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THE STRUCTURE OF PAPERS AS SEEN IN THEIR SURFACES

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Summary

This contribution illustrates the structure of paper by presenting a selection of light micrographs of the surfaces of papers. In addition to illustrating a wide range of papers, the effects are portrayed of progressive beating; coating; creping; machine glazing and the glazing of handsheets; parchmentising; supercalendering; and water-marking. The two-sidedness of the surfaces of several papers is clearly brought out and the contribution of the surface of mechanical printing papers to their printability is illustrated.

Of particular interest are the effects of progressive beating on the density of the sheet, the closeness of its surface structure and its response to glazing. It was observed that cellulosic material has the ability to replicate fine scratches on a surface with which it is dried in contact.

La structure du papier examiné en surface

Cette communication présente la structure du papier par un choix de micrographies optiques de surfaces de papier. En plus des vues représentant une vaste gamme de papiers, les auteurs illustrent les effets d'un engraissement progressif, du couchage, du crêpage, de la friction, du glaçage en feuilles de formette, de la sulfurisation, du supercalandrage et du filigranage. Le phenomène de double-face apparait clairement et l'effet de la surface des papiers d'impression à base de pâte mecanique sur l'imprimabilité apparait.

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Les effets de l'engraissement progressif sur la densité de la feuille, la compacité de sa structure superficielle et son aptitude au glaçage sont particulièrement intèressants. On a observé que la cellulose réproduit fidèlement les fins défauts de la surface sur laquelle elle est séchée.

Die Oberflächenstruktur von Papier

Es wurde die Papierstruktur durch eine Auswahl von Lichtmikrographien der Oberflächen von Papier beschrieben. An einem weiten Bereich von Papierqualitäten wurden die Auswirkungen von fortschreitender Mahlung, Streichen, Kreppen, Glätten in der Maschine und von Laborblättern aufgezeigt, sowie von Pergamentierung, Satinage und Wasserzeichen. Die Zweiseitigkeit der Oberflächen verschiedener Papiere konnte deutlich dargestellt werden, wie auch die Abhängigkeit der Bedruckbarkeit von der Bahnoberfläche bei Druckpapieren.

Von besonderem Interesse war der Einfluss der fortschreitenden Mahlung auf die Dichte der Bahn, die Geschlossenheit der Oberflächenstruktur und das Verhalten beim Glätten. Man fand, dass feine Kratzer auf der zur Trocknung benutzten Oberfläche bei Berührung mit cellulosehaltigem Stoff übertragen werden können.

Introduction

IN an earlier paper, Page and Emerton[1] indicated the difficulties that face the microscopist who wishes to study the surface of paper and described in detail some methods that had been developed to overcome them. These techniques have been applied in the authors' laboratory to problems associated with surface structure. A selection of light micrographs of a wide range of papers has been published earlier[2] and many of these are put forward here with a brief commentary, in the form of an atlas of paper surfaces.

Certain aspects call for explanation or emphasis. In all cases, these micrographs reveal only the form and structure of the surface of the paper sheet. It cannot be too strongly emphasised that no information is directly available from these micrographs of the conditions obtaining in the body of the sheet, although they can perhaps sometimes be inferred. The surface is often a region of considerable interest, especially when it has been modified by processing. Accordingly, the micrographs have been particularly chosen to illustrate surface treatments.

Save for certain necessary exceptions to which attention will be drawn, the machine-direction of the machine-made paper in every case is parallel to the long edge of the micrograph. Without exception, the 'lighting' has been arranged to fall down the length of the micrograph from the top at an angle of $15° \pm 2°$ to the plane of the paper sheet (so that the projection of the beam in this plane is parallel to the machine-direction).

The great majority of the micrographs were taken using the zero-stage replica method, which guarantees perfectly faithful reproduction of detail and form of the surface. A few were taken using the two-stage replica method, which is rather less reliable. (For further details, see the earlier paper.[(1)])

The term *fibre* is used in its broad papermaking sense—that is, to include those cells of wood tissues that are known botanically as tracheids.

Finally, it must be emphasised that, although sufficient work has been done to establish the validity of generalised statements and the representativeness of the micrographs, the appearance of different makings of papers designed for the same purpose can vary considerably and much further work of this nature remains to be carried out.

Two-sidedness

VIRTUALLY all machine-made paper differs in the structure of its two sides. This, in certain cases, leads to marked two-sidedness in their smoothness and printing behaviour; in their optical properties, including depth of colour; and in the extent to which the surfaces take up felt marks.

Structural two-sidedness is characterised by the comparatively smooth surface on the top side due to a high proportion of fines and loading that, on the under side, tend to pass through the machine wire, leaving exposed a preponderance of longer fibrous elements with concavities between them. The effect is particularly marked in papers with a high loading and appears to be aggravated by the presence of groundwood pulp with its fine fibre fragments, by high machine speeds[(3)] and by the use of the dandy roll.[(4)]

It would seem to be established that structural two-sidedness is created before the sheet reaches the suction boxes. Some hold that there is a substantial loss of fines and filler from the under side as a result of the flushing action of water carried round by the table rolls and forced up through the wire into the sheet.[(3)] On the other hand, it has been claimed that two-sidedness is established immediately the stock flows on to the wire.[(4)] Whatever the mechanism, the effect is clearly apparent in the accompanying micrographs.

Cigarette tissue

Fig. 1—Top side

Fig. 2—Wire side

This sheet had about 12 per cent loading. The paucity of filler on the wire side is clearly seen, the skeletal fibres standing out on the surface. On the top side, the form of the flax and hemp fibres can only faintly be traced beneath the loading.

Newsprint, machine-finished

Fig. 3—Top side
Fig. 4—Wire side

The clay filler (approximately 15 per cent) and fines, which are prominent in the surface of the top side, are almost completely missing on the wire side.

Of additional interest in Fig. 4 are the prominent longitudinal ridges on certain fibres. These consist of intercellular material at the edges of the cell where the middle lamella is thicker.[5] They are largely removed by full chemical pulping and bleaching and, in this case, probably indicate groundwood fibres.

Also worthy of note are the two fibres at the top and bottom of Fig. 4 showing prominent bordered pits. The form of these pits indicates that they are viewed from the lumen—that is, the fibres have been split open, probably during grinding.

Greaseproof

Fig. 5—Top side
Fig. 6—Wire side

Structural two-sidedness is quite appreciable even with this type of paper. The fibres tend to be obscured by fines on the top side, but stand proud on the wire side. The dense nature of the sheet is apparent in both cases.

Glassine

Fig. 7—Top side
Fig. 8—Wire side

It is generally not possible to identify the two sides of glassine after supercalendering; nevertheless, a marked difference is apparent by this technique. The top side is seen to be a relatively uniform surface that has been smoothed evenly except for shallow depressions here and there. The wire side appears more or less equally smooth, but this has been achieved by flattening exposed—more or less intact—fibres, the form of which may still to some extent be traced.

At low magnifications, it can be seen that the rough, shallow depressions in both surfaces have a regularity of size and spacing that indicates a relationship with the mesh of the Fourdrinier wire. The scattering of light by these areas contributes considerably to the visibility to the unaided eye of the wire mark in this kind of paper.

The furnish was bleached sulphite woodpulp with a small proportion of bleached sulphate pulp.

Fig. 1—Cigarette tissue, top side (× 275)

Fig. 2—Cigarette tissue, wire side (× 275)

Fig. 3—Newsprint, top side (× 275)

Fig. 4—Newsprint, wire side (×275)

Fig. 5—Greaseproof, top side (× 275)

