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MICROSCOPIC STUDY OF LEATHER DEFECTS

II. INHERENT VERTICAL FIBER STRUCTURE IN SIDE LEATHER*

A. L. EVERETT, H. J. WILLARD AND W. WINDUS

Eastern Regional Research Laboratory†
Philadelphia, Pennsylvania 19118

ABSTRACT

"Vertical fiber" consists of an abnormal arrangement of corium fiber bundles, in a direction nearly vertical to the grain surface, whose basic cause has not been determined. Upper leathers made from defective hides can usually be recognized by their characteristic pulpy texture and inferior strength. Microscopic examination of hide cross sections is the only accurate method of identifying typical examples of the defect in rawstock. By reviewing the sections in polarized light, which provides striking contrast, one is better able to recognize the abnormal fiber structure and to appraise its severity. Horizontal sections (parallel to the surface) are especially useful with this method, showing larger dark areas of vertical fiber bundles in defective samples. Objective evaluation, expressing the structural differences in numerical terms, was accomplished by measuring total light transmission through photographic films of the polarized-light views. Plots from a scanning densitometer graphically illustrated this difference between normal and abnormal structure. Differences were further emphasized in a multicolor effect by adding a special filter to the polarized light.

Several samples of defective domestic and South American leathers are illustrated, but most of the material was drawn from a large-scale study of the problem at the Tanners' Council Laboratory. This paper is intended to supplement the one by Tancous, Schmitt and Windus appearing in this issue of the *Journal*.

INTRODUCTION

Tanners are constantly faced with a variety of problems affecting the quality of their products. Sometimes the esthetic properties are primarily involved, as

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†Eastern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.

in the case of veininess. This can still be costly, but it can often be minimized (1) and somehow tolerated. However, when the essential properties of leather fall outside of acceptable limits, tanners must take immediate steps to determine whether processing is at fault or the raw material is defective.

Leather strength, in terms of ability to withstand lasting and to give good performance in wear, is an essential property of paramount importance to makers of upper leather and to shoe manufacturers. Strength of a fibrous material can usually be related to its structural features, which in turn can often be influenced by processing variables (2). In 1958, Amos (3) discovered an entirely new condition in a small percentage of Australian Hereford hides, which he appropriately named "vertical fibre." This vertical fiber orientation persisted in the finished side leather and could not be corrected by changes in processing. By means of photomicrographs and diagrams the distinguishing characteristics of this defective leather were well explained on structural grounds. Amos reported that the leather showed: low grain strength; soft, flat feel; very fine break; deep penetration of fat liquor and dye. He also pointed out that it could be made even worse by paste drying and staking which further distend and disrupt the loose structure. If used for shoe uppers, the leather would usually crack during lasting; but, if used at full thickness, "these hides should make good wearing sole leather because of the very feature which makes them undesirable for upper leather" (3, p. 89).

Although the problem had apparently existed for some time, attention was sharply focused in this country in 1961 when the technical director of a tannery (M. H. Battles), noting extreme weakness in the butt area of certain sides, was able to relate the defect to a corresponding condition in the cured stock by sampling the butt flap area. Subsequent work by Ornes, Tancous and Roddy (4) confirmed this by showing that the kidney area‡ is typically the weakest part of a cured hide and that tensile strength decreased with an increased angle of weave in the corium. By selecting plump type Hereford and Angus hides for further study, Tancous (5, 6) showed that vertical fiber and its accompanying weakness occurred far more frequently in plump Herefords, that it was not due to improper curing or processing, and that it could often be detected by sampling the kidney area. The defect had become known as "pulpy butt" because of the pulpy appearance of the flesh side of the grain after splitting, as shown in Tancous' picture (5, p. 6), and because it was commonly observed in the butt area. From a structural viewpoint, the term "vertical fiber" is more descriptive of the underlying defect.

Because of its higher incidence in Hereford hides, the vertical fiber defect is sometimes thought (3, 7) to have a genetic origin from a particular strain of this breed. To explain its occurrence in other breeds, it would be necessary to prove genetic cross relationships in all such cases (an extremely difficult and unlikely prospect). Since the condition can vary so much within a given hide and

‡Six to twelve inches from tail root and the same distances from backbone.

is strongly associated with plumpness, it seems more likely that localized environmental factors are involved.

This report is primarily a micrographic survey of the problem, presenting photographic evidence to clarify the nature of the defect as well as to provide improved experimental methods of evaluation. Various facets of the problem necessitated some apparent repetition which, although recognized, was retained for the sake of completeness.

EXPERIMENTAL METHODS

Histological Preparation.—With most of our own material, cross sections were made with a freezing microtome after embedding the samples in gelatin to preserve tissue integrity, as described in a previous publication (1). Fat staining was also frequently employed, as described previously. Material obtained from the Tanners' Council Laboratory consisted of prepared slides of unstained horizontal sections through the upper corium of cured hides, vertical cross sections stained with hematoxylin and eosin, and some vertical sections of paraffin-embedded finished leather mounted unstained.

Microscopy.—The same equipment and materials were used as in the previous work (1). In addition, for viewing in polarized light (8, p. 755), a built-in analyzer slide was used along with an adjustable polarizing filter in crossed position, revealing birefringent material brightly against a black background. For further interpretation by color effect a first-order red compensator or retardation plate (9) was inserted at 45° to the polarization plane. This filter has two perpendicular vibration planes through which light passes at different speeds. With a doubly refractive object (collagen) it is blue in the addition position (slower wave train) and yellow in the subtraction position (faster wave train). Background and nonrefracting objects appear red. Polarization microscopy has proven most useful in studies of this nature, as pointed out previously (10).

Photometry.—Available equipment was assembled to provide a method for measuring total light transmission through negative films of polarized-light views. After considerable testing and adjustment, this improvised arrangement gave highly reproducible results. An Ortho-Illuminator "B" (Silge & Kuhne, San Francisco, California)** was used as light source. This is a combined lamp and microscope base with built-in filters and diaphragm. The film holder was made of hinged cardboard, with rectangular windows slightly smaller than a single frame on the 35 mm. film, and fitted with a light-tight adapter to connect it to the light source. The light meter was a Microphot Model 1500 (Gamma Instrument Co., New York)** modified with a larger photocell. It has two intensity settings and a galvanometer calibrated in arbitrary scale units. With the film

**Mention of brand or firm names does not constitute an endorsement by the U. S. Department of Agriculture over others of a similar nature not mentioned.

holder firmly seated over the light source and the photocell inverted over it, total light transmission through the film was indicated on the galvanometer scale. Appropriate filters were used to control the light intensity, supplemented by using the diaphragm to equalize variations in the line current, in order to produce a standard blank reading (no film in film holder). Blank, or maximum, readings were taken before each film reading and were adjusted when necessary to an arbitrary standard (81 in the series reported).

