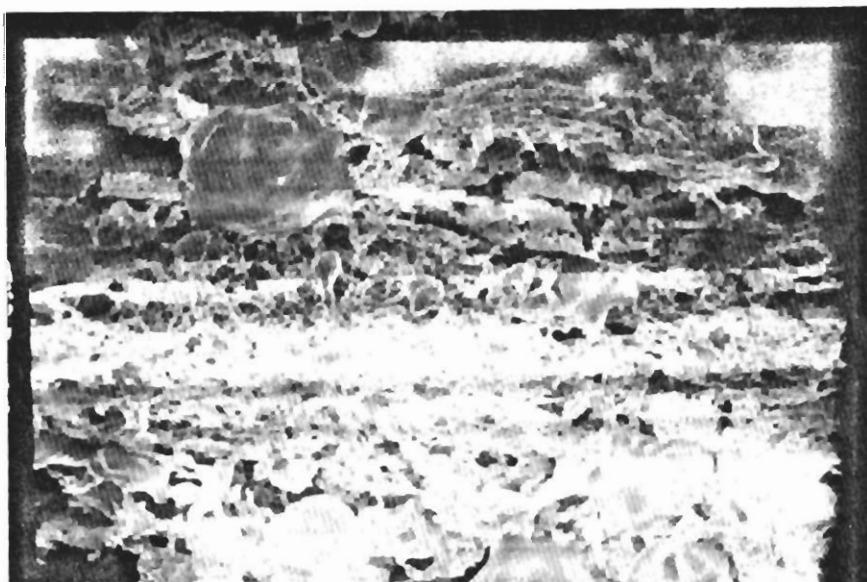


Fig. 63. Magnolia leaf. Detail from upper left corner Fig. 61. 450X.

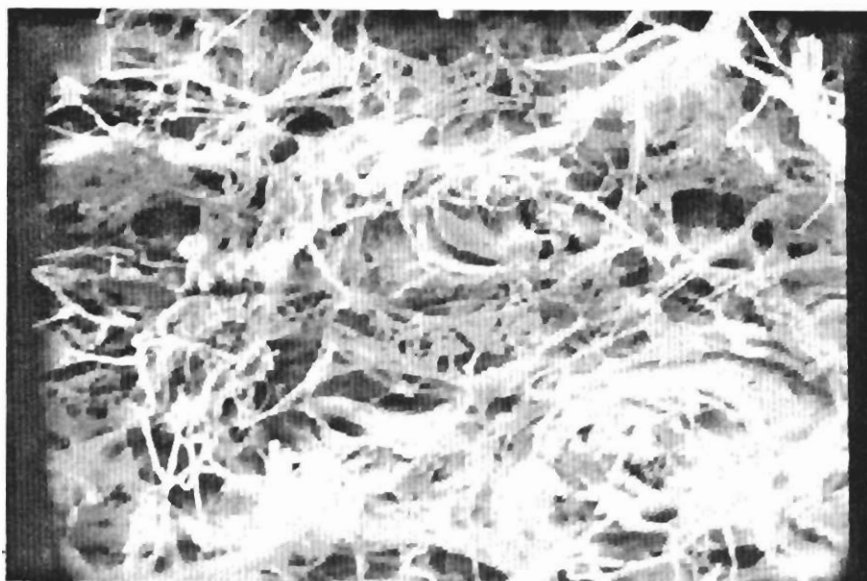


Fig. 64. Magnolia leaf. Detail from 61. 950X.

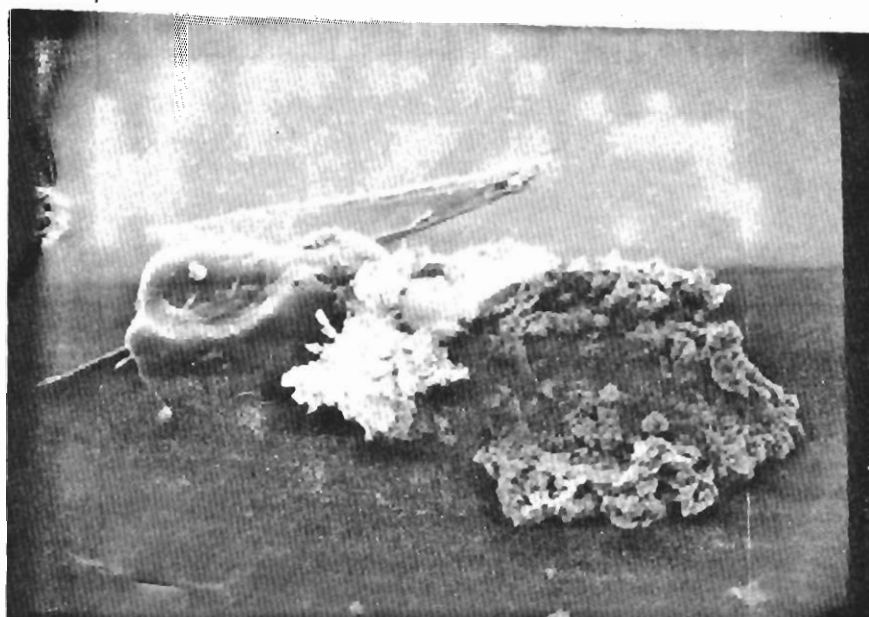


Fig. 65. Wiregrass airborne particulate. 160X.



Fig. 66. Wiregrass airborne particulate. Higher magnification of Fig. 65. 1265X.

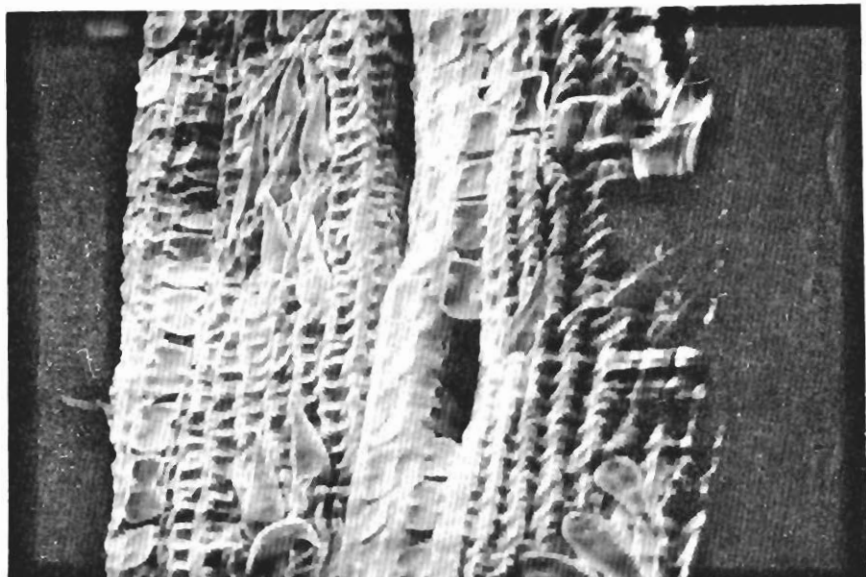


Fig. 67. Wiregrass airborne particulate. Stem section showing trichomes and opaliths (dumbell shaped.) 640X.

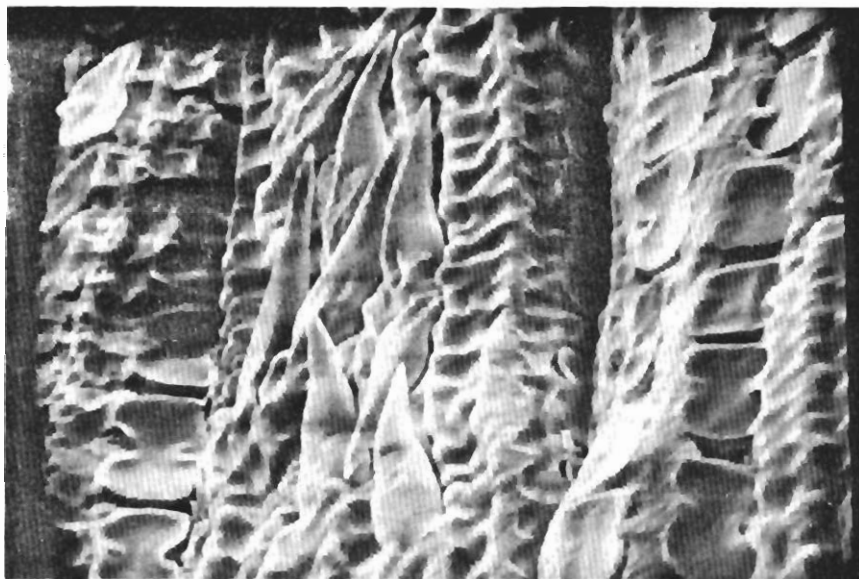


Fig. 68. Wiregrass airborne particulate. Higher magnification of Fig. 67. 1280X.



Fig. 69. Broomsedge airborne particulate. 130X.

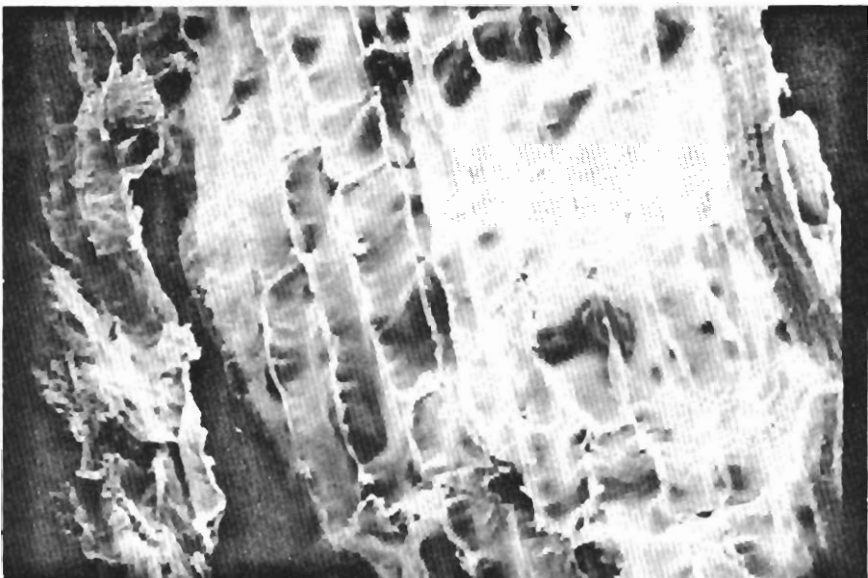


Fig. 70. Broomsedge particulate, showing opaliths. 560X.

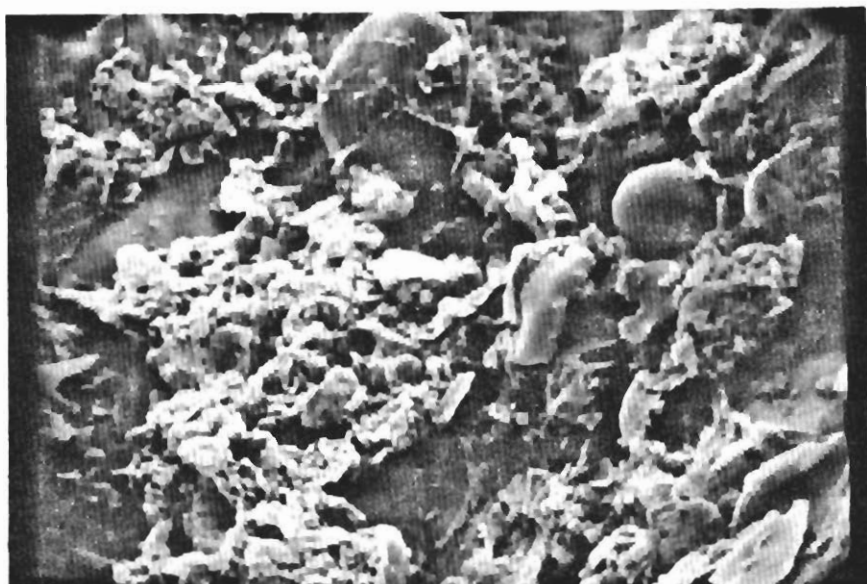


Fig. 71. Broomsedge particulate. Different than Fig. 69. 1050X.

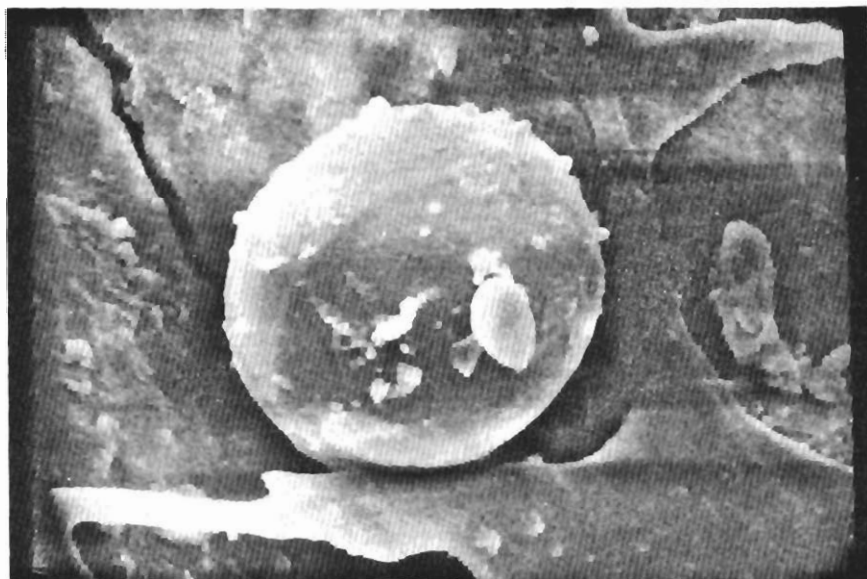


Fig. 72. Close-up photo of broomsedge opaliths. 2000X.