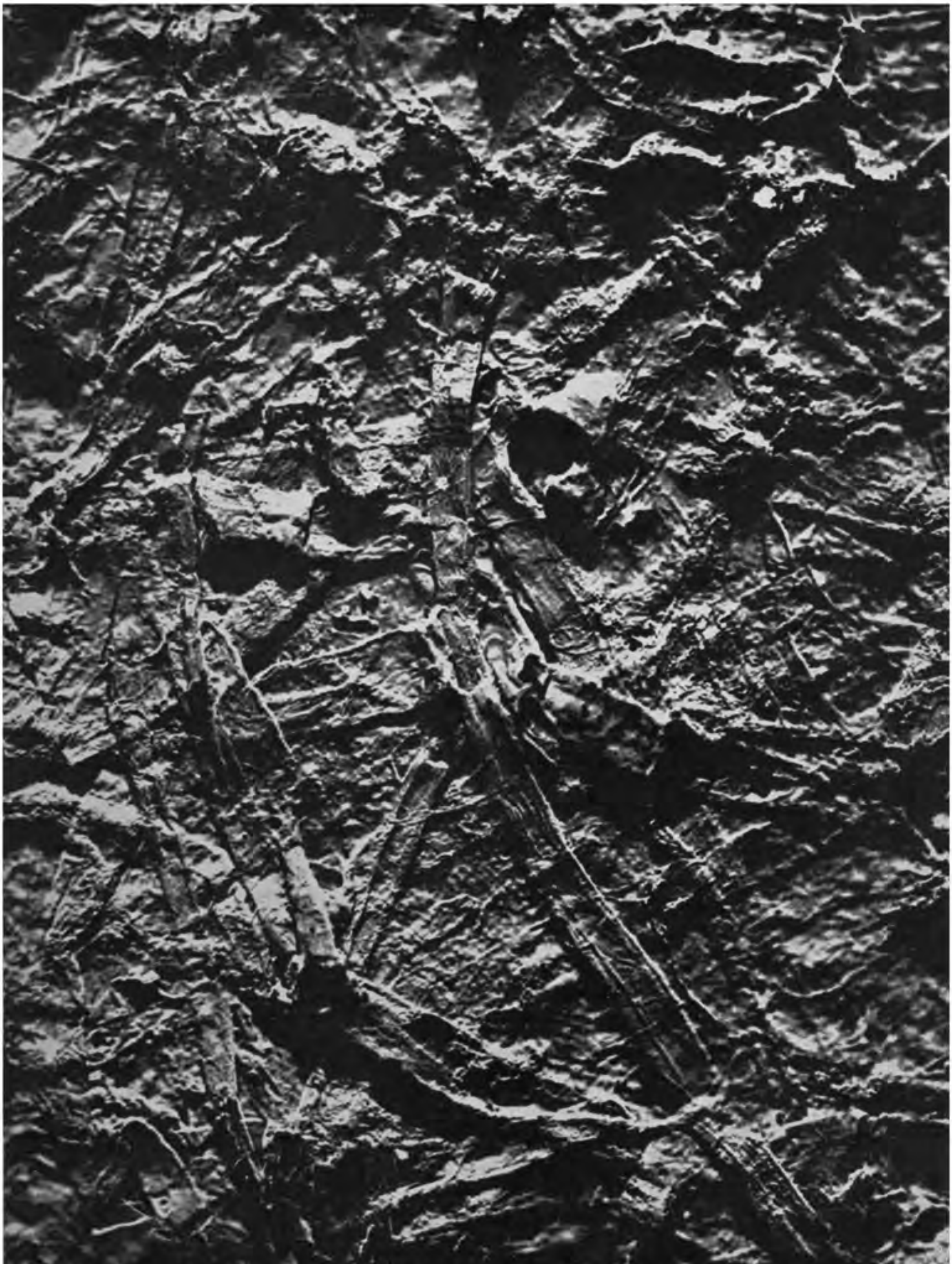


Fig. 6—Greaseproof, wire side (× 275)

Fig. 7—Glassine, top side (× 215)

Fig. 8—Glassine, wire side (× 215)

The effect of supercalendering

Mechanical printing

Fig. 9—Top side before supercalendering
Fig. 10—Top side after supercalendering
Fig. 11—Wire side before supercalendering
Fig. 12—Wire side after supercalendering

The top side is seen to be relatively rich in fines and filler, which respond to supercalendering to produce locally a high glaze. The fibres alone are incapable of yielding such a high finish as is evident from the skeletal appearance of the wire side. Comparison of Fig. 10 and Fig. 12 shows that the top side provides a much closer surface for the reception of print and it is for this reason that the top side is always selected for multi-colour gravure printing.

The characteristic appearance of groundwood fibres may again be remarked: in Fig. 10, the fibre lying from top centre to right centre is clearly heavily lignified along the edge running approximately down its centre, also around the bordered pits; on the fibre running into the picture at the top centre of Fig. 11 can be seen fragments of ray tissue that define the original position of the transverse cells of a crossing ray. In addition, split-open fibres (for example, top left of Fig. 10) are evident from the convex form of the bordered pits (compare with Fig. 4). The furnish is 30 per cent sulphite woodpulp and 70 per cent mechanical woodpulp.

Glazed imitation parchment

Fig. 13—Wire side of base paper
Fig. 14—Wire side after supercalendering

Again the reduced length of shadows of the supercalendered surface indicates a lowering of the proud-standing fibres, which are also smoothed. This effect has earlier been shown[(6)] in the perspective view given by the reflection electron microscope.

Fig. 9—Mechanical printing, top side, before supercalendering (× 275)

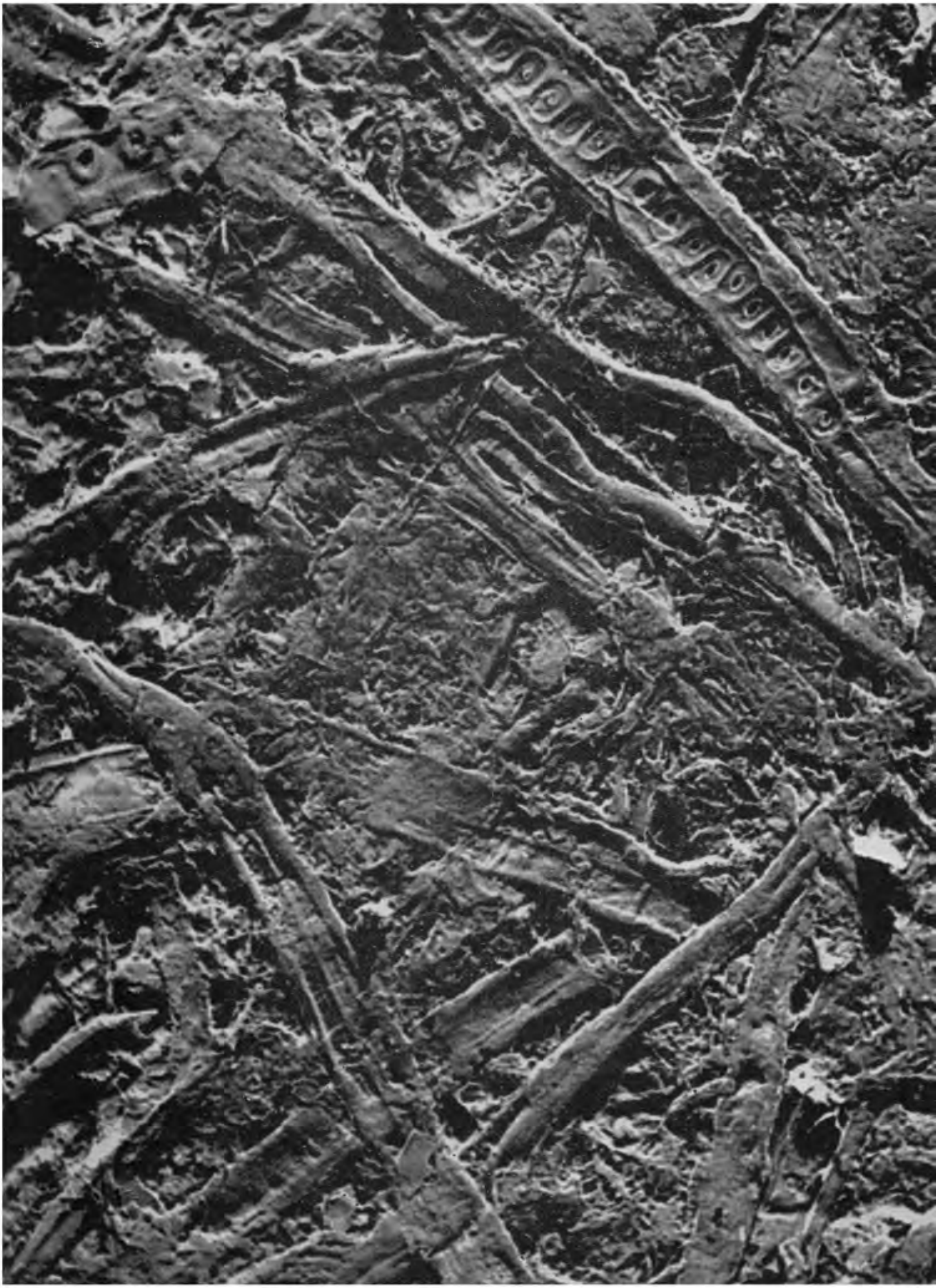


Fig. 10—Mechanical printing, top side, after supercalendering (× 275)

Fig. 11—Mechanical printing, wire side, before supercalendering (× 275)

Fig. 12—Mechanical printing, wire side, after supercalendering (× 275)

Fig. 13—Glazed imitation parchment, wire side, before supercalendering ($\times$ 275)