To illustrate the detailed density variations in the polarized-light films, brief tests were run with a Chromoscan (Joyce, Loebl and Co., Ltd., Great Britain)** scanning densitometer with read-out integrator, arranged for transmission of visible light. The films were scanned lengthwise along a narrow central line. On the plotted curves, peak heights represent relative brightness or darkness while their widths are a function of distance.

RESULTS AND DISCUSSION

Vertical Fiber vs. Normal.—To clarify the concept of "vertical fiber" and how it differs from the normal fiber†† architecture, it is helpful to examine vertical cross sections of representative hides. Figure 1 shows composite pictures of the full thickness of two cured hides from the Cincinnati studies. On the left (Fig. 1a) is a plump Hereford hide (side no. 71R) showing typical vertical fiber. Note that the majority of fiber bundles are perpendicular to the surface and thus have an extremely high angle of weave. The vertical dark line is a blood vessel connecting the lower and upper levels. On the right (Fig. 1b) is a fairly plump Angus hide (side no. 79R) with normal structure. It is apparent that some of the fiber bundles have a high angle of weave, but they are intermingled with many others running at lower angles so that the average inclination is close to 45°. Comparative tensile strengths (pounds per square inch) of these particular hide samples were: Hereford 1745; Angus 3598.

The lower portion of Figure 1 shows cross sections of the finished side leather made from these hides. Figure 1c is leather made from the same hide shown in Figure 1a; it had a tensile strength of only 880 and a Mullen strength of 142 pounds. Figure 1d is leather from the hide shown in 1b; it had a tensile strength of 3972 and a Mullen strength of over 400. Both the pictures and the strength values show that the defective structure had carried through to the finished leather. The fiber structure in the upper corium largely determines the strength of the resultant leather since the lower corium is split off.

Horizontal Sections in Polarized Light.—In normal hides there are more fibers approaching the horizontal plane than the vertical, while in the defective hides the reverse is true. Therefore, to detect this condition, it becomes a matter of evaluating the relative proportion of horizontal to vertical components. For

††Fibers seen at low magnification are actually bundles of smaller fibers which, in turn, are made up of still smaller fibers; only the coarse fiber bundles are dealt with in this report.

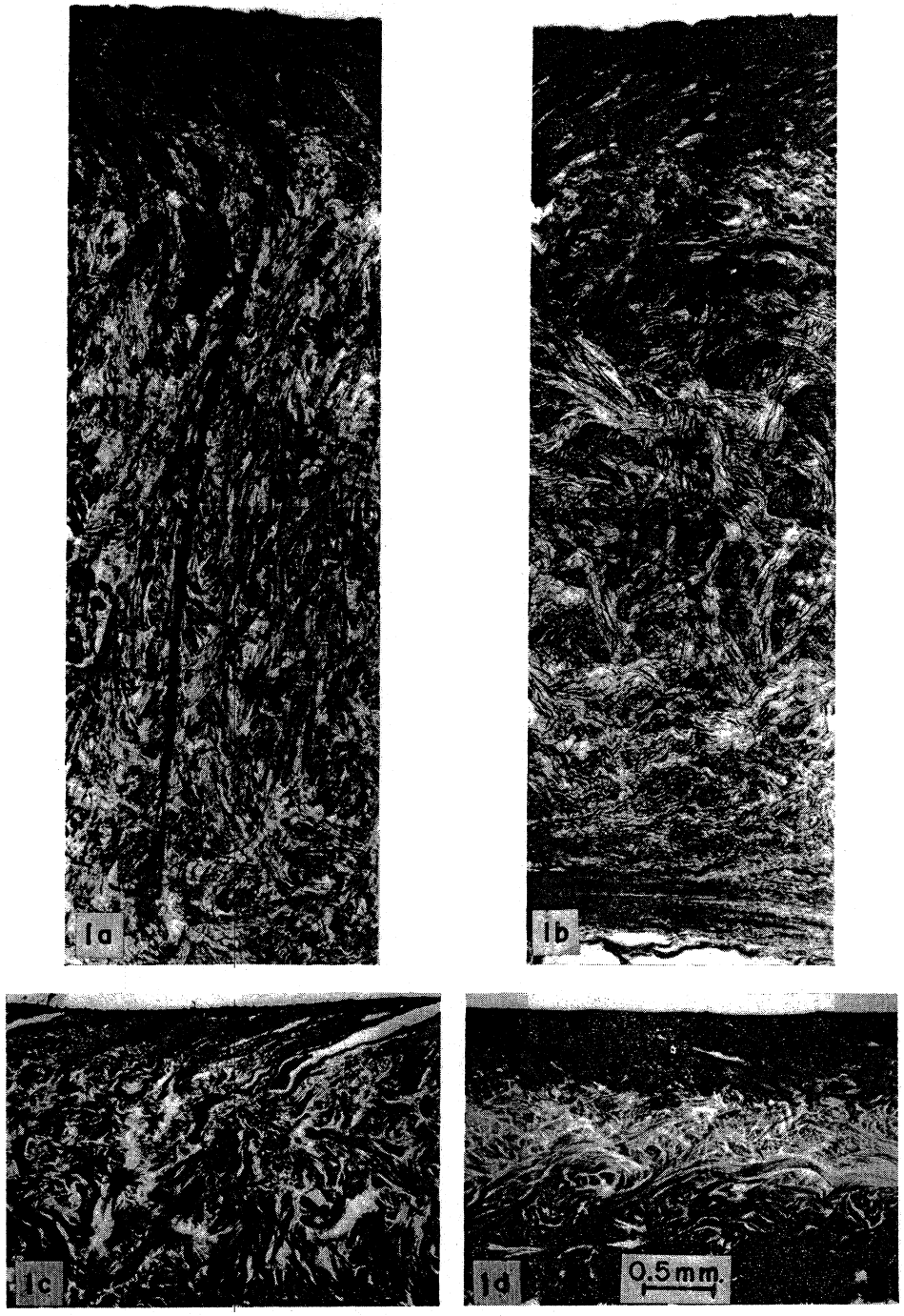


FIGURE 1.—Comparative fiber structure in defective hide vs. normal and their resultant leathers: (a) Hereford #71R with vertical fiber; (b) Angus #79R with normal structure; a and b stained with hematoxylin-eosin, x 20; (c) finished black side leather from hide a; (d) finished side leather from hide b. Scale applies to all sections.

this purpose, it is helpful to examine horizontal, upper-corium sections cut perpendicular to the plane shown in Figure 1, thus cutting across the vertical fibers. By viewing such sections in polarized light (see under Microscopy) it is easier to distinguish between vertical and horizontal fibers than by using regular light. Because of their longitudinal orientation, collagen fiber bundles are strongly birefringent in the horizontal plane and thus appear bright in polarized light. Those fibers in the planes perpendicular to the section become invisible (black). Figure 2 shows horizontal corium sections cut from the same two hides of Figure 1. The left views (2a, 2c) are in regular light, while the right ones (2b, 2d) show the identical fields in polarized light. The defective hide is on the top (2a, 2b), and the normal is on the bottom (2c, 2d). Comparative study of these polarized-light pictures quickly reveals that the horizontal (bright) fibers are thinner and more widely spaced in the defective Hereford hide, with a concomitant increase in the number and diameter of the vertical (dark) fibers. Also