Fig. 73. Broomsedge airborne particulate, showing very porous structure. 35X.



Fig. 74. Broomsedge airborne particulate. Same as Fig. 73. 180X.



Fig. 75. Broomsedge airborne particulate of stem. 200X.

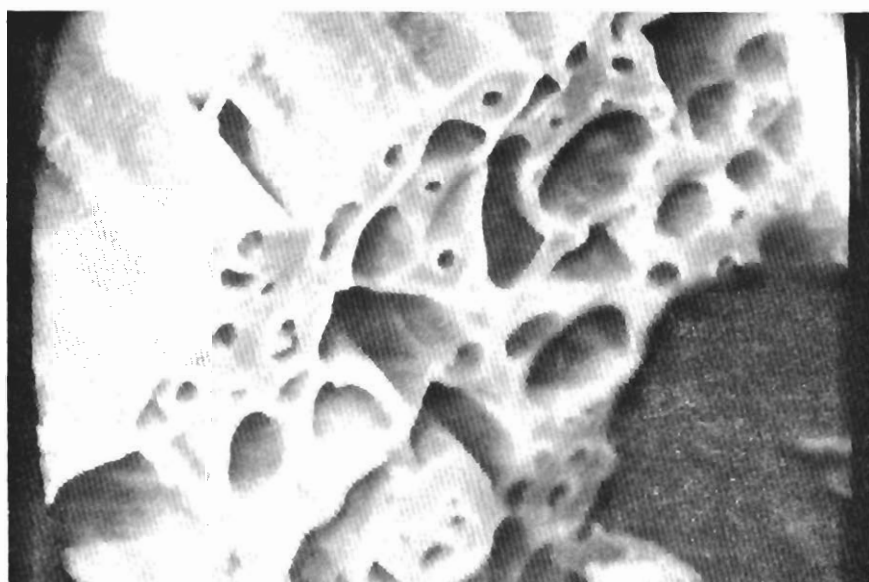


Fig. 76. Broomsedge charred stem cross section. 2215X.

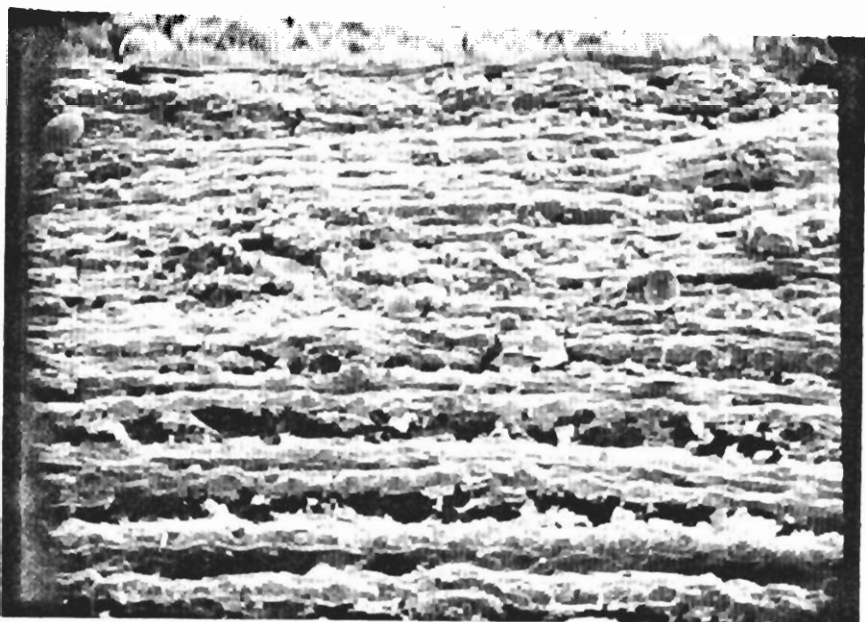


Fig. 77. Bahia grass airborne particulate. 200X.

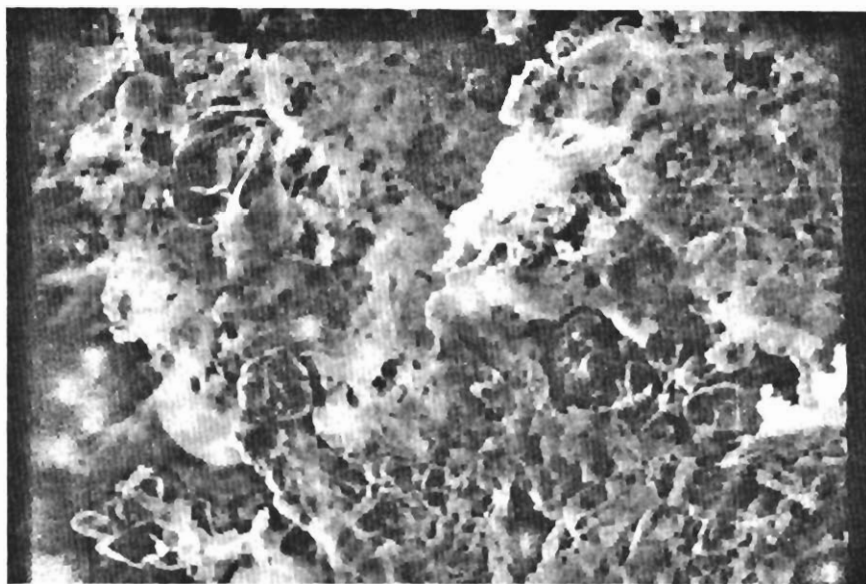


Fig. 78. Bahia grass airborne particulate, white ash. Higher magnification of Fig. 77. 1050X.

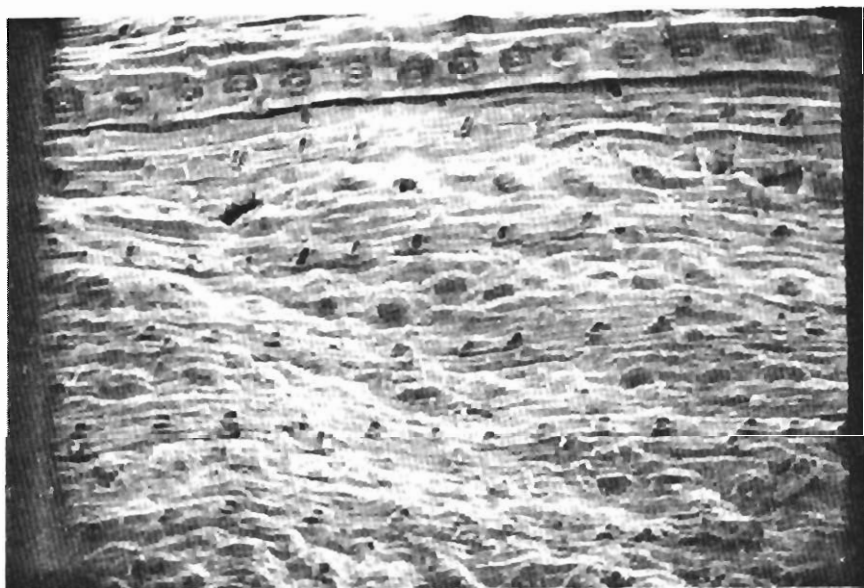


Fig. 79. Bahia grass airborne particulate. 200X.

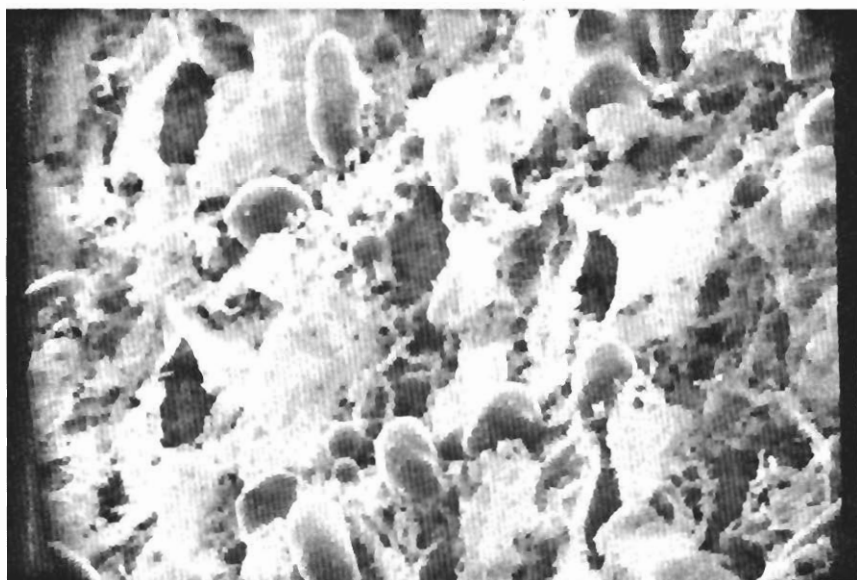


Fig. 80. Same as Fig. 79 but enlarged, showing opaliths. 1050X.



Fig. 81. Napier grass airborne particulates. 90X.

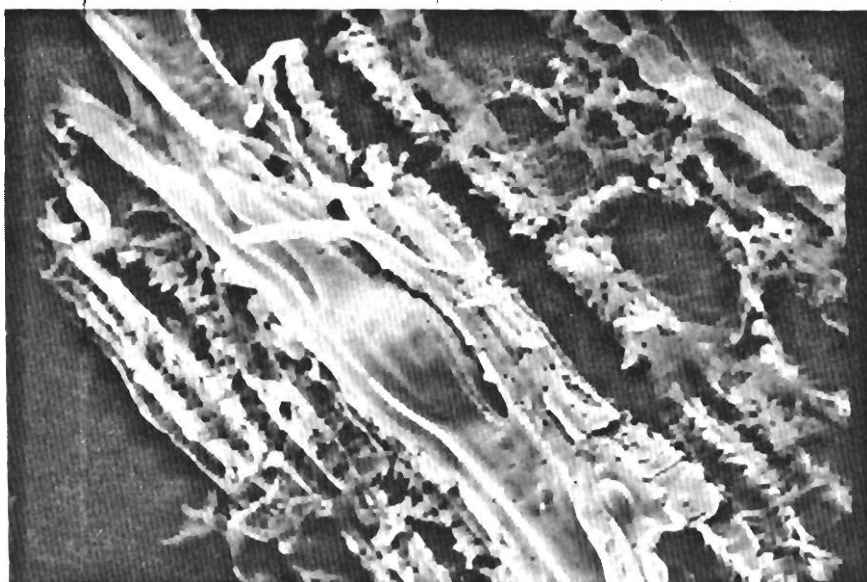


Fig. 82. Napier grass airborne particulate in Fig. 81. 1100X.



Fig. 83. Napier grass airborne particulate of stringy construction. From Fig. 81. 1000X.

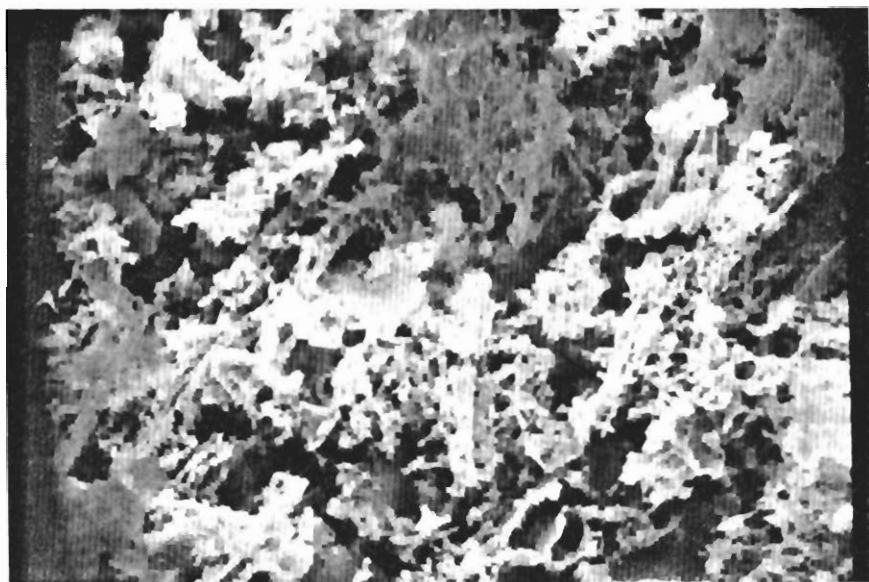


Fig. 84. Napier grass stem airborne particulate. Black charred, stringy type. Same as Fig. 81. 200X.