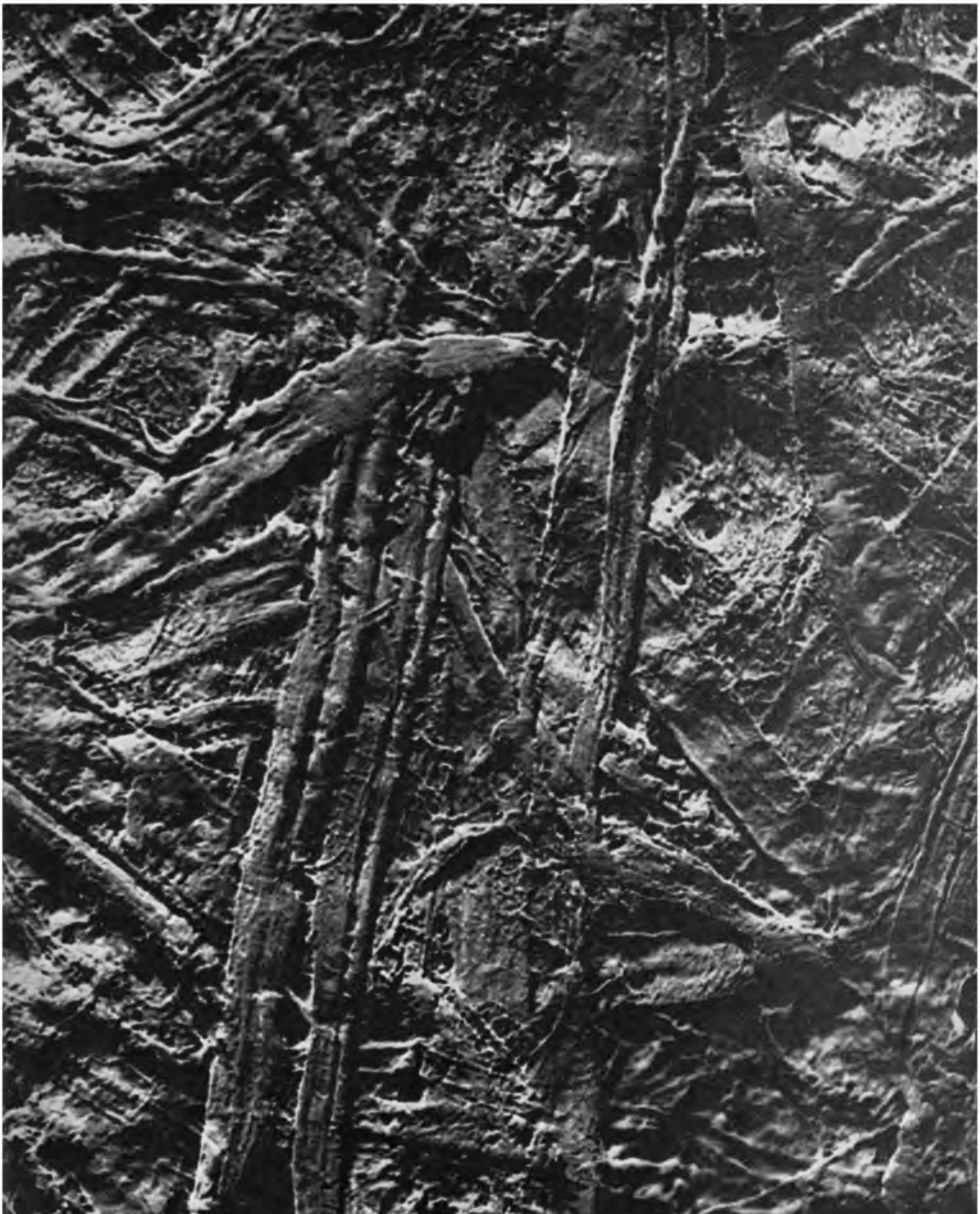


Fig. 14—Glazed imitation parchment, wire side, after supercalendering ($\times$ 275)

The effect of machine glazing

Fig. 15

The micrograph shows a kraft paper. The open structure, typical of the wire side, has been glazed on an MG cylinder. It was frequently observed that scratches—a few microns wide—on the surface of the cylinder, caused possibly by grit lodging at the doctor, are replicated by the wet and plastic surface of the fibres.

In this case, the machine-direction is east–west across the page.

The effect of parchmentising

Fig. 16—Base paper
Fig. 17—After parchmentising

Parchmentising is a process that has been studied in some detail by Bucher,(7) who distinguished three phases in the operation—the acid treatment, the water bath and the drying. The effect of the sulphuric acid is to cause the individual fibres to swell and partially disperse. This results in their rounded out, less well-defined form that is so clearly revealed in the second illustration. Bucher concluded that, when subsequently treated with water, the short-chain beta-cellulose and gamma-cellulose, which have to some extent been leached out by the acid, are reprecipitated between the fibres. Finally, during the drying operation, the dispersed short-chain polysaccharides form membranes, which may completely fill the spaces if sufficient dispersed material is present. Bucher found also that, if the drying is carried out too rapidly, the surface of the paper becomes impermeable to the water vapour in the interior, which then ruptures the surface and forms blowholes. Craters, of which two can be seen in the upper right corner of Fig. 17, were common on this specimen and were almost certainly caused in this way.

Note in Fig. 16 the bridge formed by part of the fibre at the foot of the illustration. (This is best seen by turning the page upside down.) To the right of this is a fibre, the end of which passes out of the picture. This shows twisting, an effect that arises from the shrinkage of a predominantly spiral structure during drying,(8) but which is usually prevented by surface tension holding the fibre in position until it has bonded to its neighbours.

The furnish is 100 per cent bleached sulphate, mainly softwood.

Fig. 15—Machine-glazed kraft paper, wire side (× 275)

Fig. 16—Vegetable parchment, base paper (× 275)

Fig. 17—Vegetable parchment (× 275)

The effect of progressive beating—unglazed handsheets

Fig. 18	(*above*)	Unbeaten	(Breaking length 3 600 m)
	(*below*)	After 5 min beating	(5 300 m)
Fig. 19	(*above*)	After 10 min beating	(6 700 m)
	(*below*)	After 20 min beating	(7 800 m)
Fig. 20	(*above*)	After 45 min beating	(8 000 m)
	(*below*)	After 90 min beating	(9 000 m)

The micrographs show the top side of handsheets prepared, by the Technical Section standard method, from a bleached sulphite pulp that had been beaten in accordance with the TAPPI method T200 m–45 (5.5 kg load).

The two major effects of beating (the making of the fibres plastic and the production of fines, the latter arising partly from external fibrillation and partly from fibre shortening) are revealed by this sequence of micrographs.

The surface of the unbeaten handsheet is bulked up and like a brush heap. The fibres are relatively unresponsive to wet pressing and to surface tension forces during drying as indicated by their wide separation and by the deep cavities and long shadows. As beating proceeds, the fibres rapidly become more flexible and, during drying, are brought closer together, so that the surface cavities become concavities and, finally, virtually cease to exist, the shadows at the same time shortening considerably. This increased flexibility is evident after only 5 min beating and before marked external fibrillation occurs and to it may be attributed the appreciable increases in paper strength that coincide with the first few minutes beating. For a fuller treatment of this, see two papers.[8b,9]

This investigation has shown also that in the early stages of beating the surface fibres exhibit many kinks and twists, but that, as beating proceeds, the fibres tend to straighten out. The following explanation is offered. When its wall is water-saturated, the fibre is substantially straight and completely untwisted. As the fibres shrink on drying, they are subjected to strong torsional stresses.[10] The relief of these is to a large extent inhibited by the trapping of the fibres and by surface tension dragging the fibres down all along their length into close contact with their neighbours. By the time that the water finally evaporates, they are usually in sufficiently close contact for bonding to occur and the fibres are then fixed in position with considerable dried-in torsional stress. The relatively inflexible fibres of an unbeaten or lightly beaten pulp, however, are not pulled down along their length to the same extent, so that there is a less total compacting force acting upon them. In this condition, it is possible for a section of the fibre to break through the retreating water surface and twist over; this section finally dries down at an angle to the general direction of the fibre. In some cases, it is the end of the fibre that is able to twist, sometimes forming one or two complete turns. The process is readily observed in the light microscope by drying individual fibres (or small clusters of fibres) on to a glass slide.

The effect of progressive beating—glazed handsheets

Fig. 21 (*above*)	Unbeaten
(*below*)	After 5 min beating
Fig. 22 (*above*)	After 10 min beating
(*below*)	After 20 min beating
Fig. 23 (*above*)	After 45 min beating
(*below*)	After 90 min beating

Similar effects to the last are observed in this series of handsheets showing the glazed wire side. In the early stages of beating, the fibres are relatively wide apart, separated by deep openings. They are also kinked and twisted. A very high degree of smoothness is imparted by the glazing plate to the uppermost fibres. As with machine glazing, it was observed that fine, sleek marks on the glazing surface are replicated by the fibres themselves; in this case, the direction of the sleeks is random. Portions of fibres are often shielded from the glazing effects by overlying fibres as, for example, in the middle of Fig. 21 (*below*).

As beating proceeds, the fibres in the handsheet surface are brought closer and the openings in the surface become shallower. The fibres are less readily able to twist in response to the torsional stresses set up within them and remain substantially straight. As the fines begin to make their appearance, the smooth area becomes more extensive, particularly at the angles formed by intersecting fibres.

After prolonged beating, considerable debris builds up between—and to some extent over—the fibres, closing the surface of the sheet. It is noteworthy, however, that this is unable to take such a high finish as the individual fibres from the lightly beaten stock and this may be due to the large amount of randomly oriented fibrillation present.

It will be noted that some of the glazed regions of the individual fibres show a variation of tone along their length. This implies that subsequent to the glazing they have undergone some distortion that may have occurred at the time of stripping the sheet from the glazing plate.