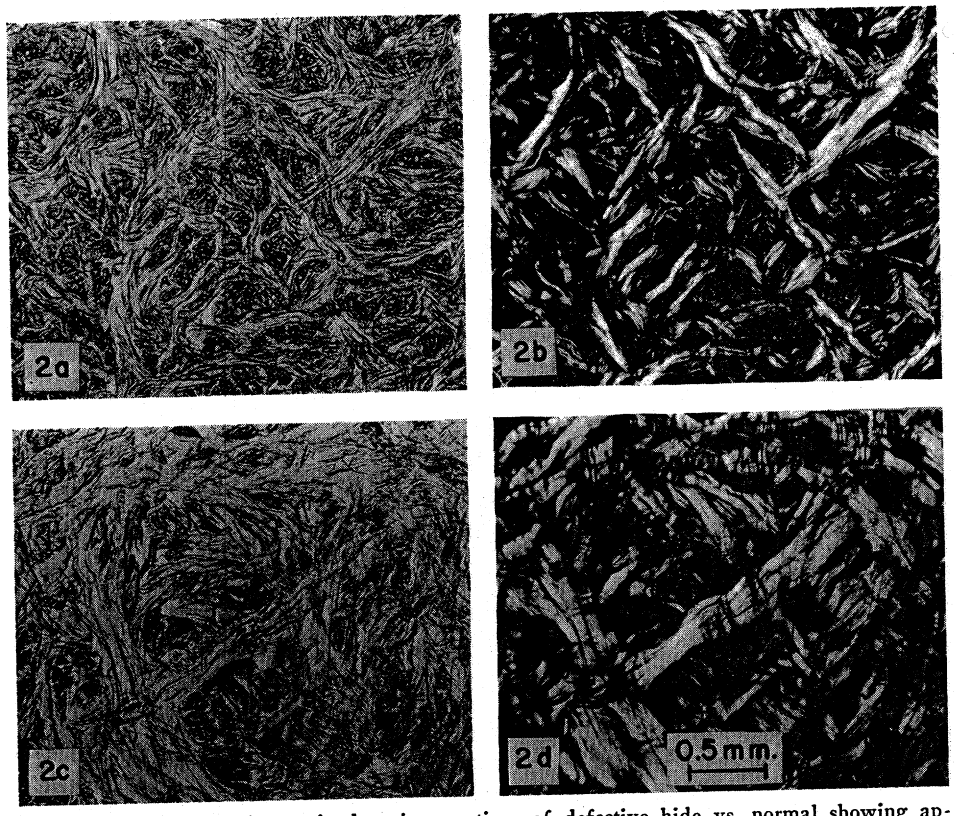


FIGURE 2.—Horizontal unstained corium sections of defective hide vs. normal showing application of polarized light: (a) section from defective hide in 1a as seen in regular light; (b) same area as seen in polarized light; (c) section from normal hide in 1b as seen in regular light; (d) same area as seen in polarized light. Scale applies to all sections.

the shrinkage undulations or waviness of the horizontal fibers, produced here by dehydration in the cured state, are more apparent in polarized light, especially in the normal Angus sample. When interpreting these pictures, allowance must be made for holes in the section and for fat cells which also appear dark in polarized light. Therefore, it is advisable to have control pictures of the same fields taken in regular light.

Photometric Evaluation.—Recognizing the defective structure is made easier with polarized light, but it is still a subjective diagnosis. It would help to have an objective test that gives numerical values independent of observer variations. This was attempted by measuring the total amount of light transmitted through the photographic negatives made from polarized-light views of horizontal sections (see under Photometry). As explained above, pictures of sections from normal hide show more bright horizontal fibers; but their negatives have reversed contrast and therefore should transmit less light. By the same reasoning, negatives of sections from defective hides should transmit more light. Table I shows the average values obtained when a set of sections from a selected group of weak and strong hides was evaluated photometrically. While the transmission differences do not seem large, analysis of variance indicated a highly significant difference between average values. The grand average of 60.9 for weak sides was obtained with a maximum or blank reading (film removed) of 81, meaning that these films transmitted 75 percent of the incident light. Likewise

TABLE I

PHOTOMETRIC EVALUATION OF POLARIZED-LIGHT NEGATIVE FILMS FROM HORIZONTAL CORIUM SECTIONS OF CURED HIDE

Weak Sides			Strong Sides		
Side No.	Light* Transmission	Tensile† Strength	Side No.	Light Transmission	Tensile Strength
2 L	61.5	1650	32 L	56.7	3986
2 R	60.8	1968	32 R	57.5	3617
4 R	59.5	2113	35 R	54.3	3875
23 R	64.0	2031	51 R	51.2	4182
62 R	58.9	1880	79 R	49.6	3598
71 R	60.8	1745	81 R	47.1	3738
Avg.	60.9	1898	Avg.	51.8	3833
	(75% of maximum)			(64% of maximum)	

*Arbitrary scale units with maximum reading of 81. Values are the average of 3 to 6 different films read in duplicate.

†Pounds per square inch, kidney area of cured hide, full thickness.

the films from strong hides transmitted only 64 percent of the light. These figures are in line with the expected results. Note that the Hereford hide of Figures 1 and 2 is No. 71R in this table; the Angus hide compared with it is No. 79R. Tensile strength values are included in the table to further define the degree of weakness observed.

It is evident that the hide samples evaluated above represented extremes of weakness and strength. With hides of intermediate strength the photometric method would be less likely to discriminate between normal and abnormal structure because the light transmission values would tend to overlap, or at least would require a larger number of sample replications to establish significance. This is further complicated by interference from photographic conditions. Variations in exposure of the films and in the subsequent development strongly affect transmission properties. Exposure conditions would be especially difficult to standardize. Despite this lack of sensitivity in quantitative terms, the polarized-light pictures can be evaluated subjectively with a high degree of confidence after sufficient experience.

Densitometric Scanning.—Photometric readings gave an over-all evaluation of the polarized-light films. It was of some interest to show graphically the quantitative variations in density within such films, in order to illustrate in greater detail the differences characteristic of the two types of fiber structure. Densitometer plots (see under Photometry) for two representative samples are shown in Figure 3. The defective Hereford sample (side No. 23R) is again on the left (3a), and the normal Angus (side No. 79R) is on the right (3b). Below each of the plots is a print of the central portion of the polarized-light film that was scanned. Curve peaks projecting upward represent light areas along a central narrow line in the prints, and those pointing downward correspond to dark areas. Comparing the height and shape of the peaks with respect to the dotted reference line, a distinct difference between the two curves is apparent: the Hereford sample produced much broader peaks below the reference line, indicating larger dark areas of vertical fibers. Quantitative data with respect to peak heights and areas under the peaks can be derived with this instrument, providing another means of expressing fiber structure in numerical terms. The extent of variation between different areas of the same sample or among a series of samples has not been investigated.