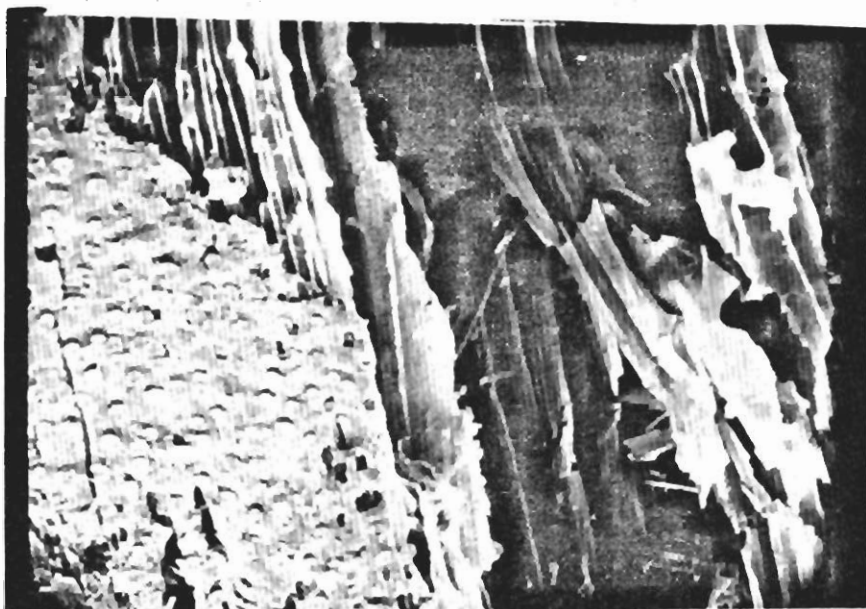


Fig. 85. Napier grass airborne particulate. 200X.

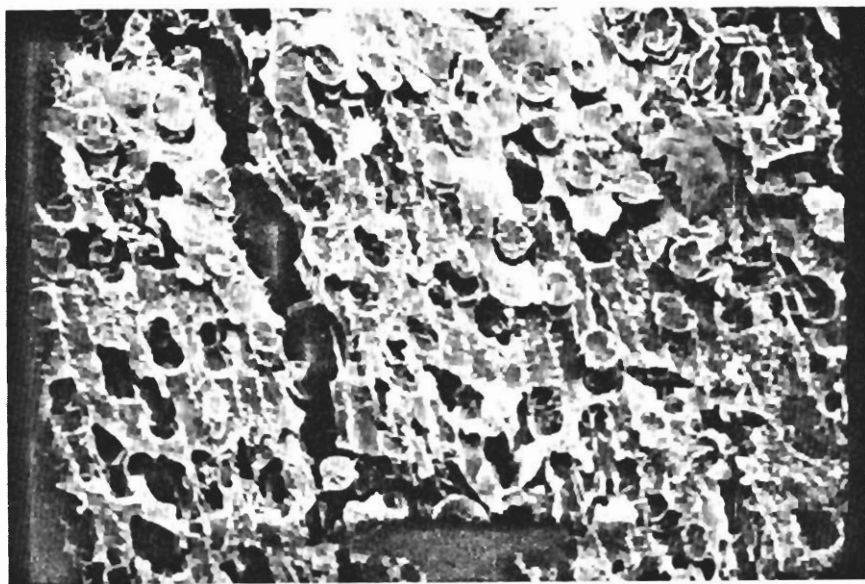


Fig. 86. Napier grass airborne particulate as in Fig. 85, showing opaliths. 450X.



Fig. 87. Napier grass particulate as in Fig. 86 but greatly enlarged. 5000X.



Fig. 88. Johnson grass airborne particulate. 1000X.

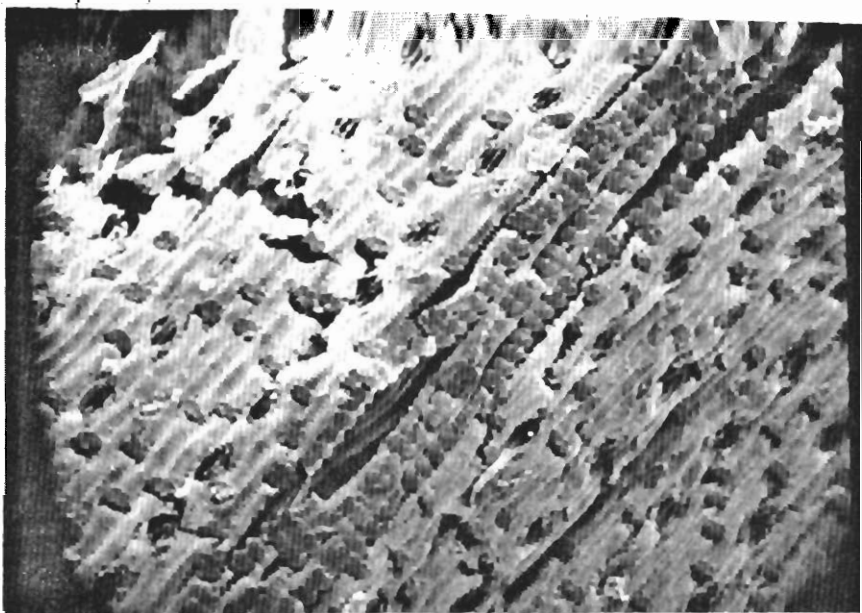


Fig. 89. Johnson grass airborne particulate, showing opaliths of two kinds. 200X.

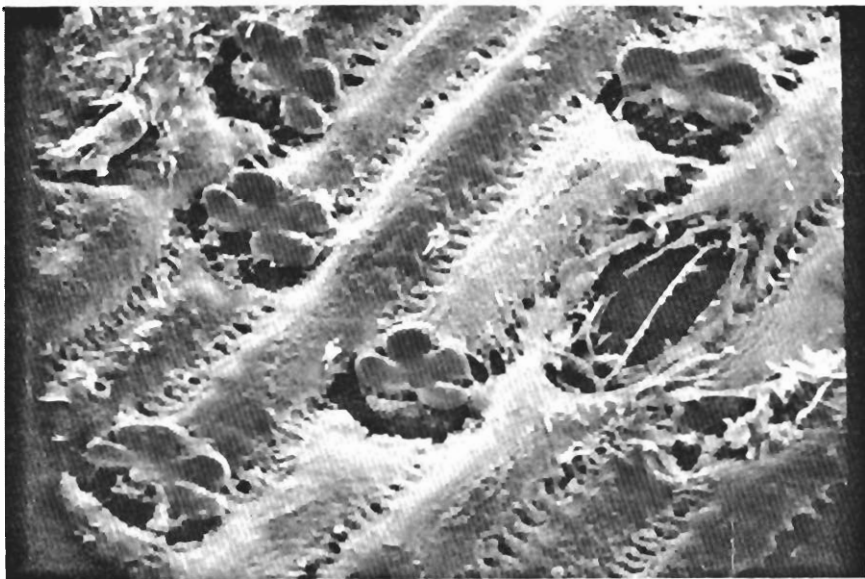


Fig. 90. Johnson grass airborne particulate. Enlarged portion of Fig. 89. 1000X.

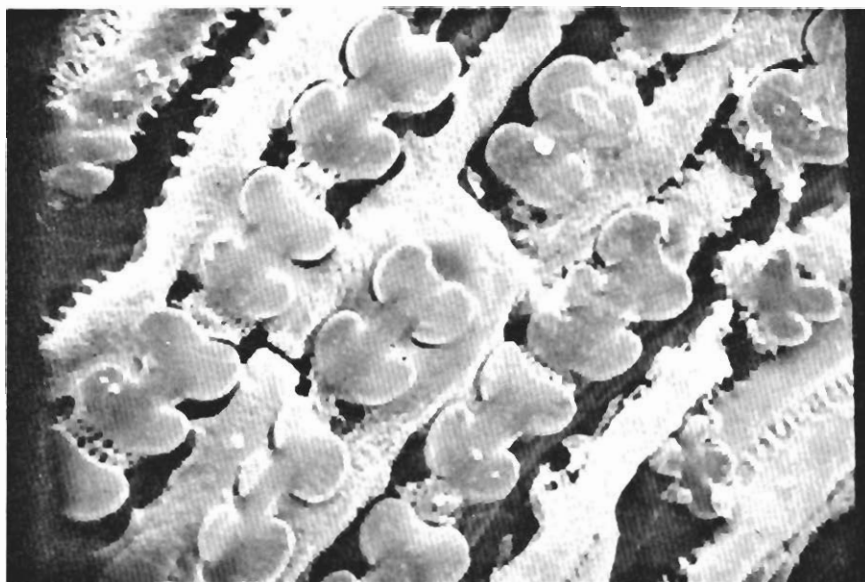


Fig. 91. Johnson grass airborne particulate. Enlarged center portion of Fig. 89. 1000X.

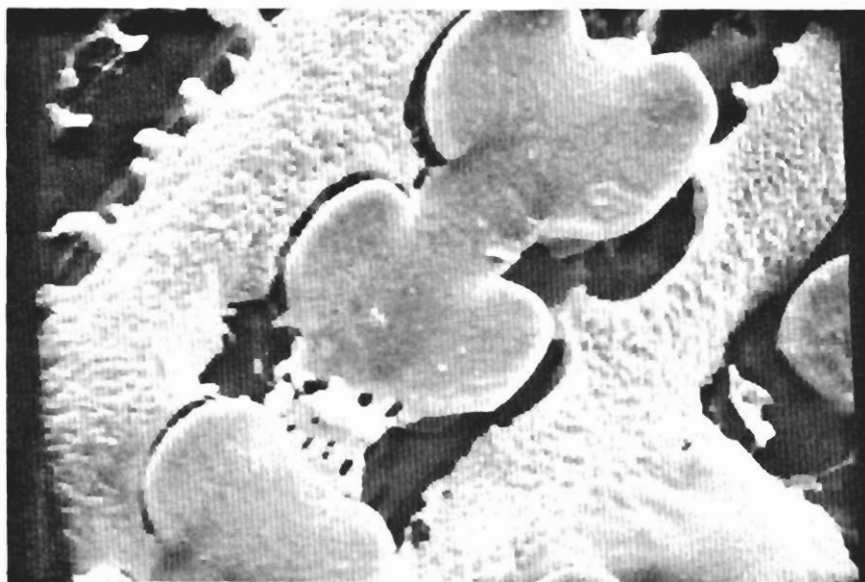


Fig. 92. Johnson grass airborne particulate. Greatly enlarged section of Fig. 91, showing detail of the opalith. 2600X.

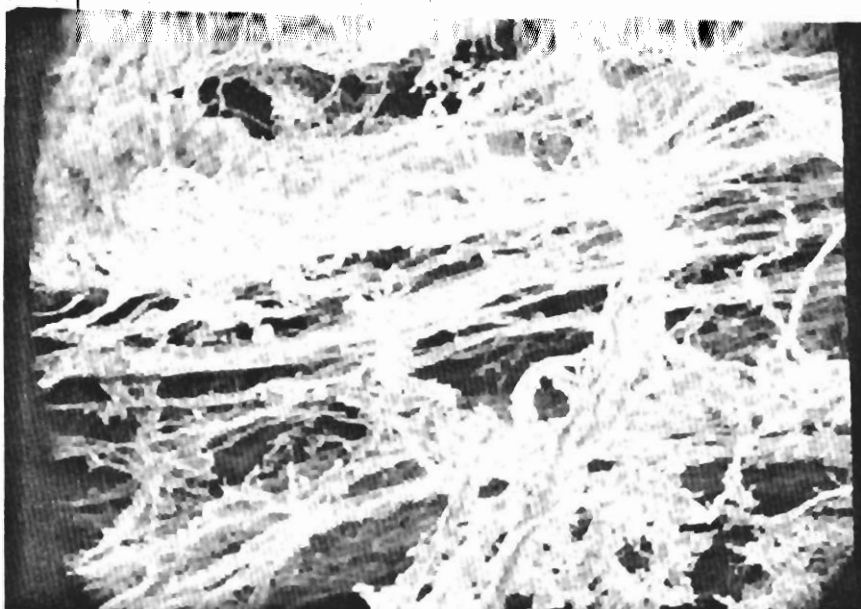


Fig. 93. Bamboo airborne particulate. 560X.



Fig. 94. Bamboo airborne particulate showing both fibrous and cottony structure. 550X.

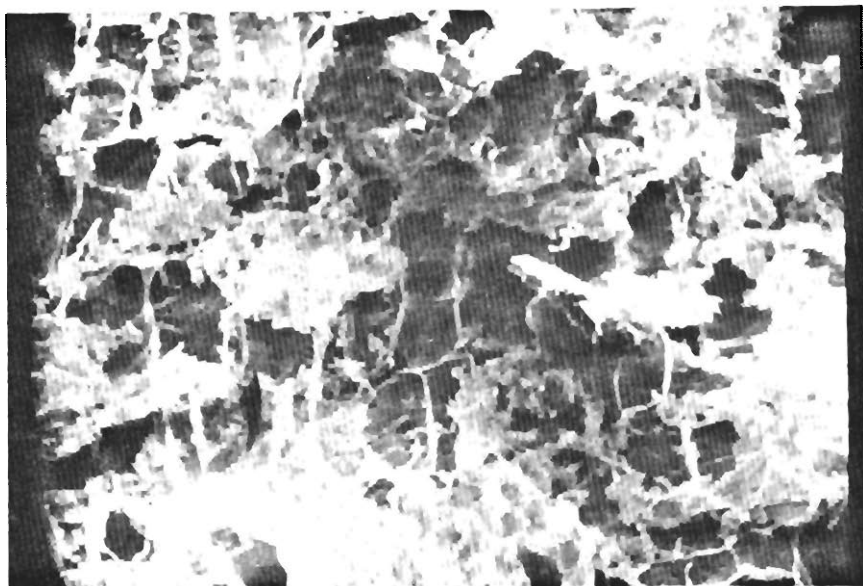


Fig. 95. Bamboo airborne particulate with reticulated structure. 540X.