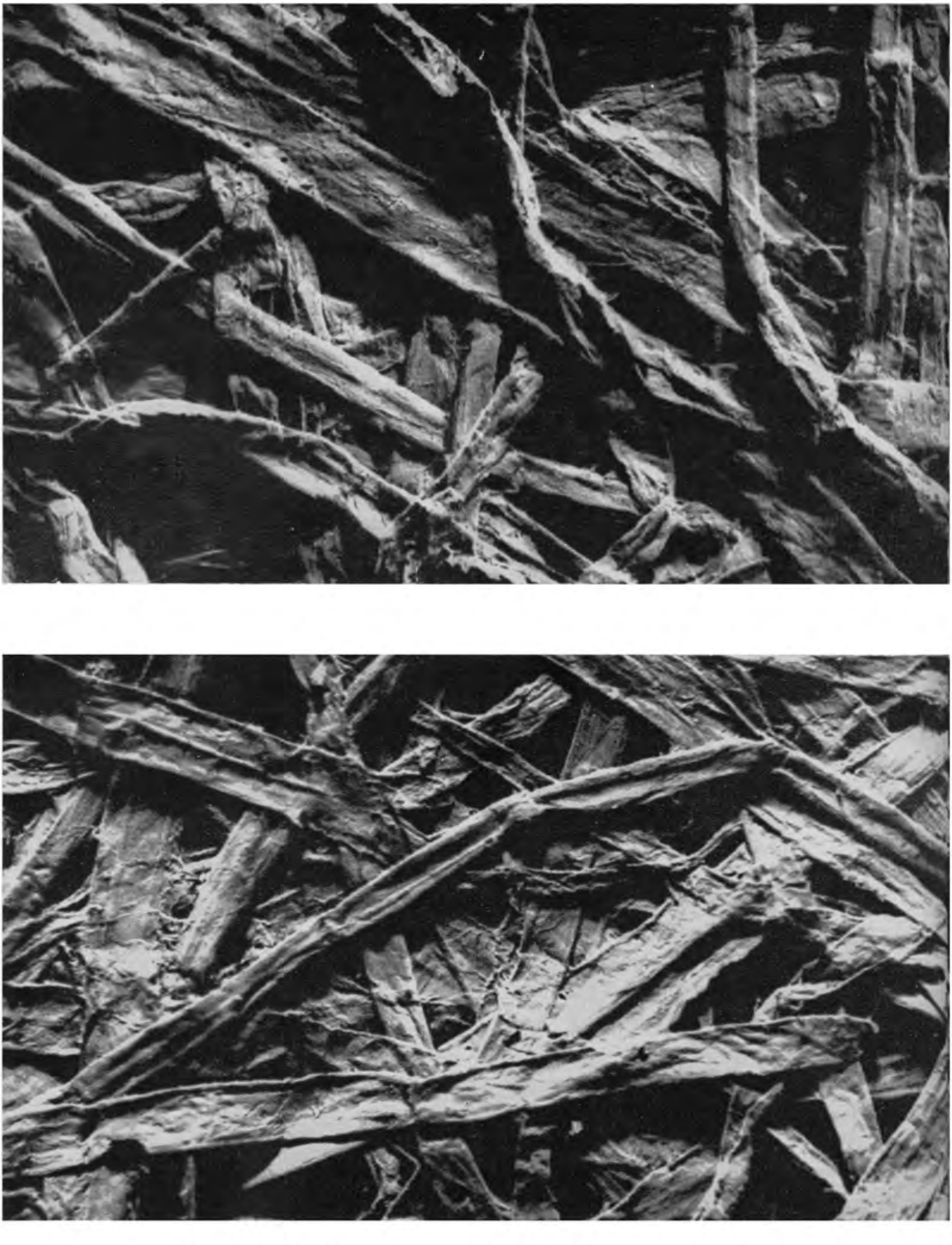


Fig. 18—Bleached spruce sulphite handsheets (*above*) unbeaten; (*below*) beaten 5 min (× 210)

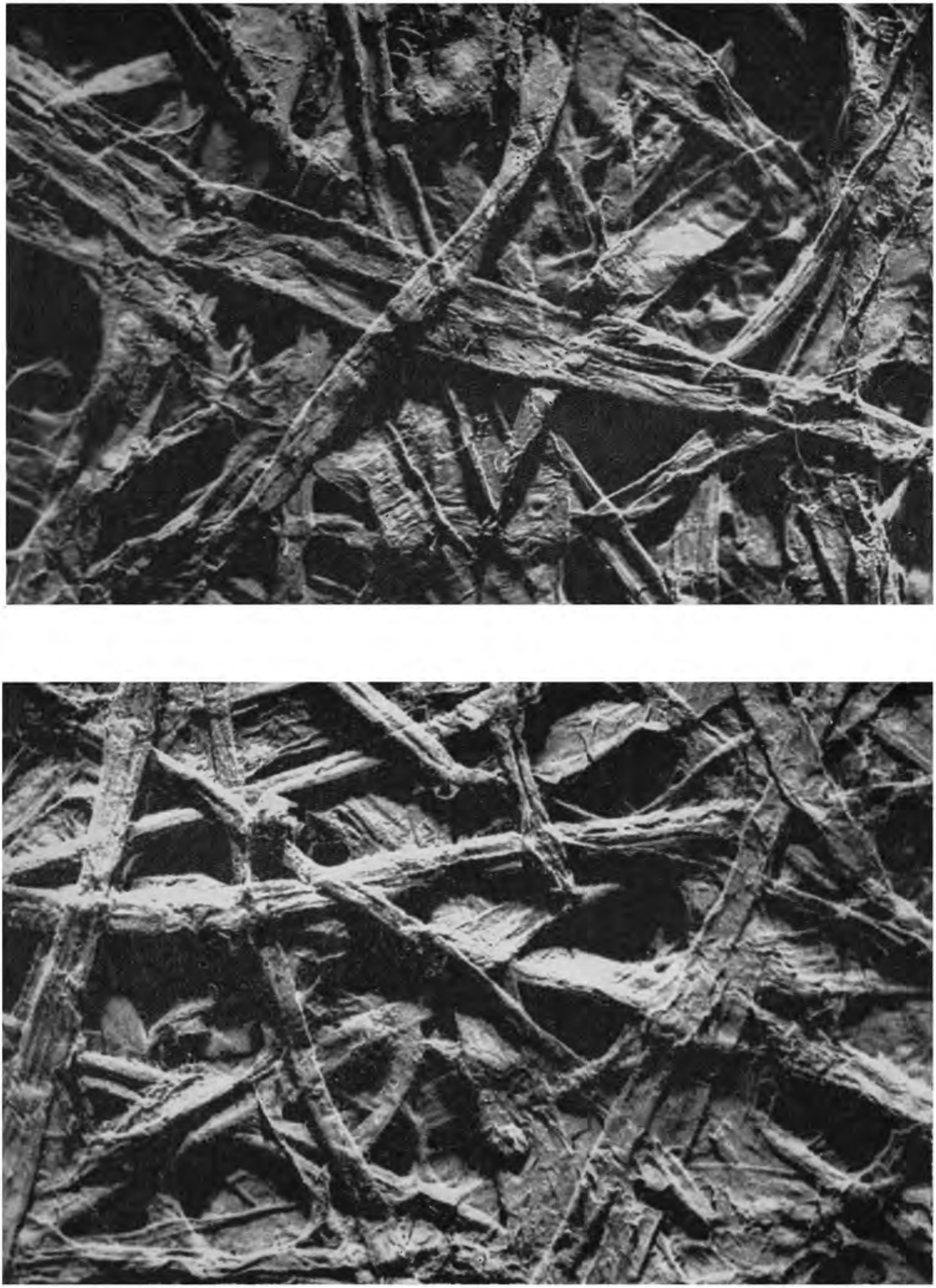


Fig. 19—Bleached spruce sulphite handsheets (*above*) beaten 10 min; (*below*) beaten 20 min (× 210)