Color Differentiation.—An interesting optical effect was induced (see under Microscopy) in polarized-light images by the use of a special filter (first-order red compensator). Without using stains this transformed birefringent horizontal fibers into two different colors according to their orientation in the section and also revealed previously obscured details in the nonrefractive background. The following sequence of pictures will illustrate its usefulness. Figure 4 shows cross sections of two cured hides from a different experimental lot than those of Figure 1. The defective Hereford hide is on the left (4a), and the normal Angus

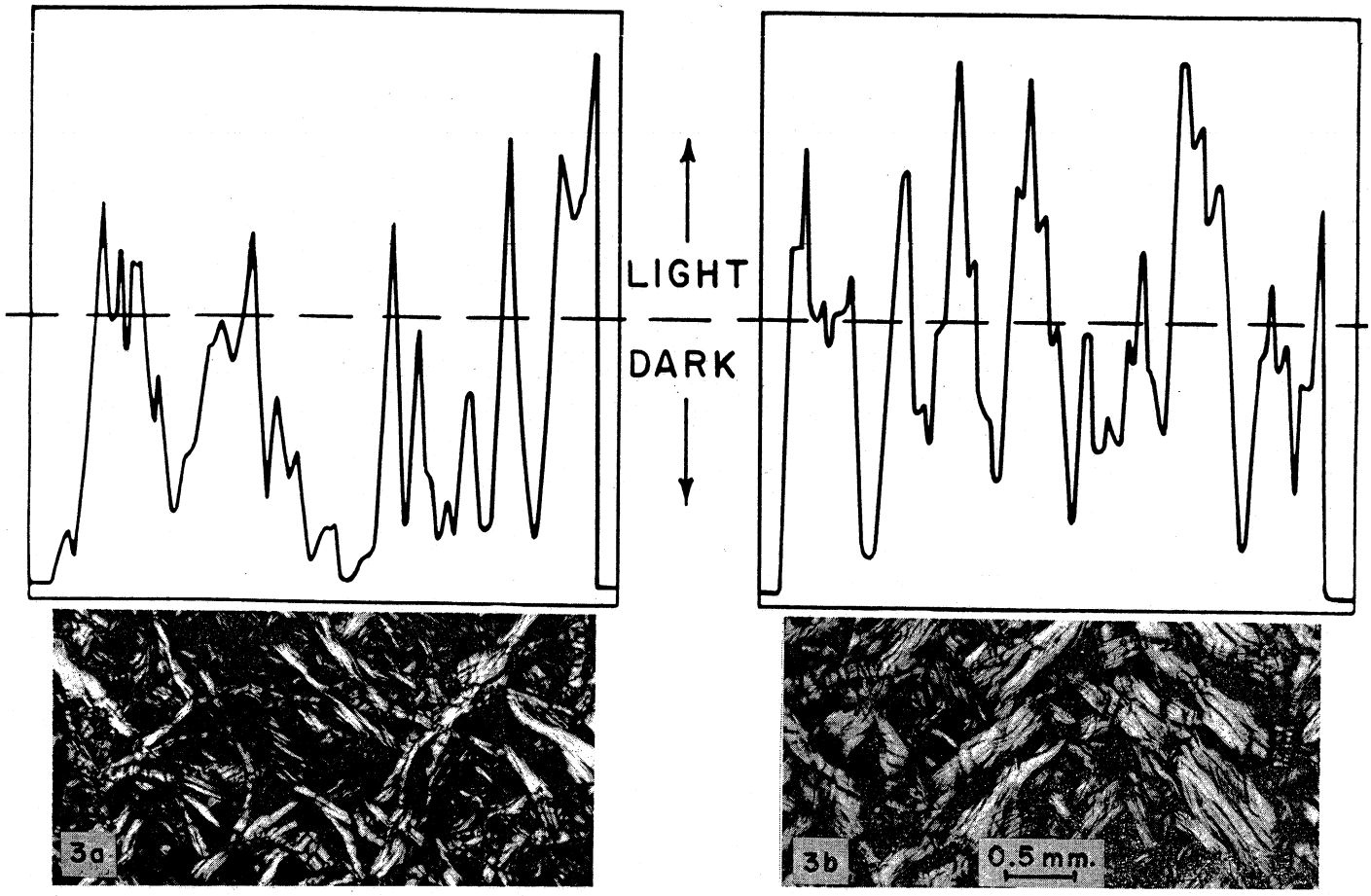
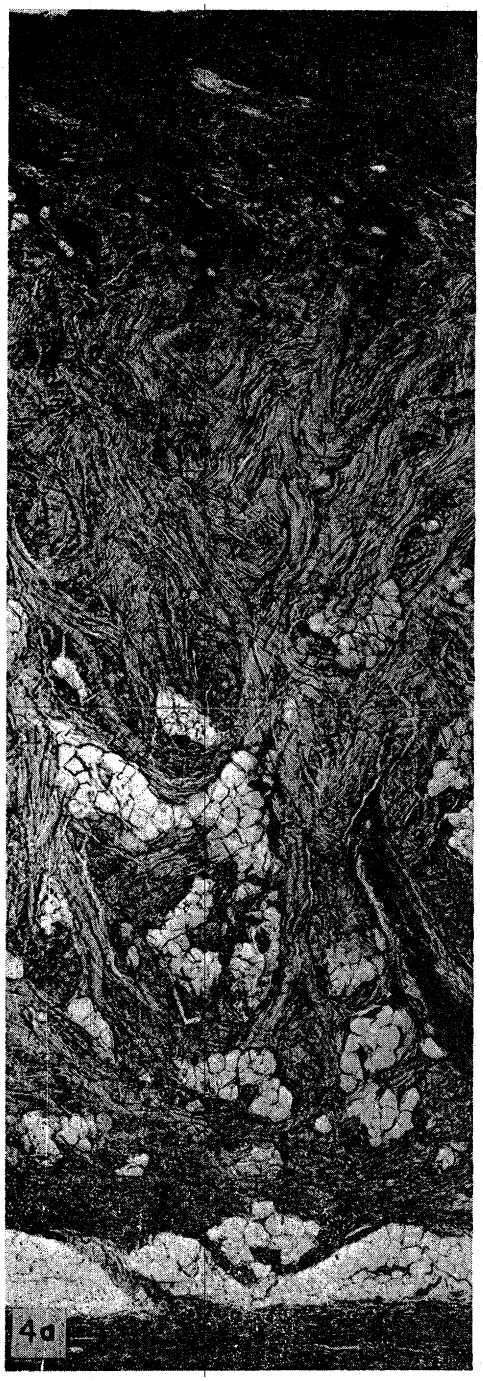


FIGURE 3.—Plots by scanning densitometer from polarized-light films of horizontal corium sections: (a) print of film which is plotted above it, from defective Hereford hide #23R. Upward peaks represent light areas along narrow central line in the print; downward peaks represent dark area; (b) print and graph from normal Angus hide #79R.