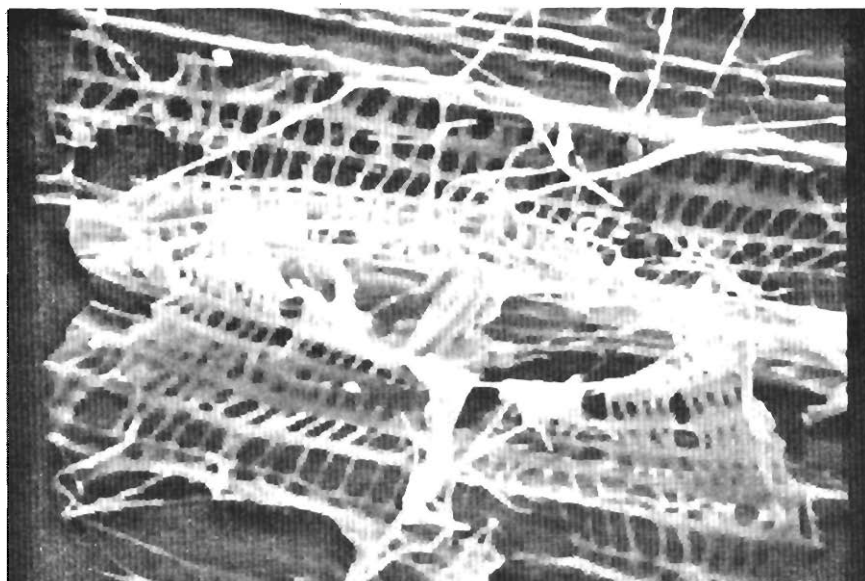


Fig. 96. Bamboo airborne particulate with basket-like structure. 1070X.

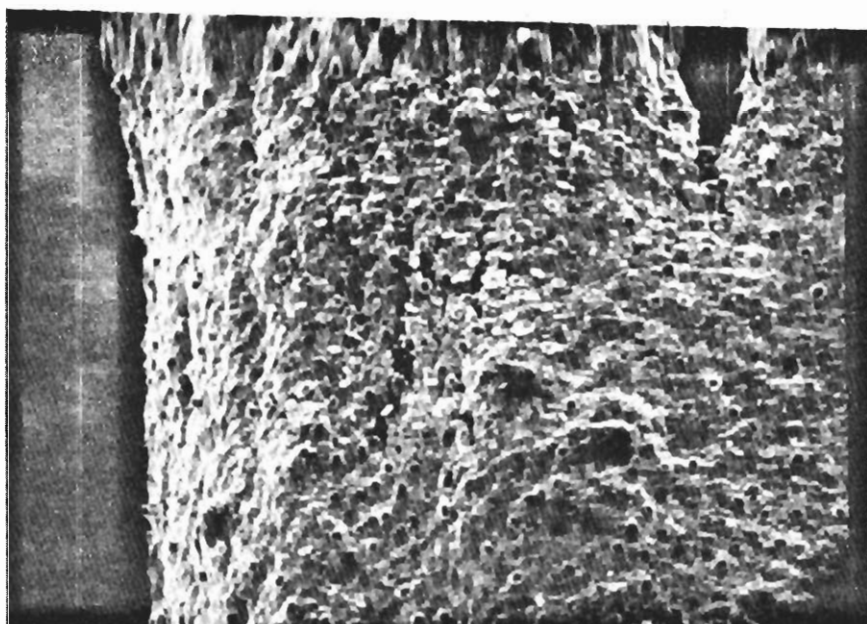


Fig. 97. Bamboo charred stem particulate. 265X.

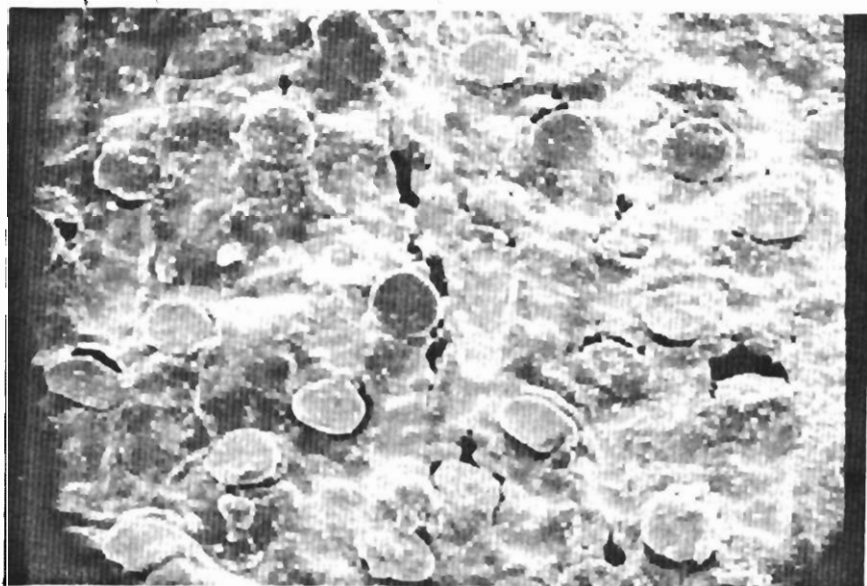


Fig. 98. Bamboo charred stem particulate, showing opaliths. From Fig. 97. 102X.

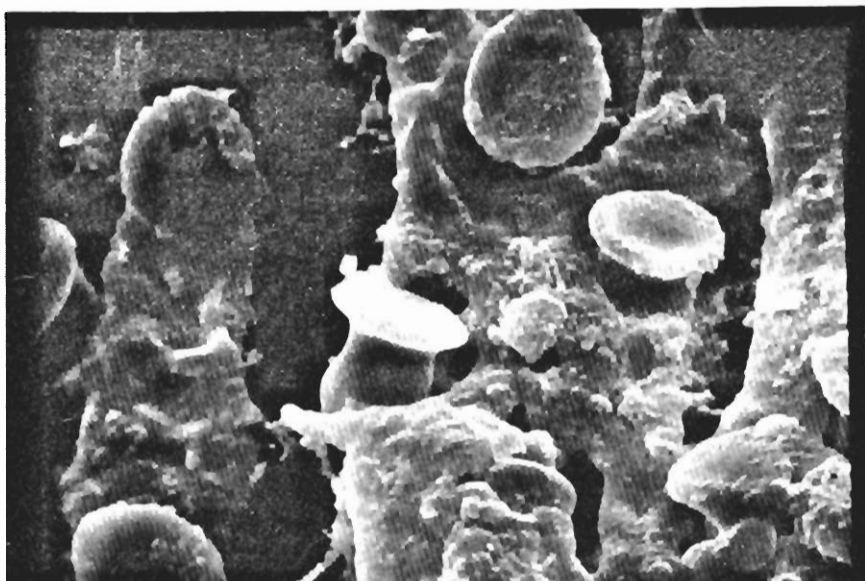


Fig. 99. Bamboo charred stem particulate from angled view, showing structure of opaliths. 2100X.



Fig. 100. Opalith enlarged from Fig. 99. 5250X.

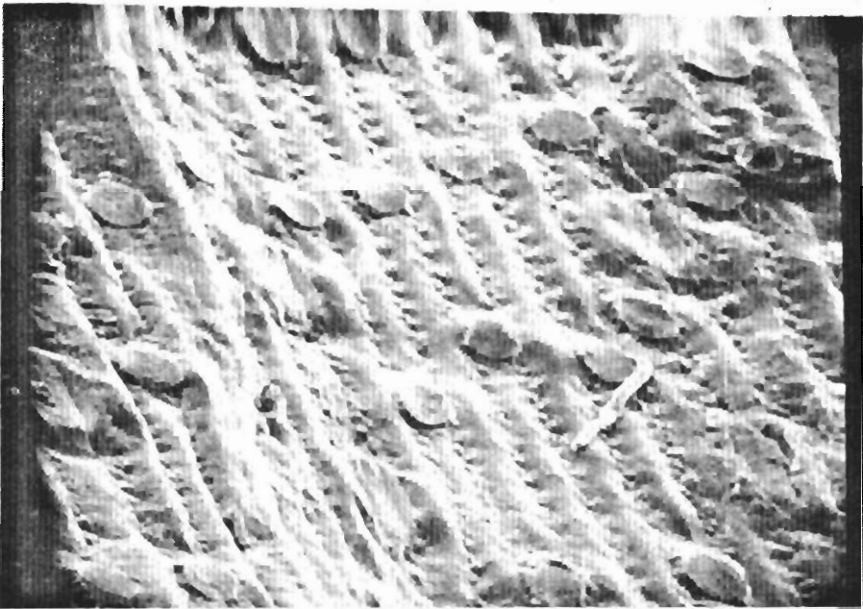


Fig. 101. Oat straw airborne particulate with opaliths. 105X.

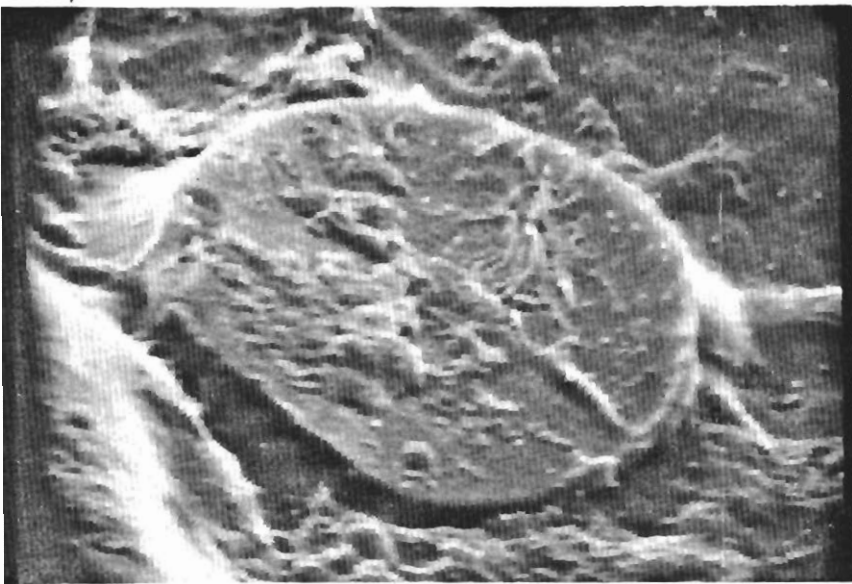


Fig. 102. Oat straw airborne particulate from Fig. 101, showing characteristic opalith.

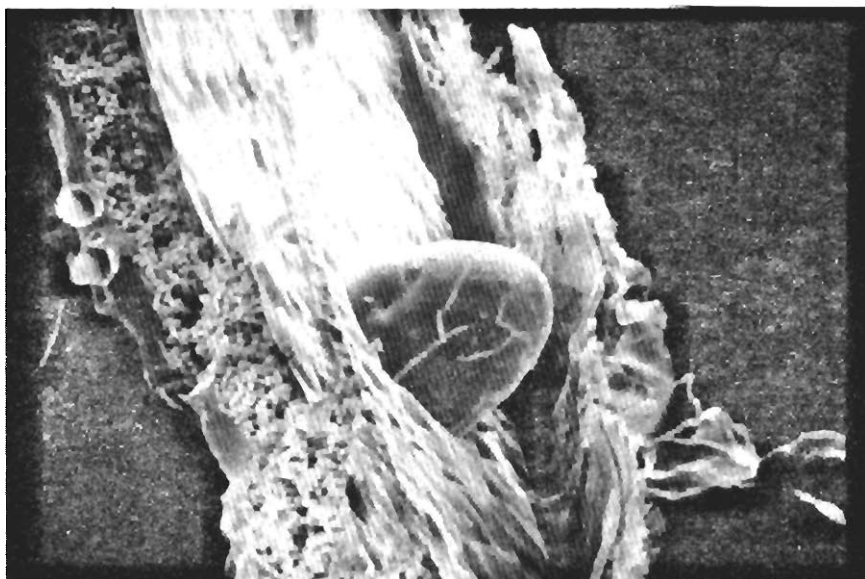


Fig. 103. Charred rice seed, showing opalith and structure. 210X.

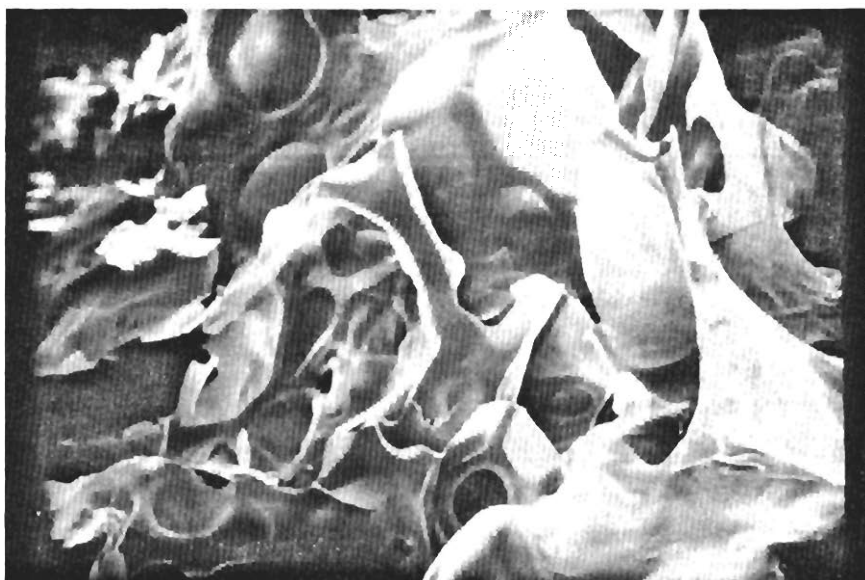


Fig. 104. Rice seed structure with opalith. Charred in test burn. 550X.