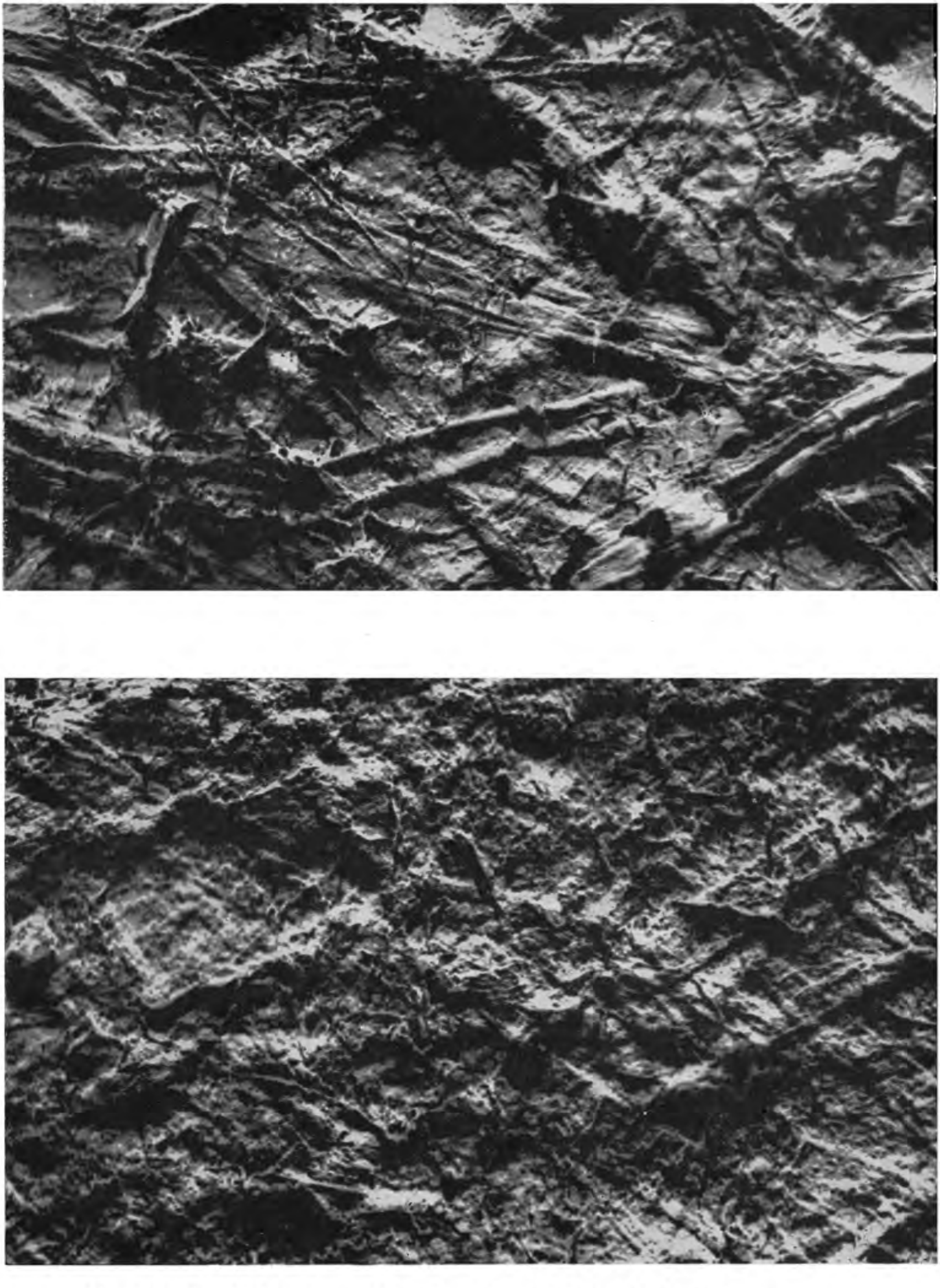


Fig. 20—Bleached spruce sulphite handsheets (*above*) beaten 45 min; (*below*) beaten 90 min (× 210)

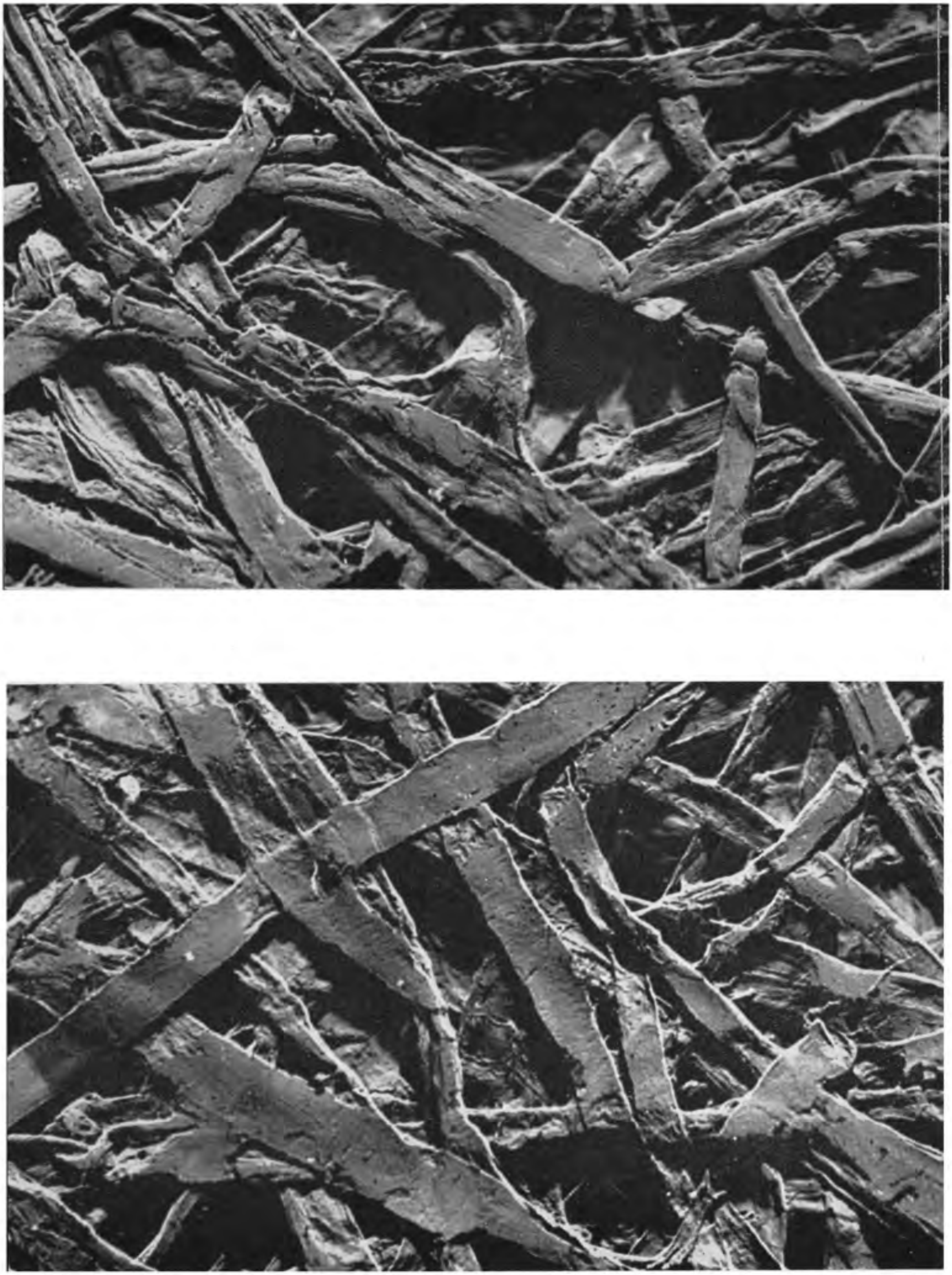


Fig. 21—Glazed handsheets (*above*) unbeaten; (*below*) beaten 5 min (× 210)

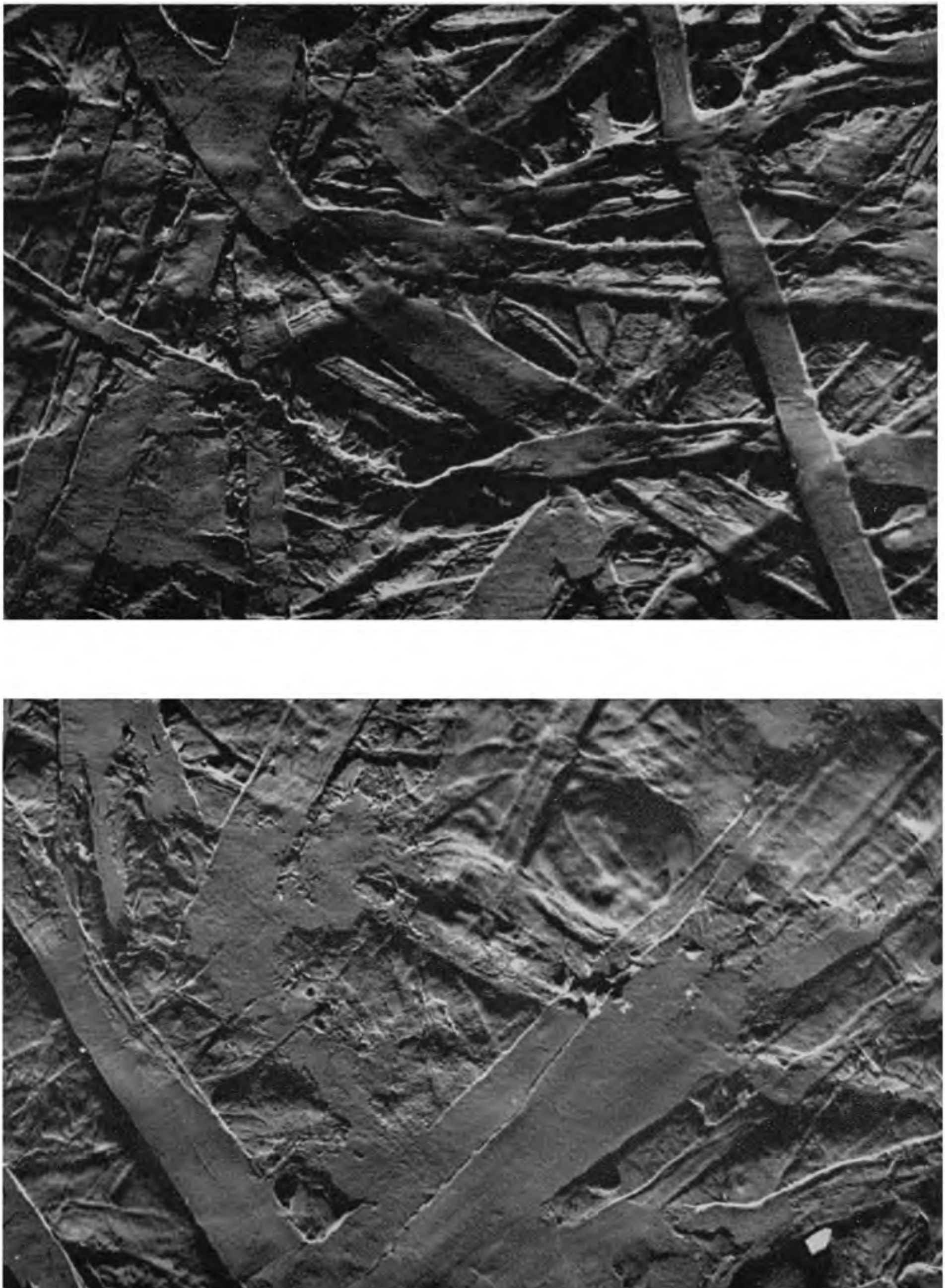
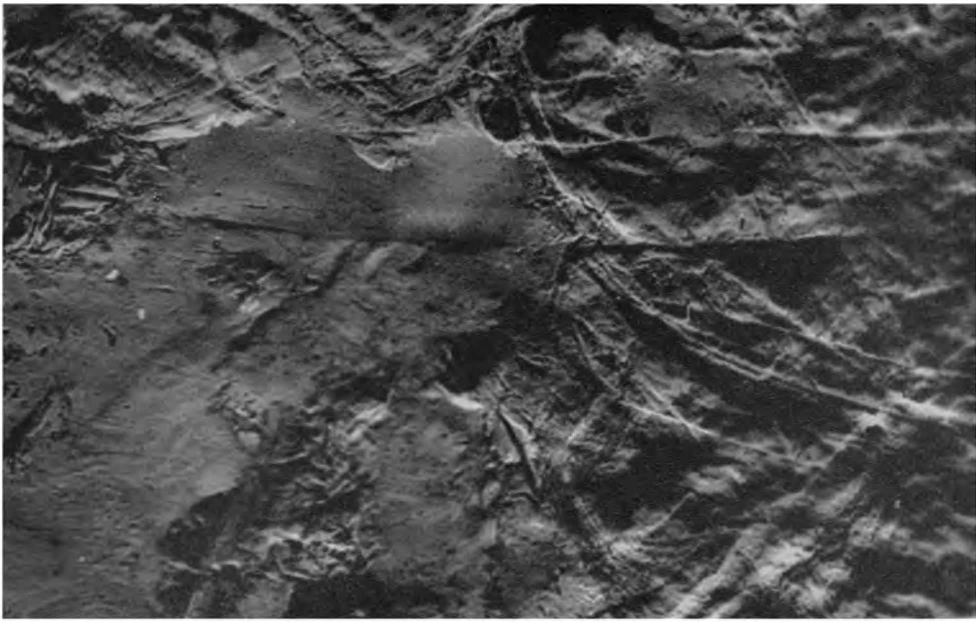