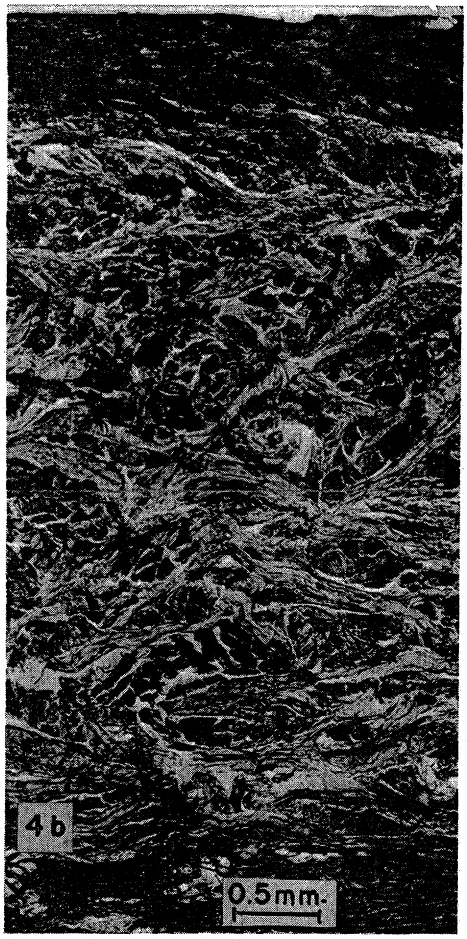


FIGURE 4.—Cross sections of defective hide vs. normal showing extreme difference in thickness and in fat content: (a) Hereford #32L with vertical fiber; (b) Angus #69R with normal structure. Hematoxylin-eosin, x 25.

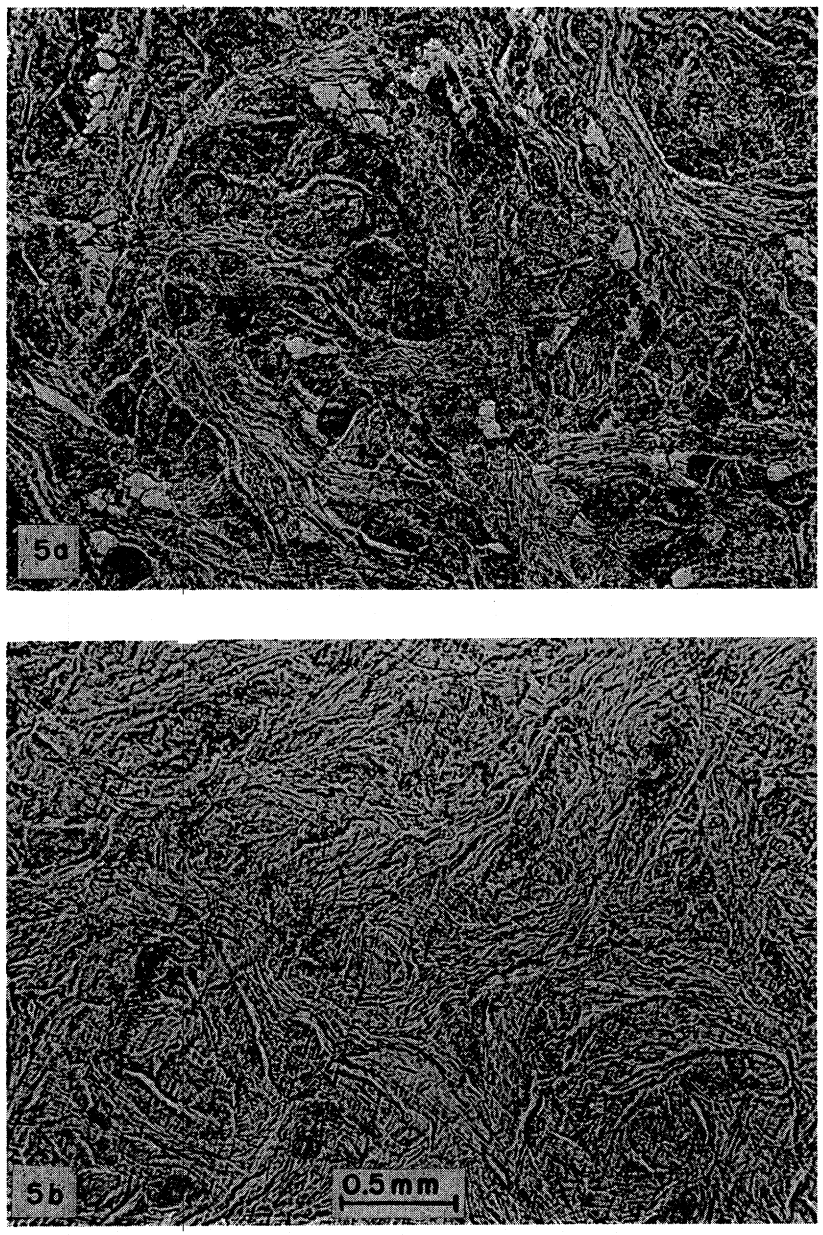


FIGURE 5.—Horizontal unstained corium sections of defective hide vs. normal as seen in regular light: (a) section from defective hide in 4a; (b) section from normal hide in 4b, x 30.

FIGURE 6.—Same areas shown in Figure 5 as seen in polarized light; (a) defective hide; (b) normal hide.