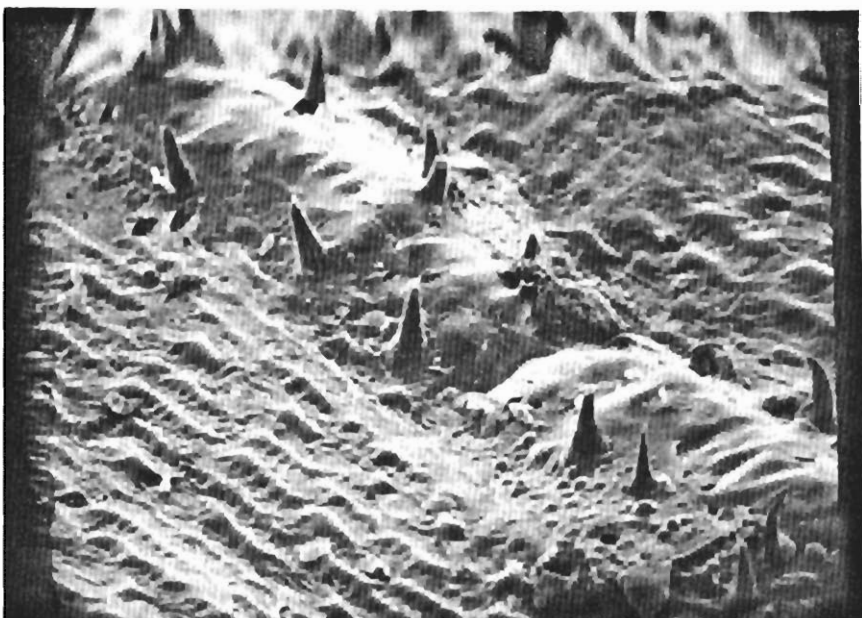


Fig. 105. Corn leaf airborne particulate. 210X.

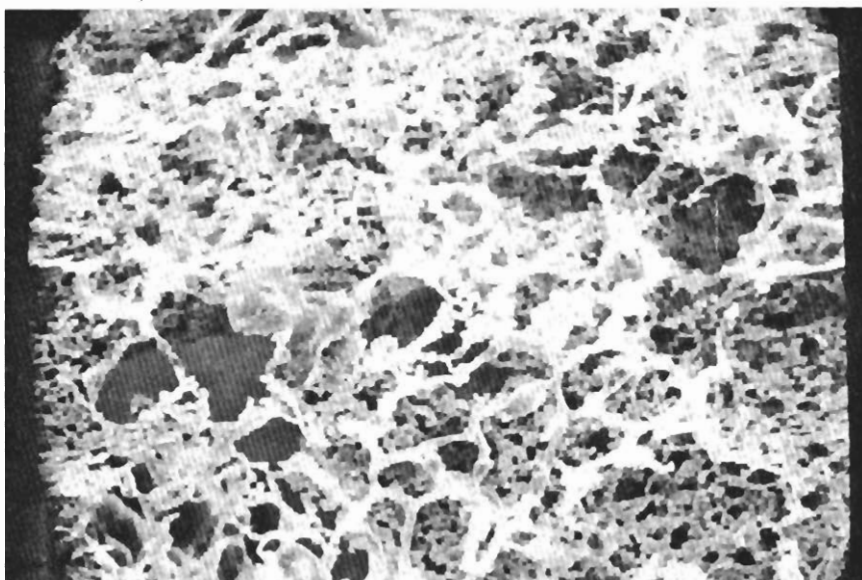


Fig. 106. Corn leaf airborne particulate, showing structure. 465X.

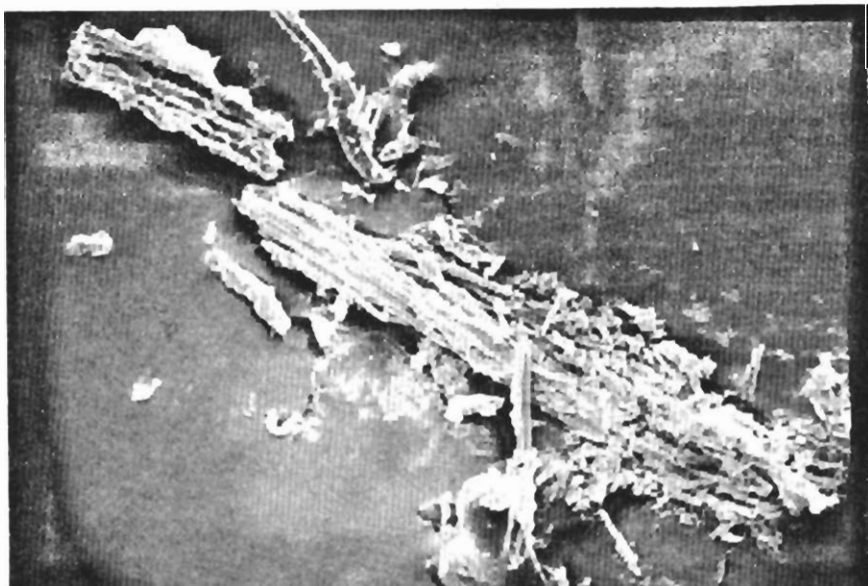


Fig. 107. Particulate of pine needle fragments. 190X.

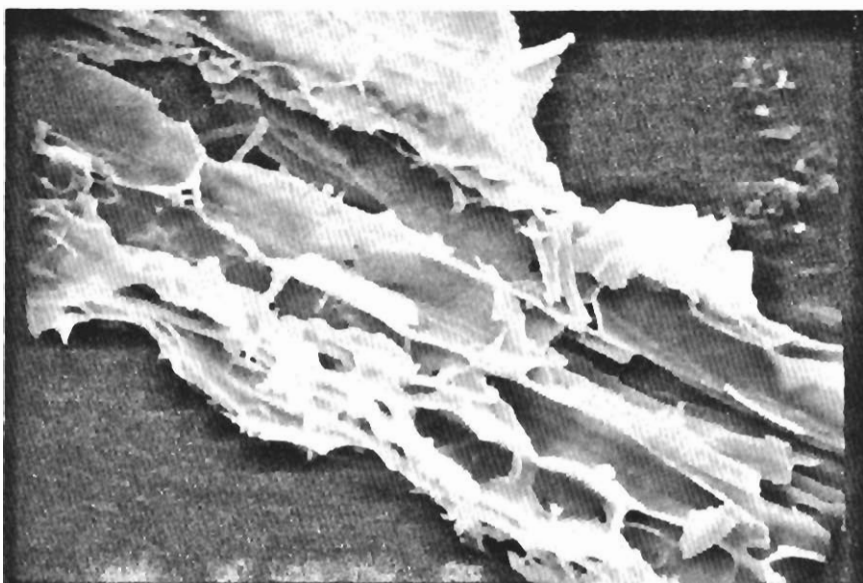


Fig. 108. Detail of above fragment. 1015X.

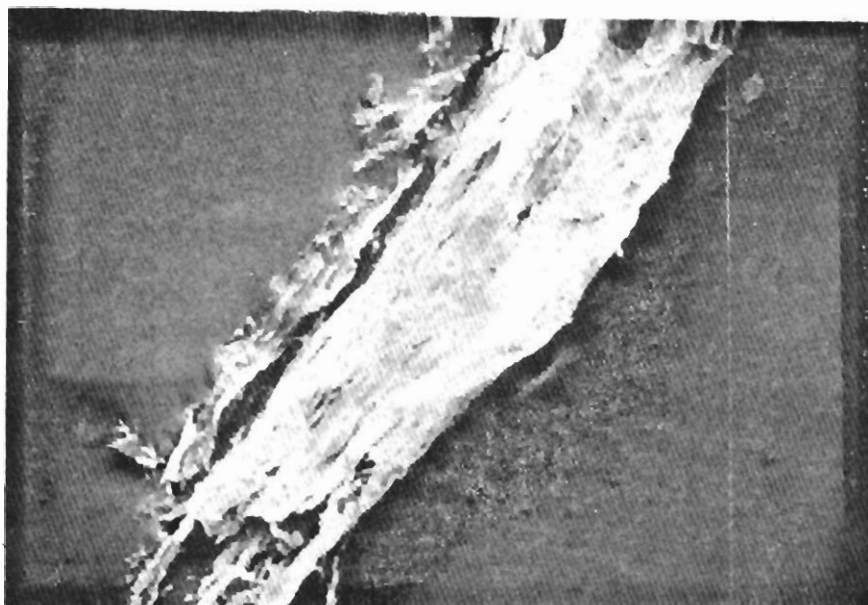


Fig. 109. Particulate of Bahia grass. 360X.

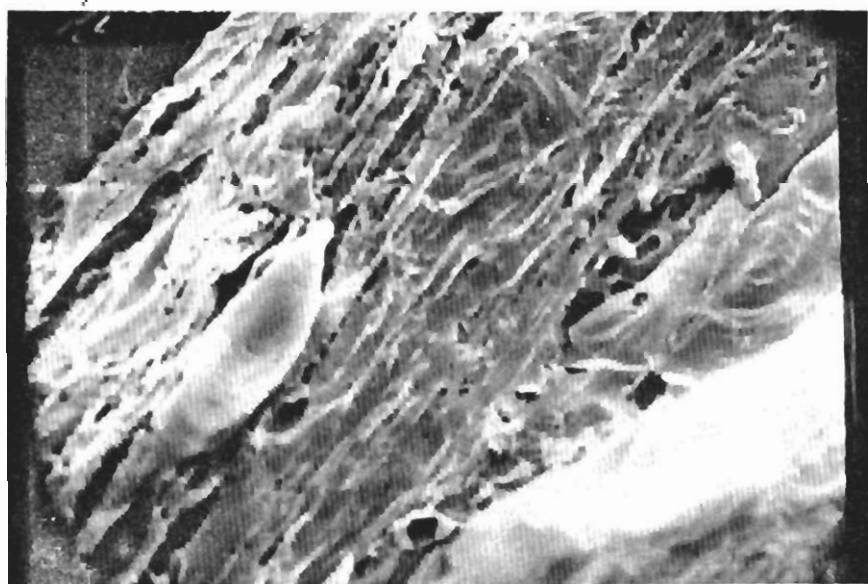


Fig. 110. Detail from above particulate. Compare with Fig. 80. 2000X.

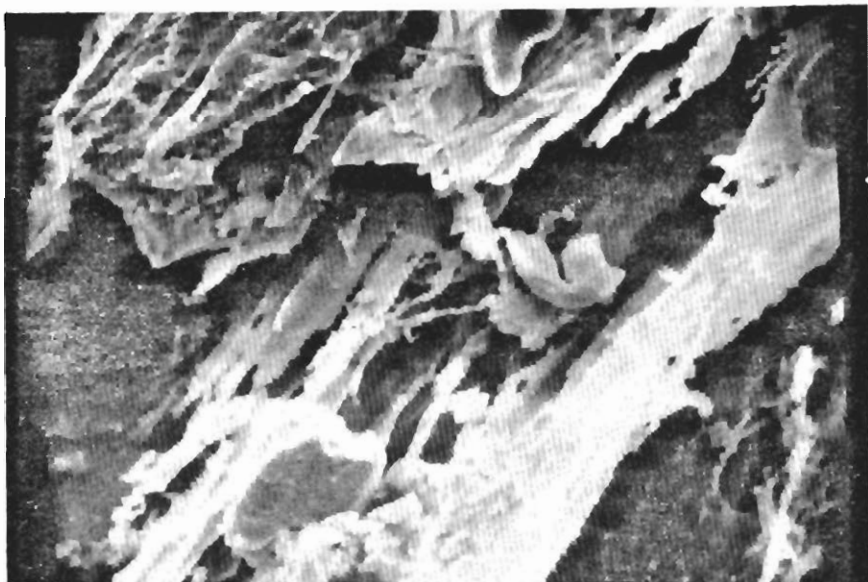


Fig. 111. Detail of upper part of particulate Fig. 109. 1800X.

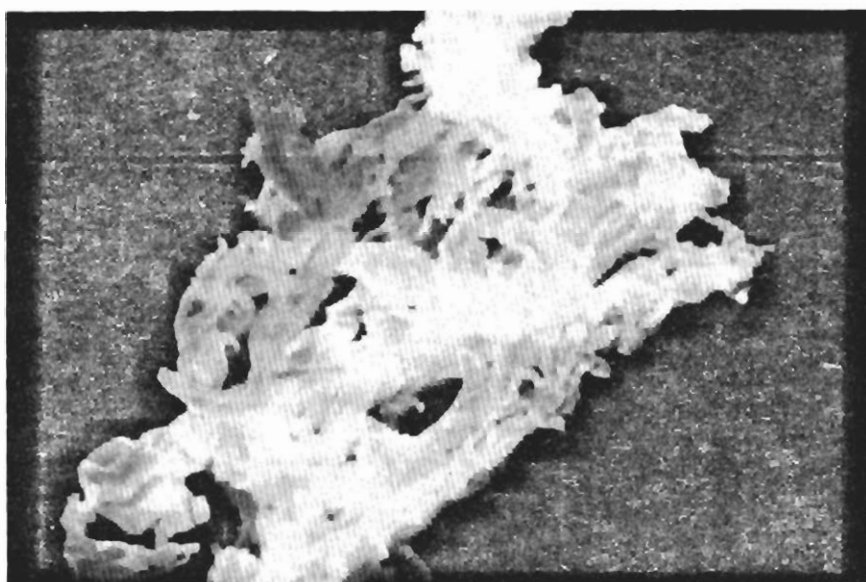


Fig. 112. Unidentified particulate. 4400X.