Fig. 22—Glazed handsheets (*above*) beaten 10 min; (*below*) beaten 20 min (× 210)



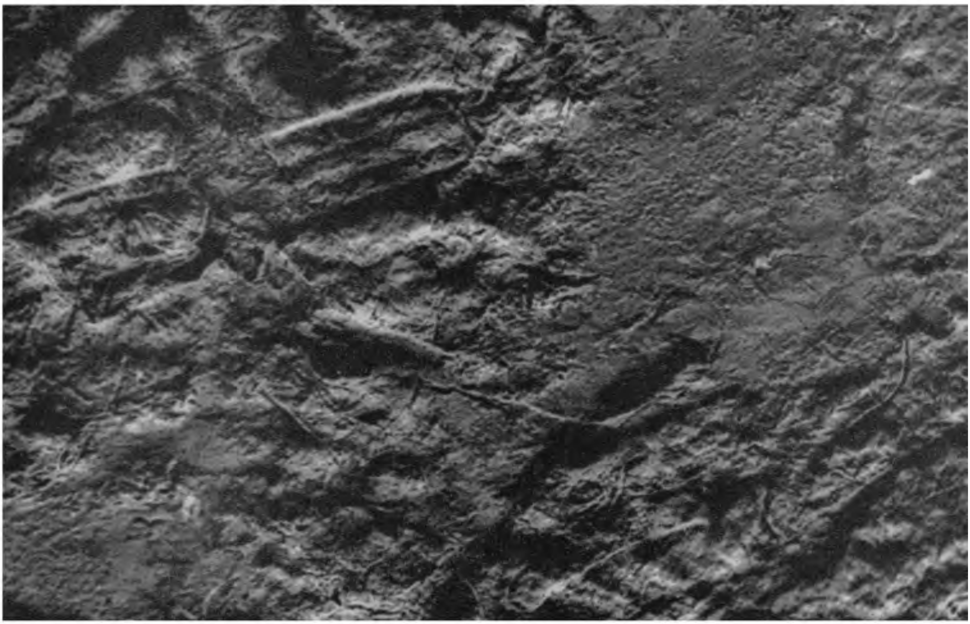


Fig. 23—Glazed handsheets (*above*) beaten 45 min; (*below*) beaten 90 min (× 210)

Effect of the surface of mechanical printing paper on gravure printing

Fig. 24 (*above*)—Half-tone dot on the paper of Fig. 26
(*below*)—Half-tone dot on the paper of Fig. 25
Fig. 25—Unsatisfactory surface
Fig. 26—Satisfactory surface

The 'closed' surface of Fig. 26 gives good reproduction of the half-tone dot pattern. In marked contrast, the concavities and openings of Fig. 25 give rise to imperfect reproduction. On the macroscopic scale, this is manifested as an undesirable white speckle.

The two sheets differ appreciably in the extent to which the surface is 'closed'.

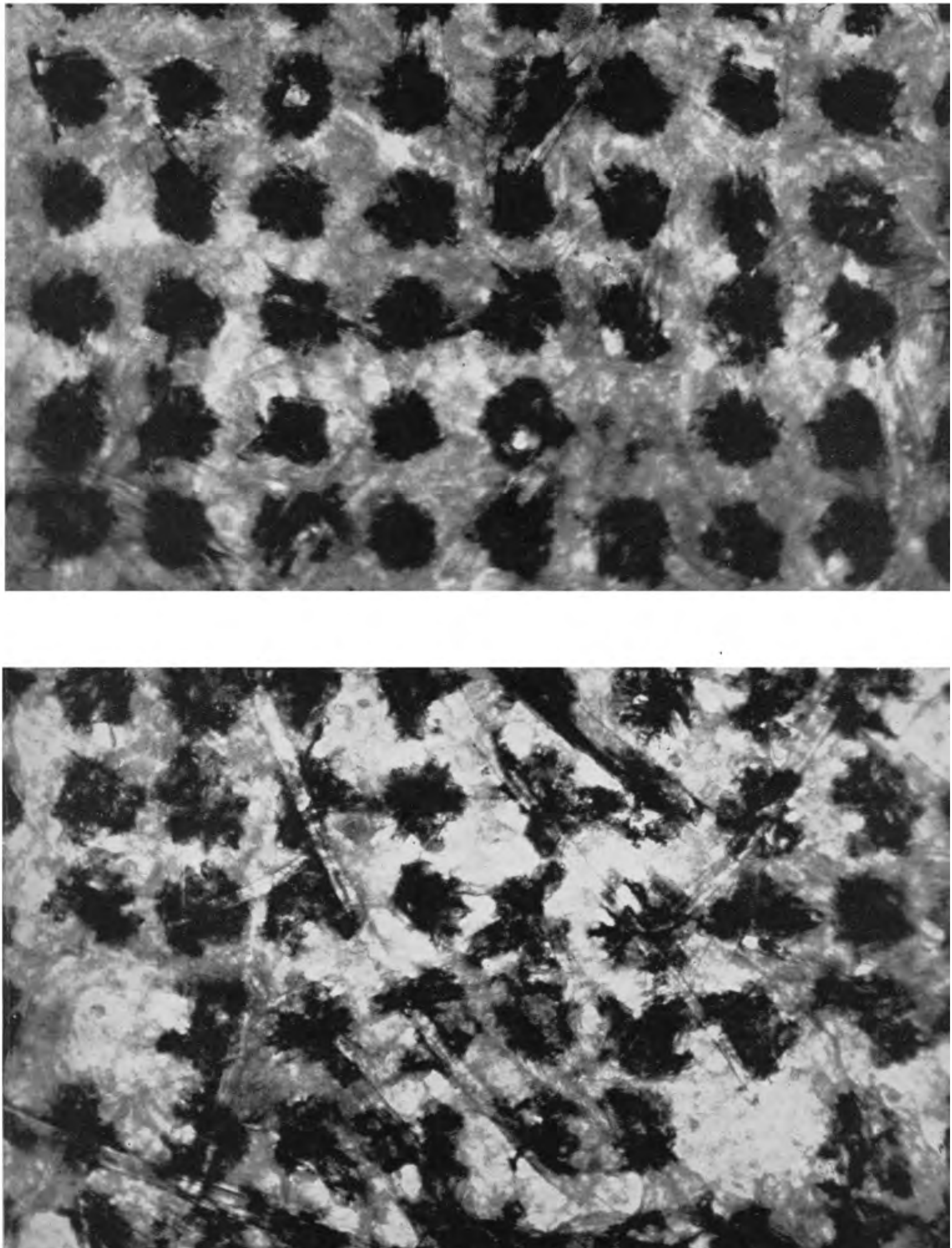


Fig. 24—Half-tone dot pattern on two mechanical printing papers (× 90)

Fig. 25—Unsatisfactory mechanical printing (× 275)

Fig. 26—Satisfactory mechanical printing (× 275)

Fig. 27—Effect of watermarking on £1 Bank of England note—The prominent watermark is seen as a depression of the surface running from centre left to the lower right corner (× 275)

Effect of watermarking on £1 Bank of England note

Fig. 27

The prominent watermark is seen as a depression of the surface running from centre left to the lower right corner.

Coated papers

Fig. 28 and 29 (above) show three machine-coated papers of different grades. The form of the fibres can be seen showing through the surface in Fig. 28, but the use of different coating mixes has produced a markedly different surface appearance. Although the paper of Fig. 29 (*above*) has a heavier coating and the fibres are obscured, the excessive granularity in the coating has given an inferior surface.