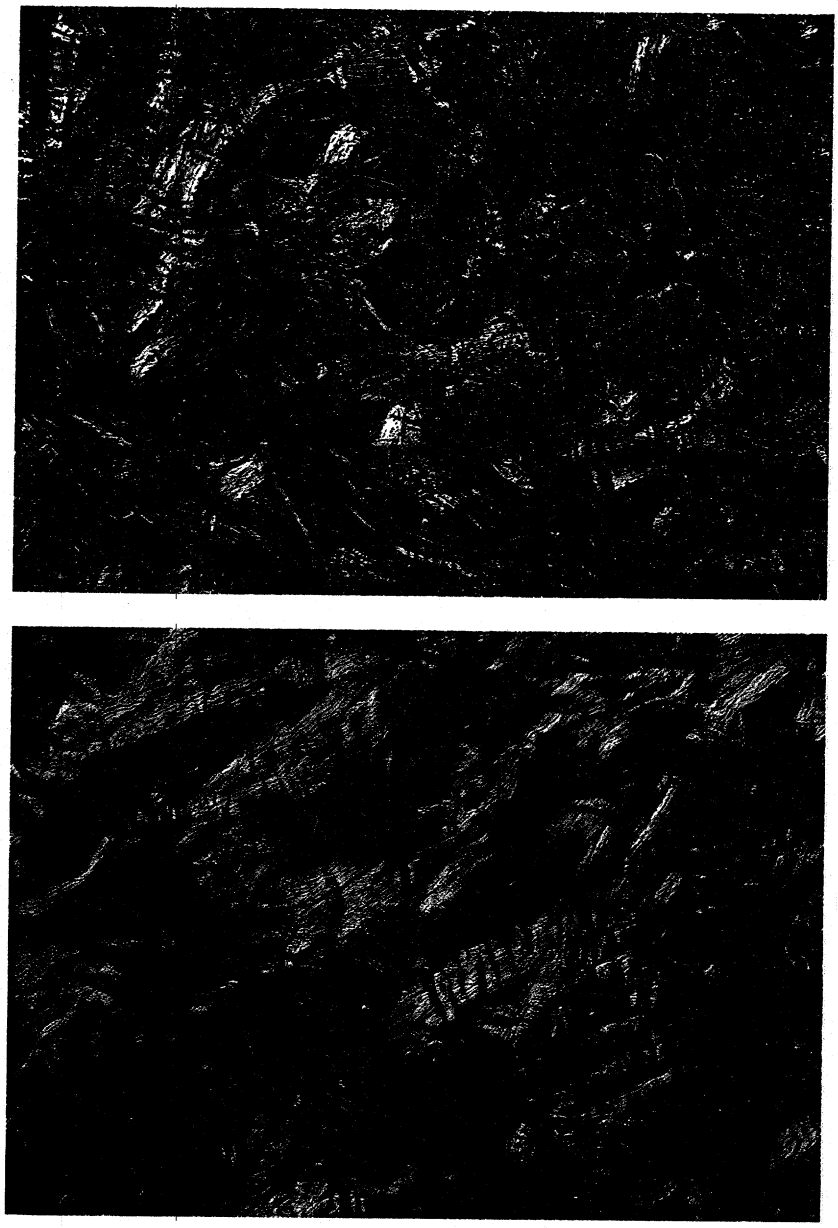


FIGURE 7.—Same areas shown in Figure 6, still in polarized light but with addition of first-order red compensator. Above: defective hide; below: normal hide.

is on the right (4b). The typical difference in thickness (plumpness) is also apparent, and there is often more fat in the plumper Herefords, as illustrated by the one shown here. Excessive fat in the corium did not always correlate with weakness, but the plump Herefords commonly contained more of it than did the plump Angus hides, according to the Cincinnati studies.

Horizontal sections through the upper corium of these two hides are shown in the next series of figures to illustrate the progressive change in appearance using black-and-white polarization microscopy as compared with the three-color effect. In Figure 5 the sections are shown in regular light with the abnormal Hereford above (5a) and the normal Angus below (5b). Besides its difference in fiber structure the Hereford sample shows scattered clusters of oval fat cells not found in the sequence of Figures 1 and 2. In polarized light these same two fields appeared as shown in Figure 6. This resulted in sharp emphasis of the horizontal fibers and made the difference in structure more obvious, but unfortunately both the vertical fibers and the fat cells became uniformly black. When the red compensator was inserted into the polarized-light path, the remarkable effects shown in Figure 7 were produced, with even more brilliant contrast than could be reproduced here. Interpretation of the two types of structure is greatly enhanced by this device. Horizontal fibers can be immediately identified in yellow or blue, as well as their interrelationships with other nearby fibers. The vertical fibers, invisibly black in ordinary polarized light, are translucently visible enough so that the component parts of a fiber bundle can be distinguished. Also the nonfibrous elements are clearly recognizable in the Hereford sample: holes or separations in the section show the clear red background color; fat cells also appear red but are usually oval in shape and surrounded by thin cell walls.

Examples of Domestic Leathers.—As mentioned in the introduction, the vertical fiber problem was first brought directly to our attention by a tanner in 1961, who presented a sample of vegetable-retanned chrome side leather showing extensive grain crack, pronounced weakness and areas with apparent depletion of substance. The flesh surface had a soft, pulpy texture from which fiber fragments could easily be dislodged by scraping. Figure 8 shows cross sections of this extremely defective leather. Its full thickness is shown on the left (8a), emphasizing the very high angle of weave in the corium and the general disruption of structure due to its looseness. Note also the deep grain crack on the right side, which often occurs during staking when there is uneven or inadequate support from the underlying fibers. Another view of this sample is shown in Figure 8b, from an area where depletion resulted from mechanical disruption and loss of fiber fragments during processing, which explains why very few vertical fibers remained. Nitrogen analyses have confirmed the extent of this loss of fibers. When specimens of equal area were cut out of a depleted spot and from a nearby region of normal thickness and analyzed, the depleted sample contained 43 percent less hide substance than the control.