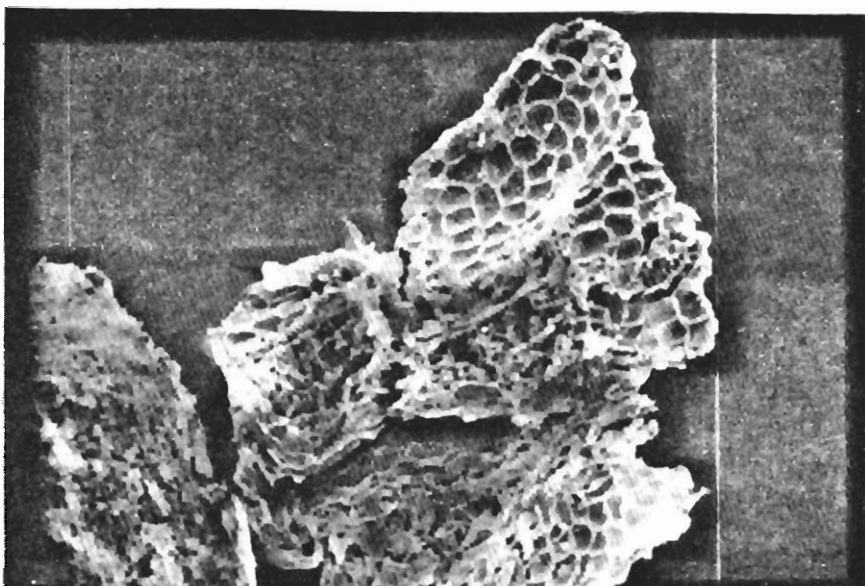


Fig. 113. Pine bark particulate. Compare with Fig. 17. 170X.

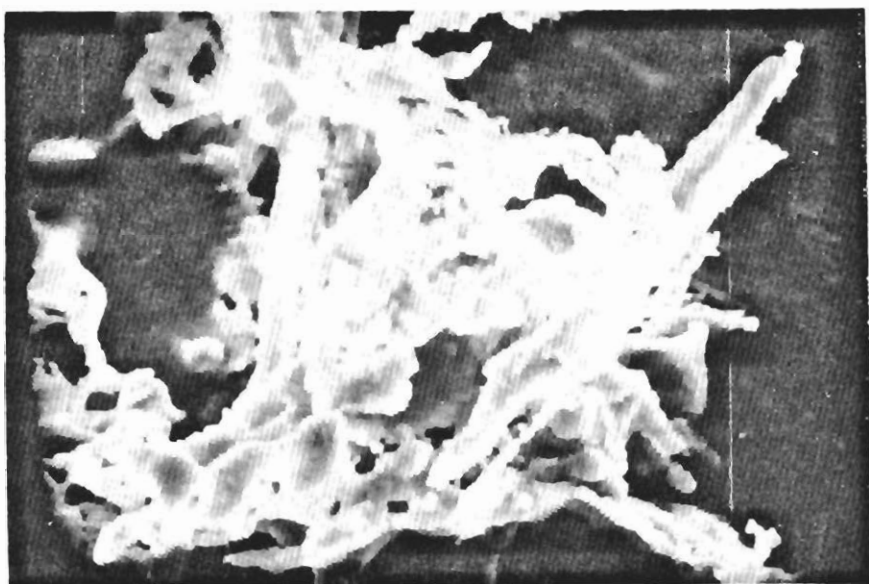


Fig. 114. Unidentified particulate. 3400X.

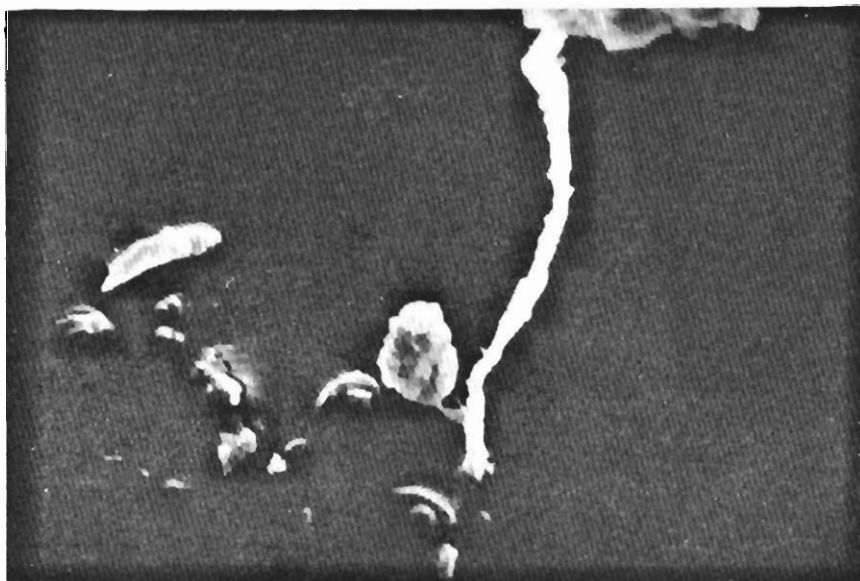


Fig. 115. Unidentified stringy, glassy particulate. 3000X.

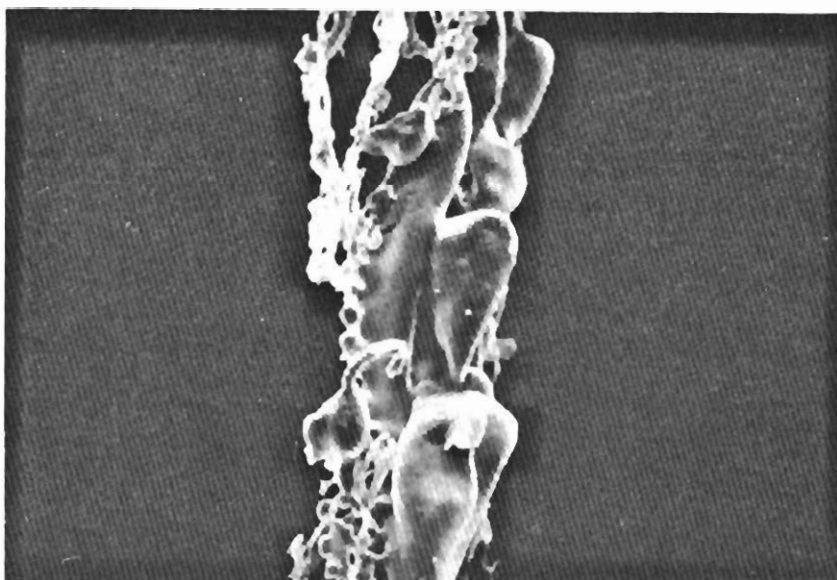


Fig. 116. Detail of above glassy particulate. 960X.

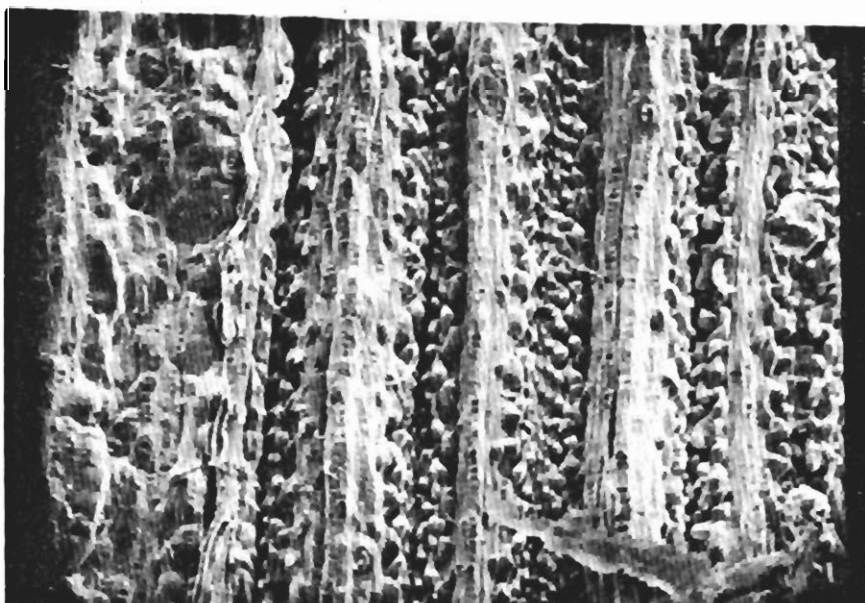


Fig. 117. Unidentified grass particulate with opaliths. 190X.

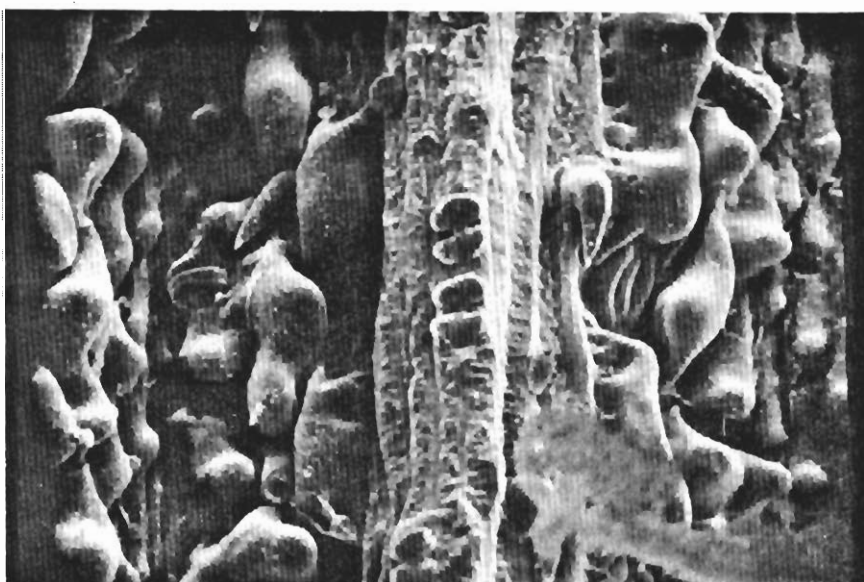


Fig. 118. Detail from above Figure. 950X.

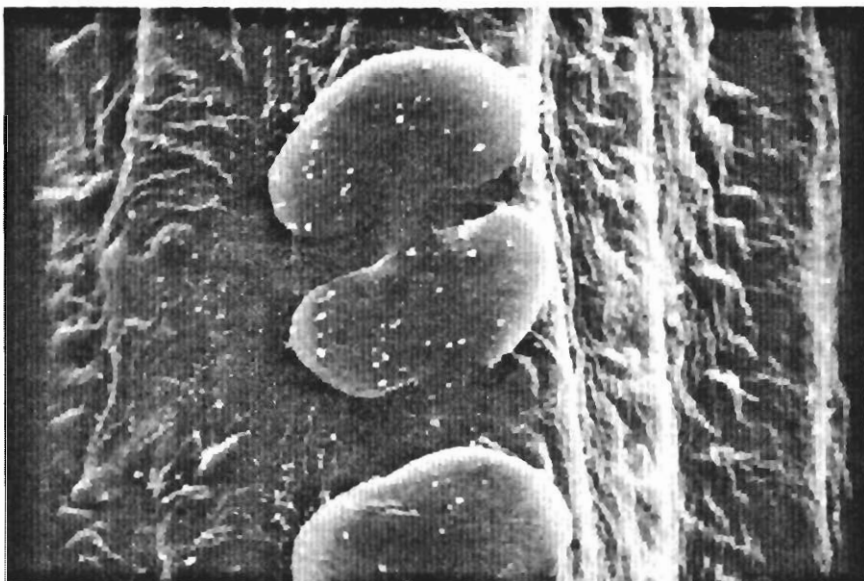


Fig. 119. Detail from Fig. 117. 10KV-4750X.

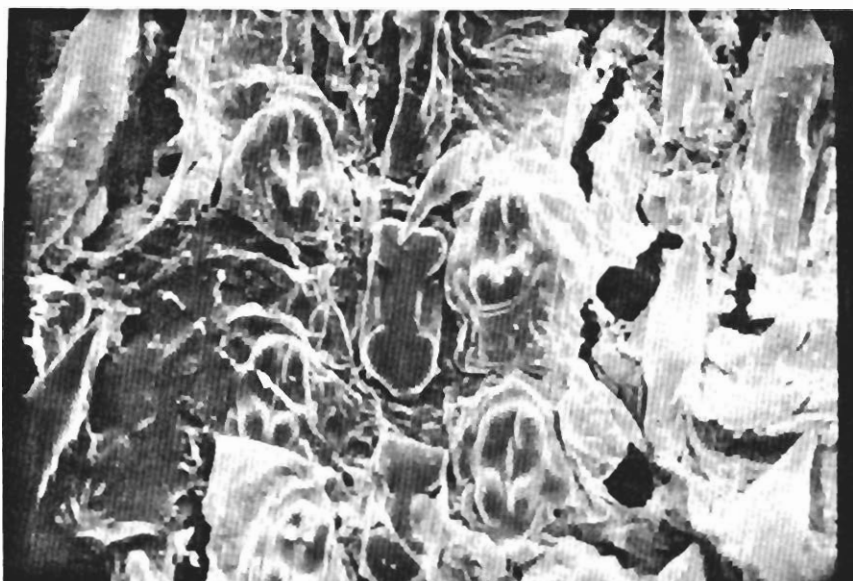


Fig. 120. Unidentified grass particulate opaliths from Fig. 6 tacky sheet. 1040X.