Fig. 29 (below) shows an art paper with pinholes and, on the lower left, scratches.

Other papers

Fig. 30–34 show the surfaces of an imitation art esparto paper, drawing, kraft and blotting papers.

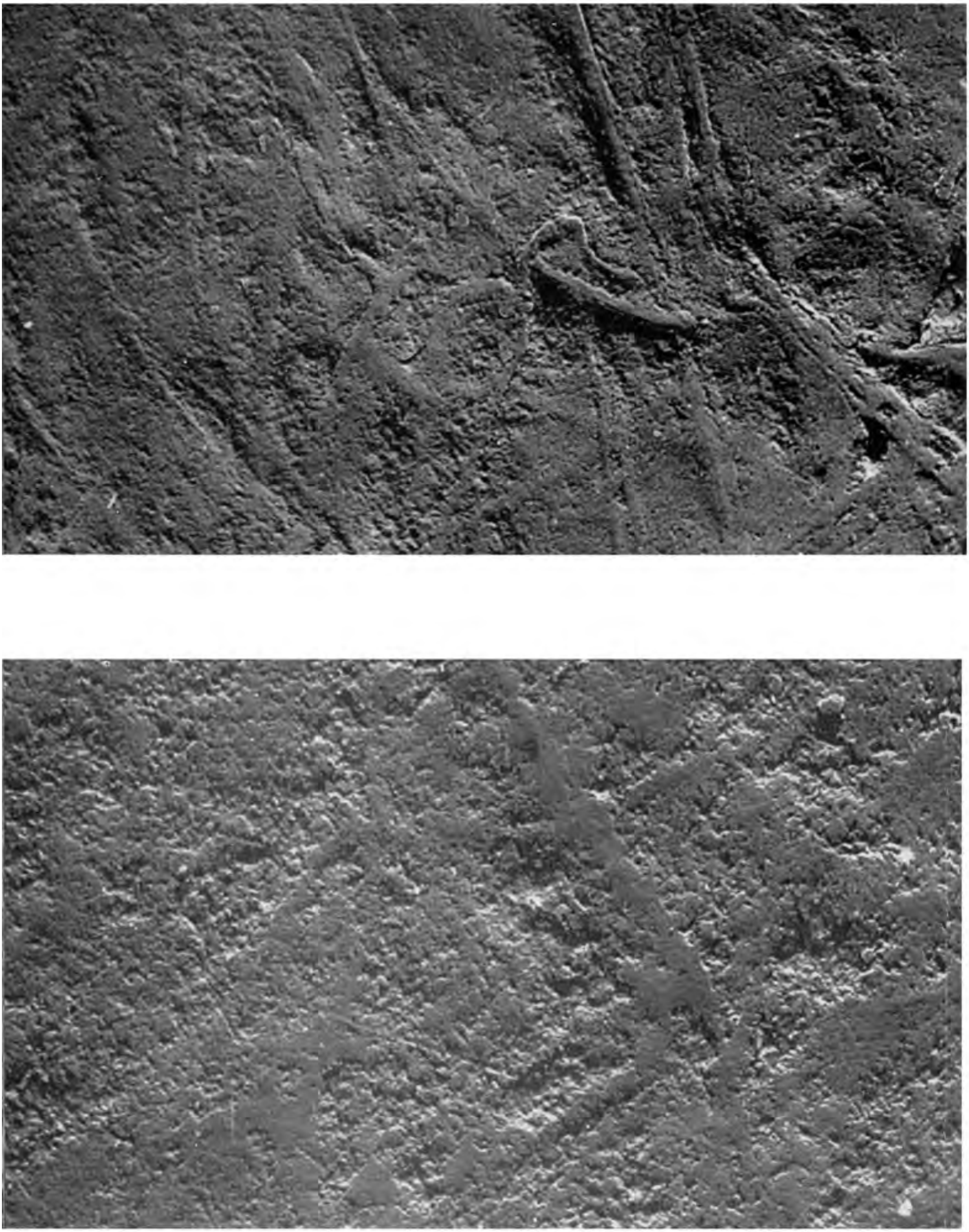


Fig. 28—Machine-coated papers (× 210)

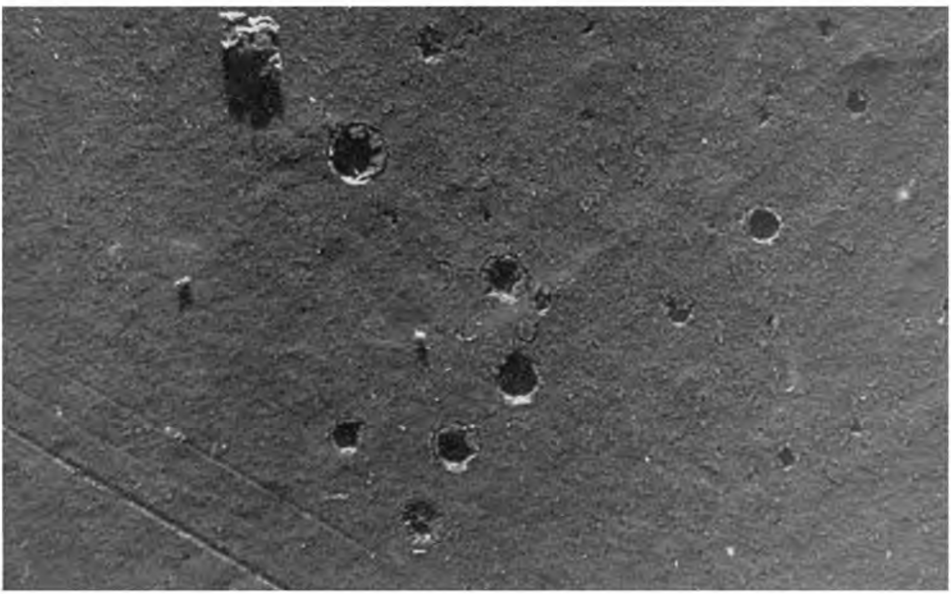


Fig. 29—(*above*) machine-coated paper; (*below*) art paper (× 210)

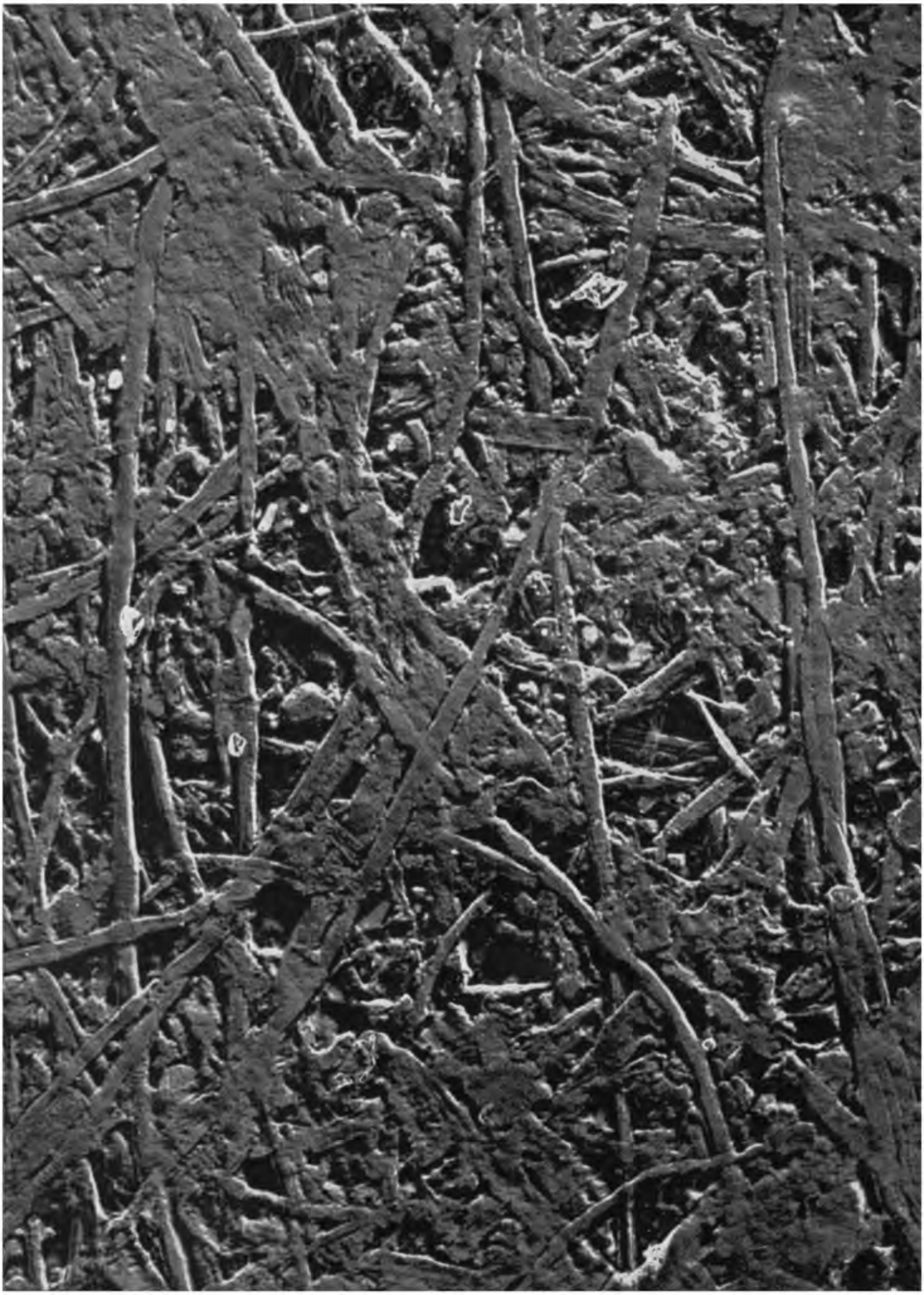


Fig. 30—Imitation art paper—the esparto furnish, the heavy clay loading and the effect of supercalendering are apparent (× 275)