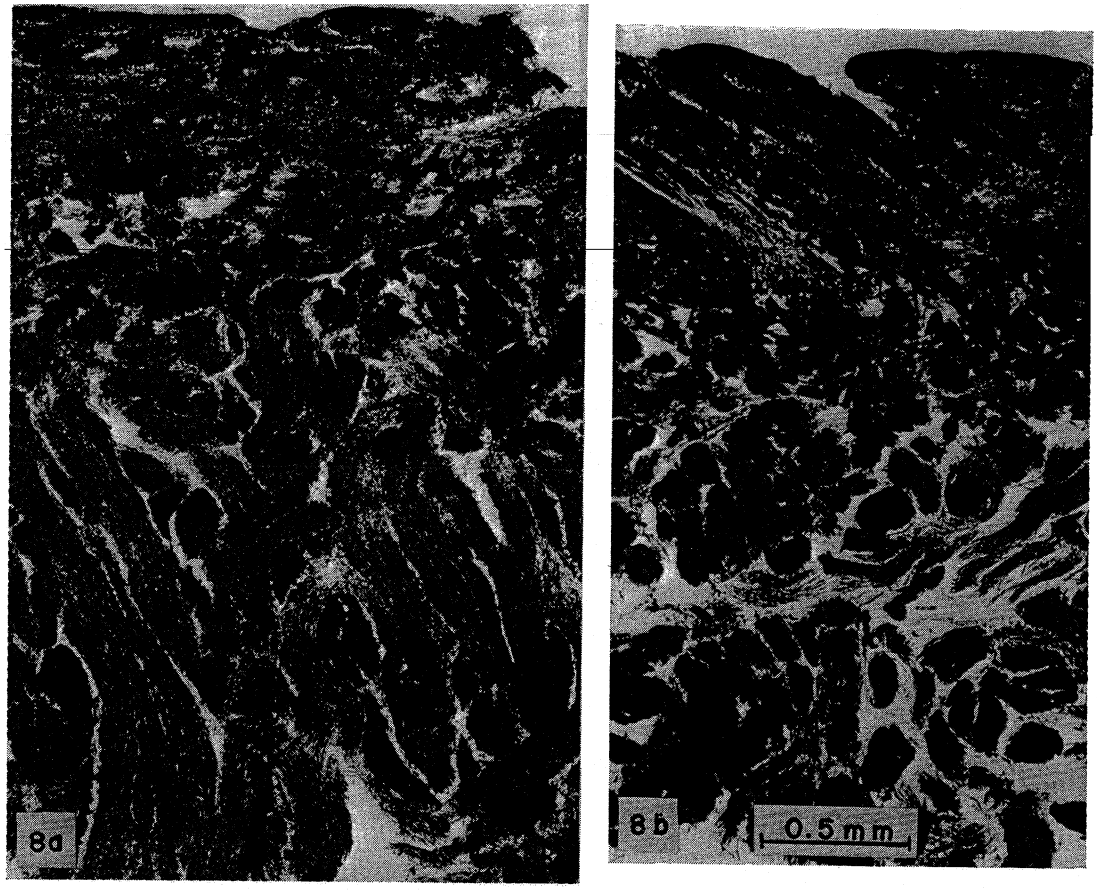


FIGURE 8.—Cross sections of "pulpy" vegetable-retanned side leather showing grain crack and mechanical depletion: (a) sample with grain crack at upper right, vertical corium fibers and highly disorganized structure; (b) sample from depleted thin spot. Unstained, x 40.

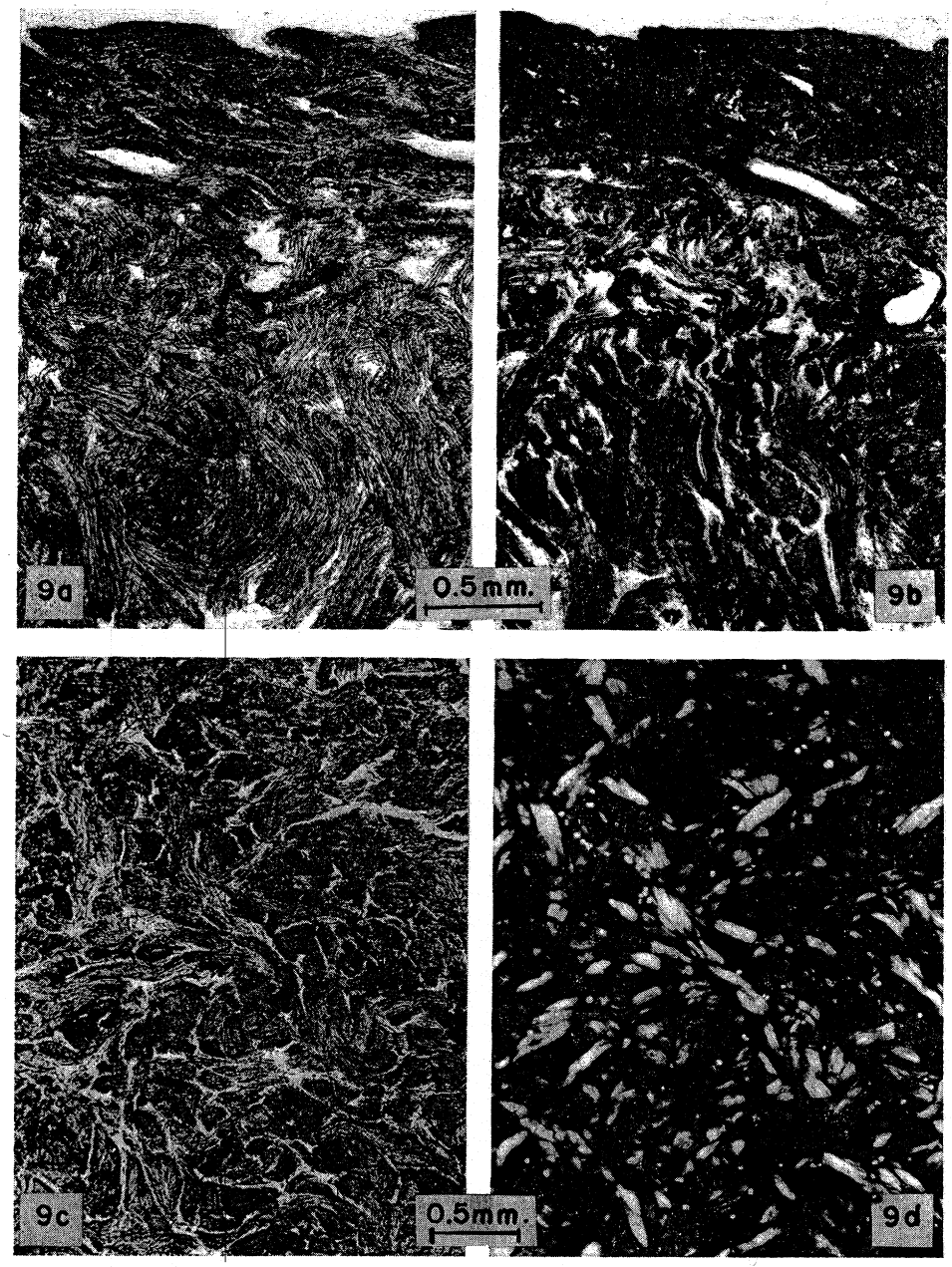


FIGURE 9.—Cross sections of chrome side leather in the crust with vertical fiber: (a) unstained section showing vertical fiber throughout corium; (b) section stained for fat showing almost complete penetration of fat liquor, x 32; (c) horizontal unstained corium section in regular light; (d) same area in polarized light showing sparse horizontal fibers and tiny starch granules, x 25.