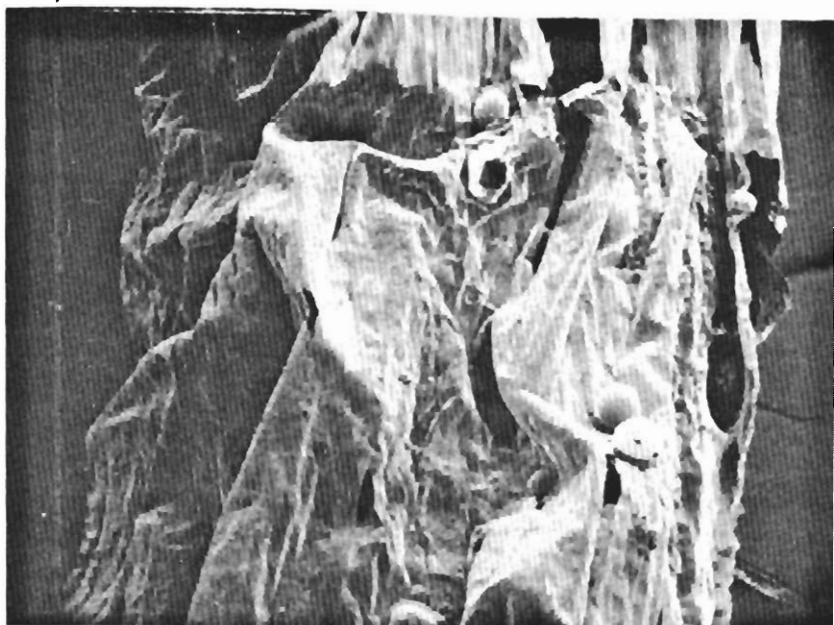


Fig. 121. Unidentified grass particulate. 50X.

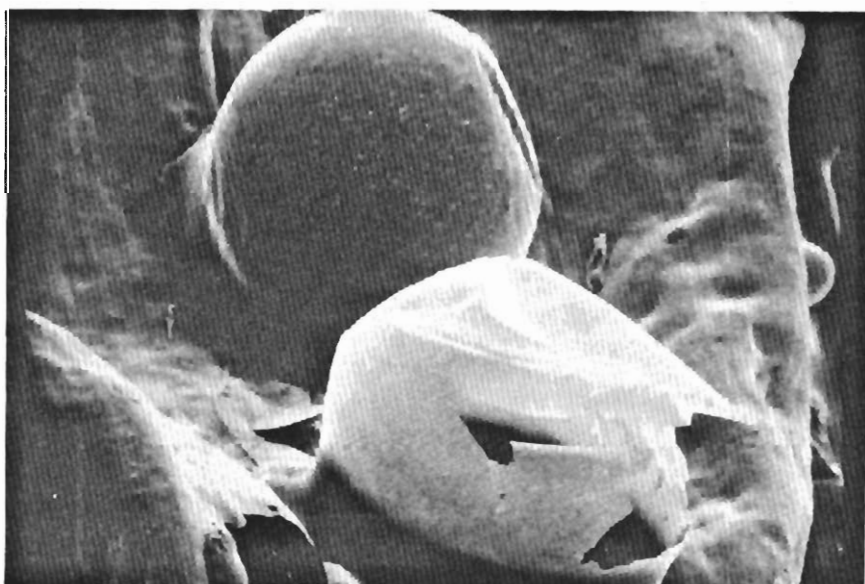


Fig. 122. Detail in above Figure. 2000X.

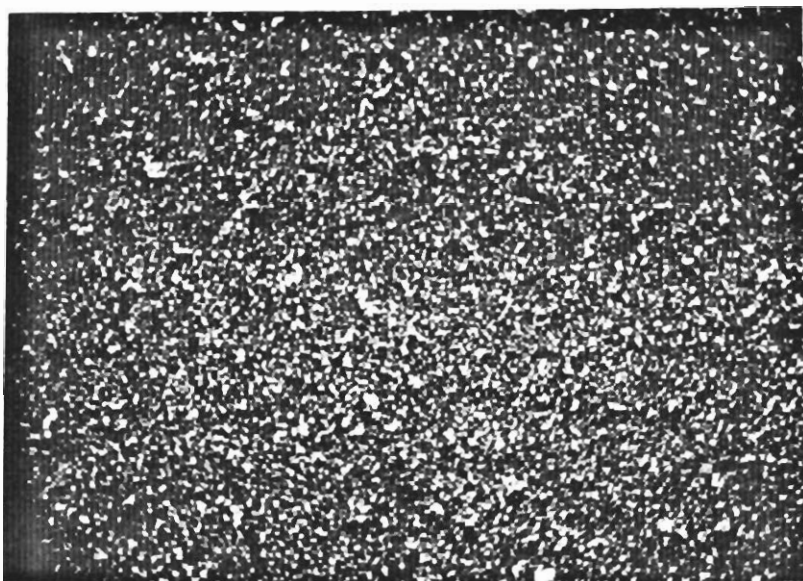


Fig. 123. Soot (lampblack) from burning resinous pine needles. 1000X.

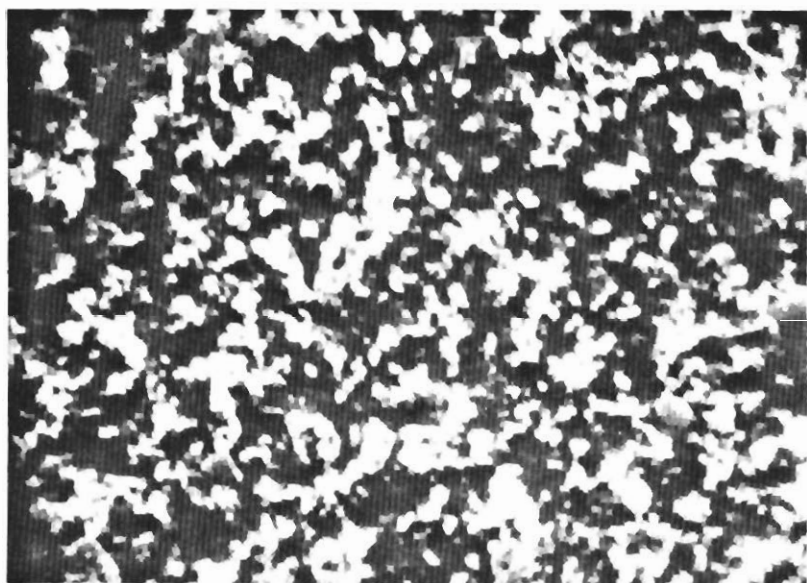


Fig. 124. Same as above but higher magnification. 10,000X.

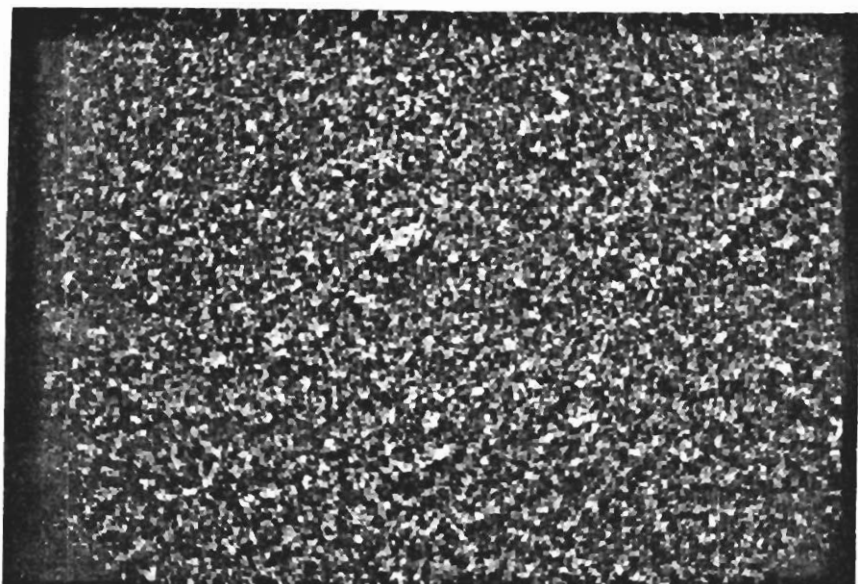


Fig. 125. Soot from burning black rubber washer. 1000X.

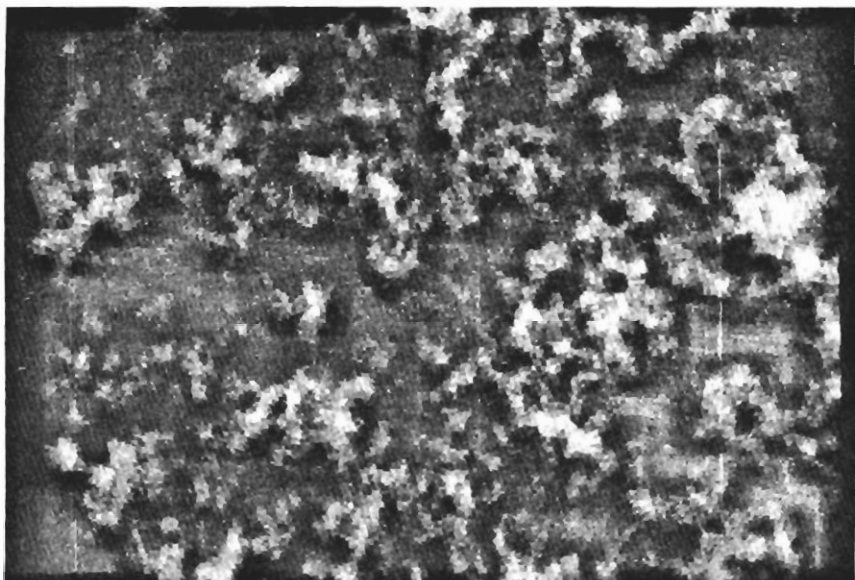


Fig. 126. Same as above but higher magnification. 10,000X.

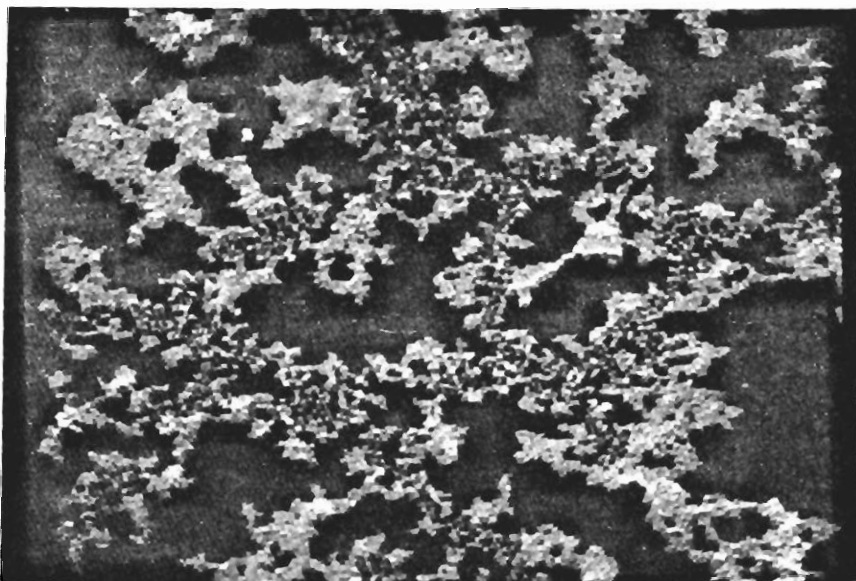


Fig. 127. Droplets from burning plastic merchandise wrapper. 1000X.

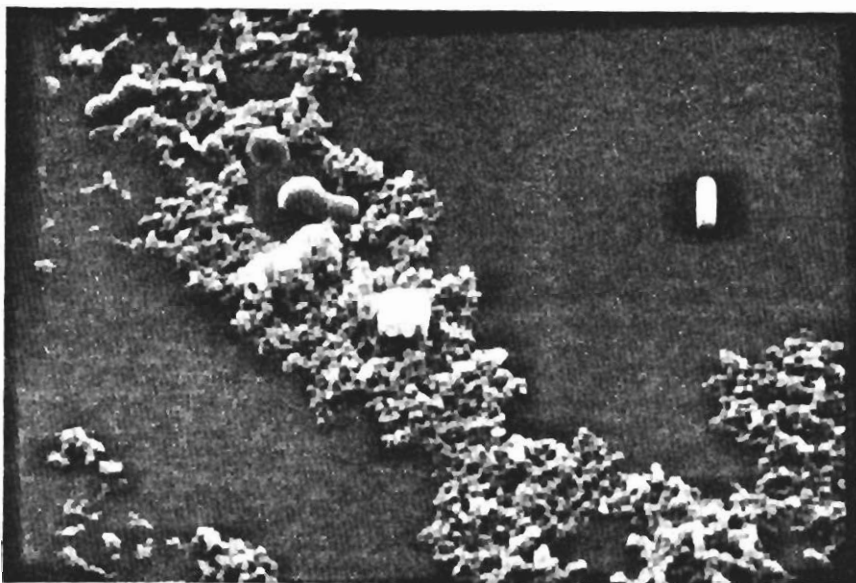


Fig. 128. Same as above but higher magnification. 10,000X.