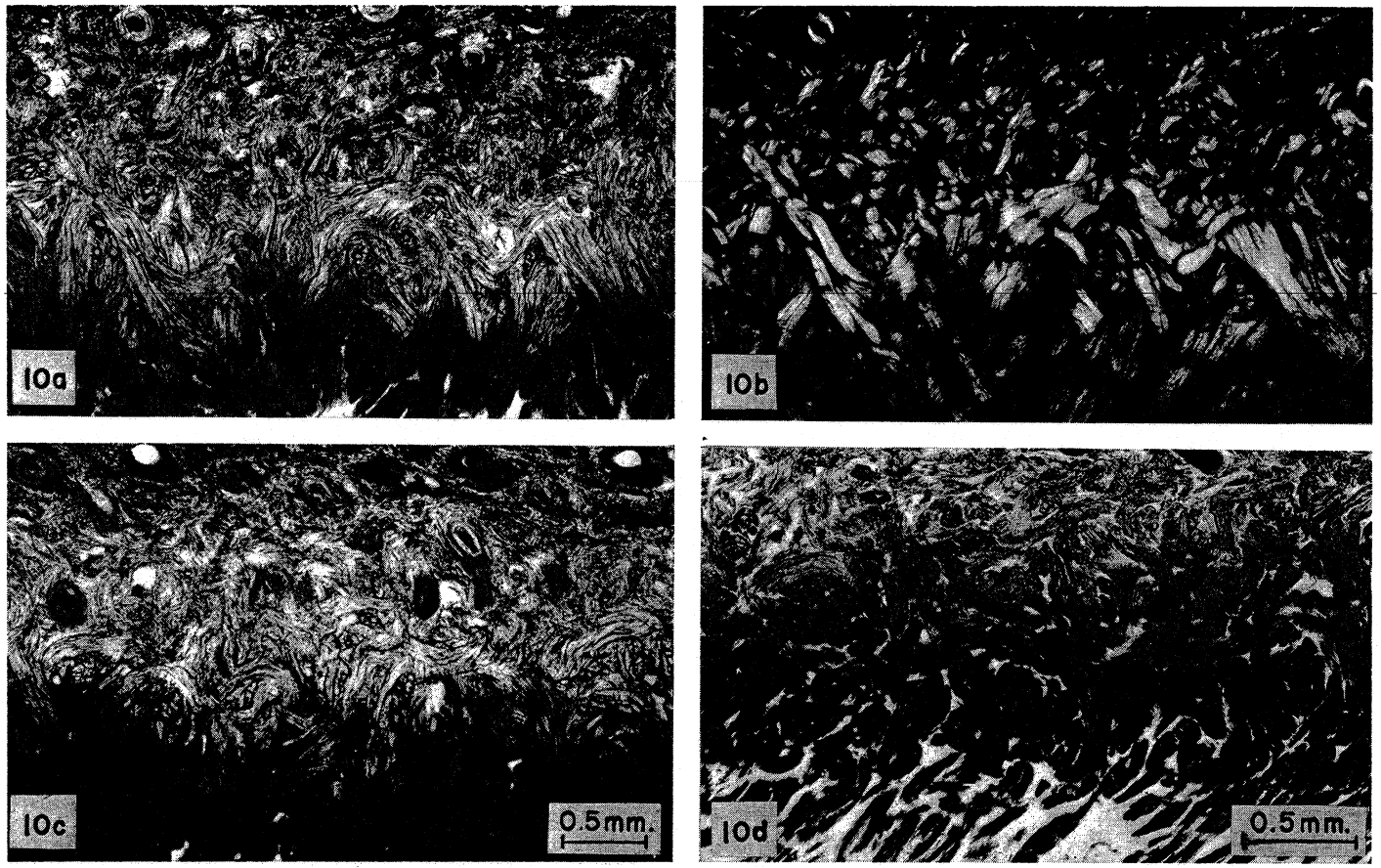


FIGURE 10.—Cross sections of South American side leathers with moderate degree of vertical fiber: (a) unstained section of brown leather in regular light; (b) same area in polarized light; (c) section stained for fat; (d) unstained section of black leather, corium area. First three sections, x 25; fourth, x 32.

Subsequently a sample of chrome side leather in the crust was examined which displayed the typical pulpy appearance on the flesh side. Cross sections of this leather are shown in Figure 9; the upper left section (9a) was unstained while the upper right (9b) was stained for fat. Both sections showed an extremely high angle of weave in the corium, and fat staining revealed that the fat liquor had completely penetrated the vertical fibers instead of leaving a broad clear zone in the center (see Fig. 1d). On the lower left (9c) is a horizontal section through the corium in regular light and, on its right (9d), the same field in polarized light. This is the same situation pictured previously in weak hide samples (Fig. 2a, 2b, 5a and 6a), but in addition it (9d) shows starch granules (small white spots) which were incorporated with the fat liquor and could readily penetrate the loose vertical structure. Starch from any source, e.g., paste drying, can easily be recognized in polarized light.

Examples of Foreign Leathers.—Three years ago we obtained two samples of South American side leather which had been selected because they showed extensive grain crack and a pulpy appearance on the flesh side. Examination of cross sections, some of which are shown in Figure 10, revealed vertical fiber limited to the lower portion of the corium. Figures 10a and 10b illustrate a representative field from the first sample in regular light as well as in polarized light. Here it can be seen that the uppermost part of the corium had a normally interwoven fiber structure which changed abruptly to a vertical orientation in the lower part of the picture. This was an unstained section of a brown leather; the dye partially obscured the polarization effect along the bottom of 10b. A section of the same sample stained for fats is shown in 10c, where it is evident that the fat liquor penetrated only to the extent of the vertical fibers. The corium region of the second sample, a black leather, is shown in 10d at a slightly higher magnification. This was essentially the same as the first but showed considerable looseness on the flesh side. Gelatin embedding retained what was left of the loose fibers, yet it is apparent that many fragments had already been lost during mechanical handling.

These samples were included in the present report to confirm that the defect is not confined to domestic leathers. No doubt it will be recognized more frequently in the future as more people become familiar with its symptoms.

SUMMARY AND CONCLUSIONS

Vertical fiber was first reported by Amos in 1958, but its relationship to a pre-existent problem in side upper leather was not recognized until several years later. The recent revival of interest in this country, through the cooperative efforts of the Tanners' Council Research Laboratory and the United States Department of Agriculture, has verified the findings of the Australian study and also revealed much additional information which further emphasized the seriousness and complexity of the problem. It is primarily a defect of plump hides —

especially Herefords -- which, because of its inherent nature, apparently cannot be overcome by modified processing. Seriously affected hides are totally unfit for making upper leather but might well be suitable for sole leather or for other products not requiring high strength. There is a strong need for an accurate, practical method of sorting out the defective hides before processing; although Tancous and co-workers (paper in this issue) report progress in this direction, the ideal solution has not yet been found.

There has also been some progress at the experimental level in further characterizing the defect. Polarization microscopy, when applied to horizontal corium sections, is a versatile technique for distinguishing between the more horizontal normal structure and the abnormal vertical fibers. Not only does this enhance visual appraisal of a series of samples; but, if extra time and effort are justified, it also permits quantitative evaluation of photographic material by means of photometric devices. Admittedly such methods are purely of research value. Realization of a practical, nondestructive and rapid test for the packer or tanner might better be sought from the physicist. It seems logical to expect that radical differences in fiber orientation would be reflected by corresponding differences in response to sound waves, x-rays, intense light rays, vibrational pressures, electric or magnetic fields, etc. In fact, a sonic testing method for evaluating properties of paper was recently proposed (11) which was claimed to respond to changes in fiber orientation. A nondestructive dynamic test under study in this laboratory (12), which measures flexibility in compression, has detected a characteristic pattern of variability at different locations in a side, although its specific applicability to the present problem has not yet been resolved. Exploraton in these and related areas should be continued, keeping in mind the primary goal of detecting the vertical fiber condition in rawstock.

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