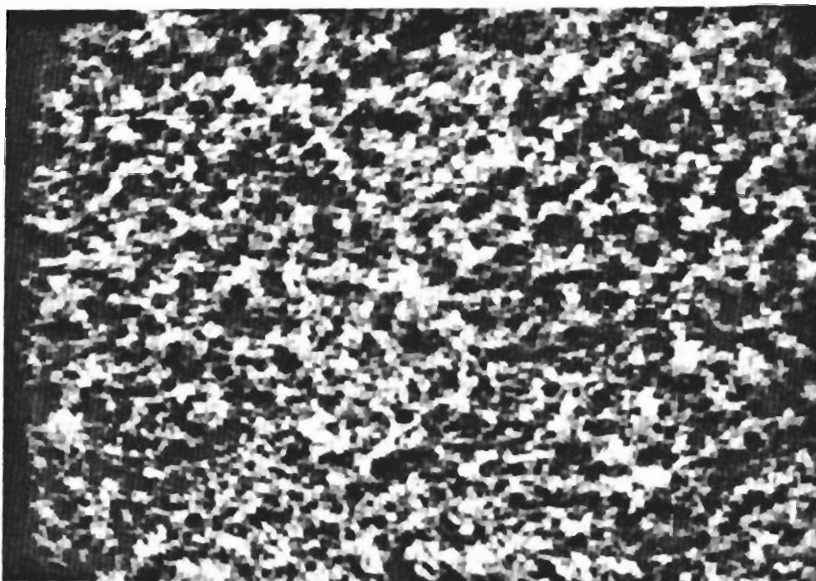


Fig. 129. Soot from burning acrylic plastic. 1000X.

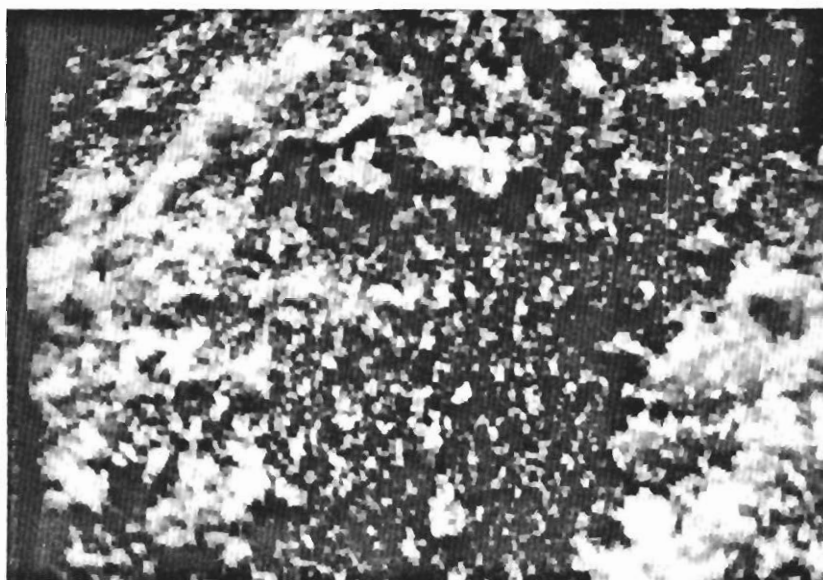


Fig. 130. Same as above but higher magnification. 5000X.

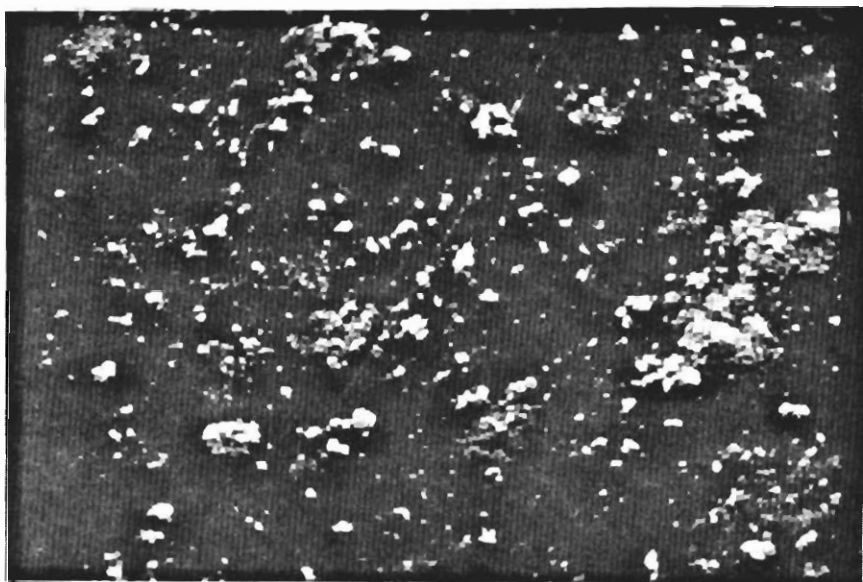


Fig. 131. Soot from combustion engine—diesel burning tractor. 1000X.

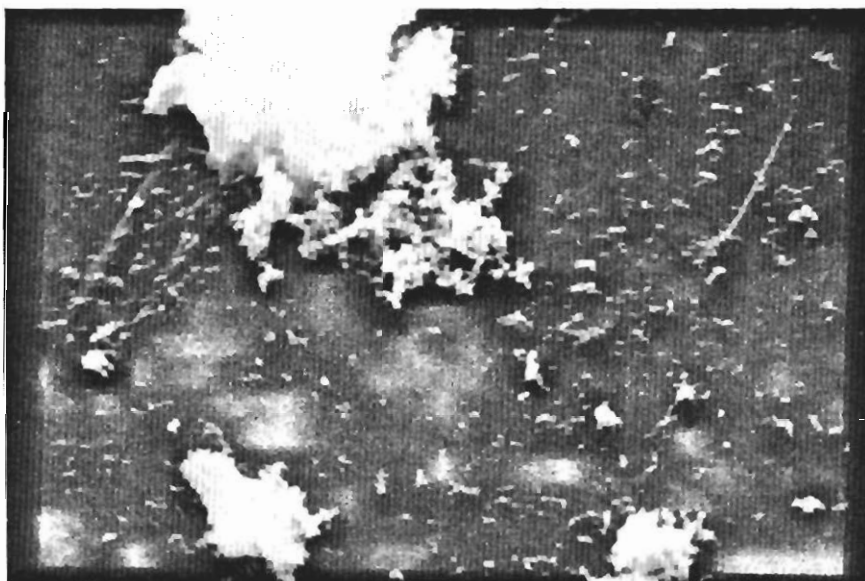


Fig. 132. Same as above but higher magnification. 5000X.

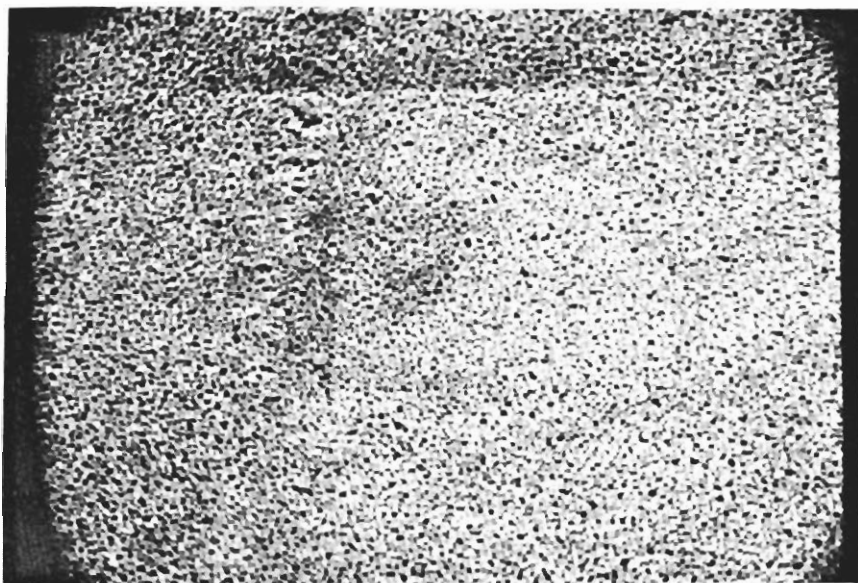


Fig. 133. Soot from combustion engine—gasoline burning tractor. 1000X.

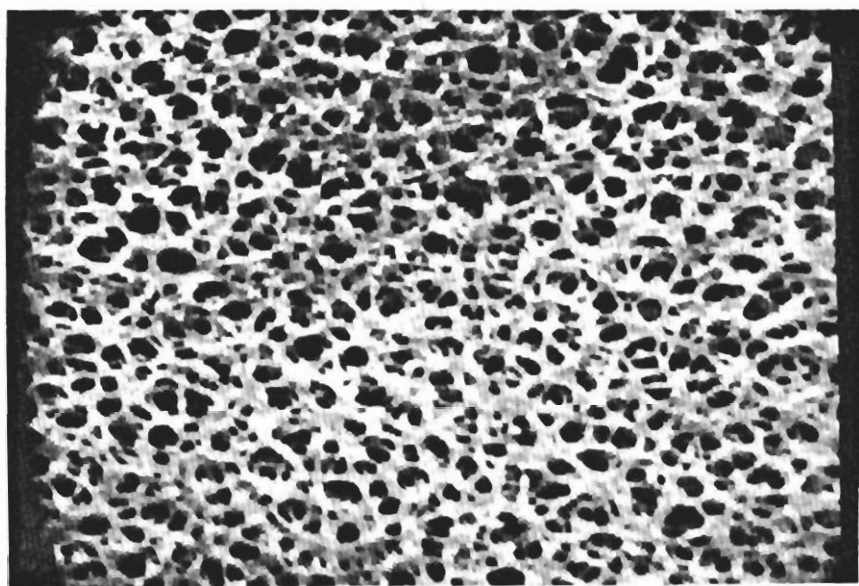


Fig. 134. Same as above but higher magnification. 5000X.

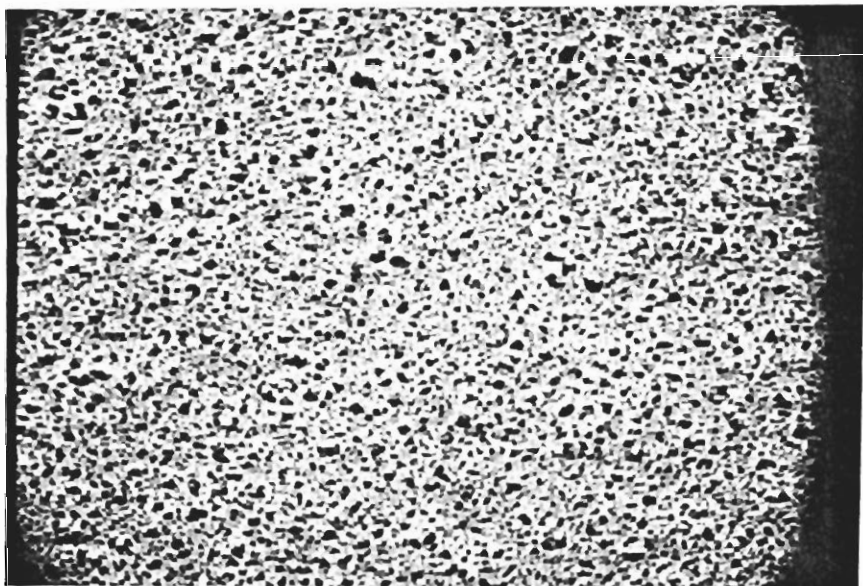


Fig. 135. Commercial filter 0.1 u (micron). 1000X.

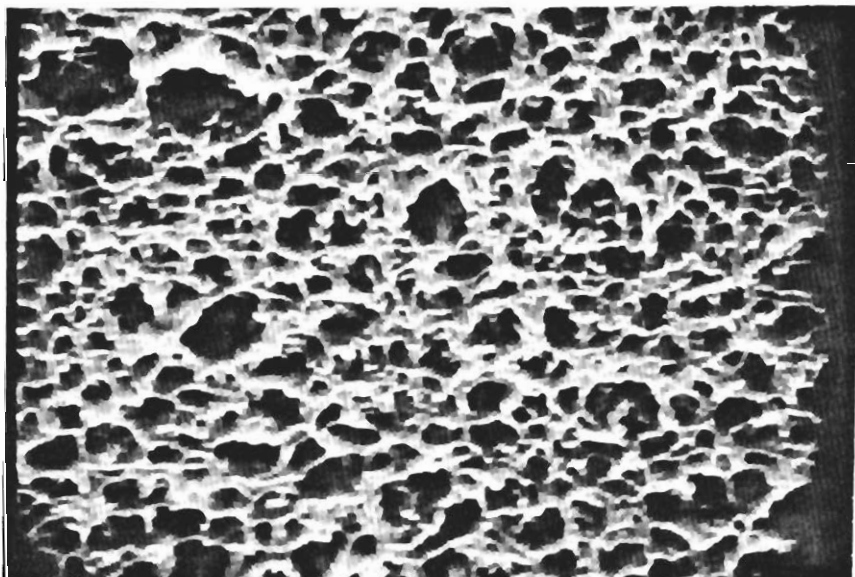


Fig. 136. Same as above but higher magnification. 4500X.