Fig. 31—Drawing paper—a hand-made sheet with 100 per cent rag furnish [The comparative roughness of the surface is indicated by the long shadows] ($\times$ 110)

Fig. 32—Kraft paper—a clear impression of the preferred orientation of fibres in the machine-direction (across the micrograph) is given at this low power (× 20)

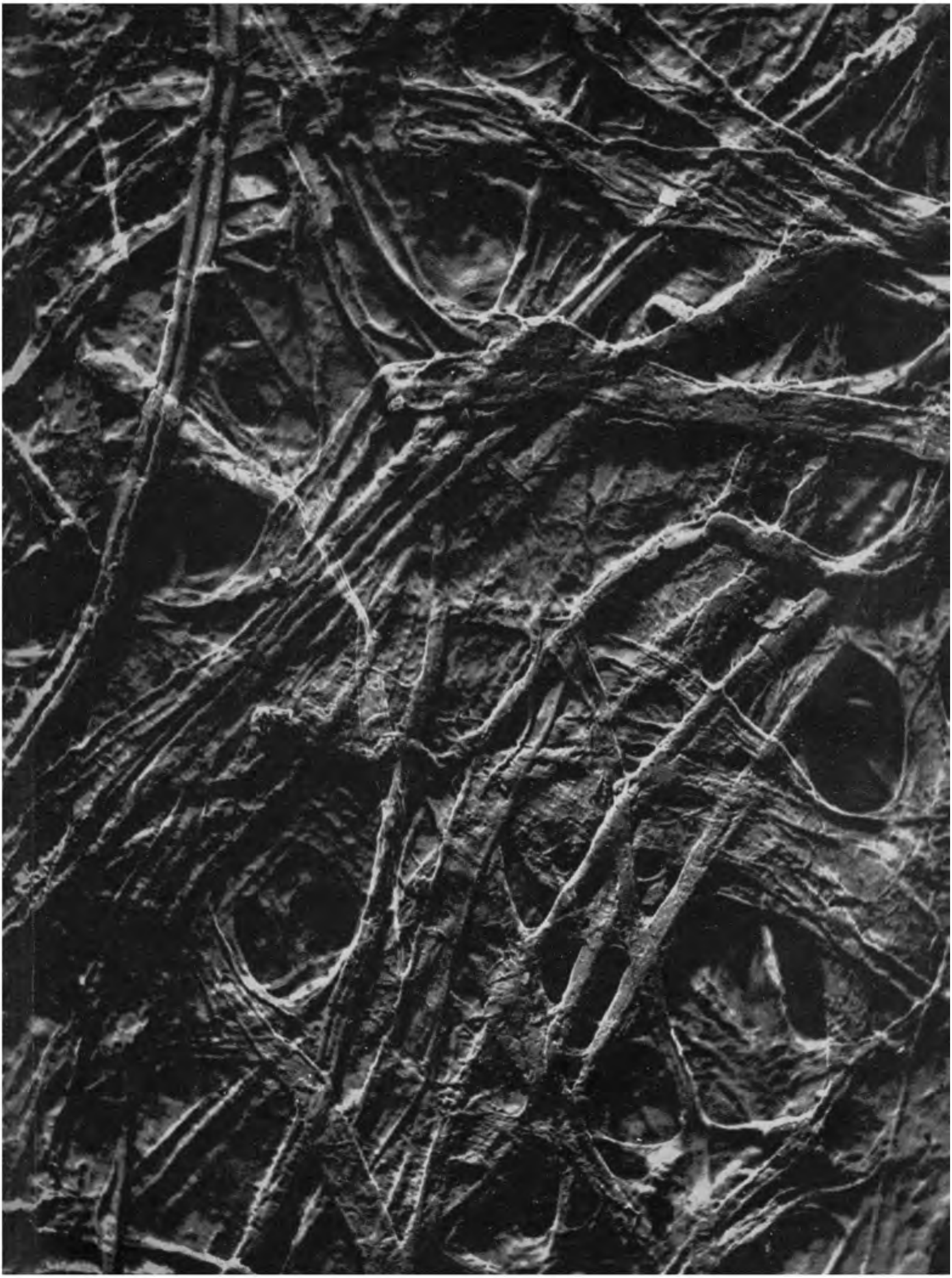


Fig. 33—Kraft paper (× 190)

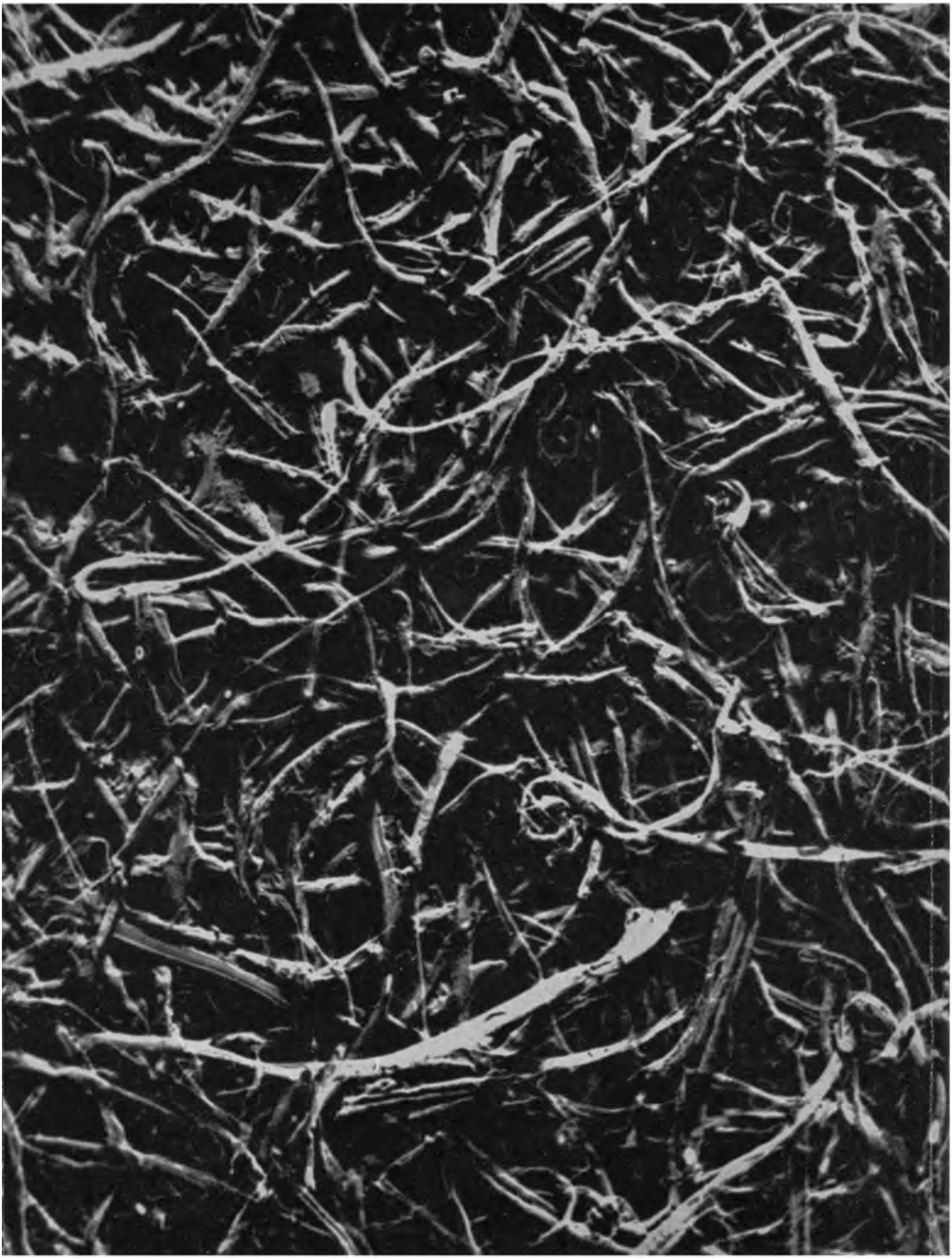


Fig. 34—Blotting paper—the loose absorbent structure is strikingly revealed ($\times$ 110)

Acknowledgement

We are indebted to our colleague, Mr. W. S. Horsey, who prepared many of the replicas.

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DISCUSSION

MR. G. F. UNDERHAY: It was a joy to hear Emerton start off his paper by telling us he is taking an area 1 mm^2 as representative of the paper and saying that any 1 mm^2 is the same as any other for this purpose. Thus, the uniformity problem that we heard about a little earlier on is almost solved by him straight off!

There is some uncertainty in the discussion this morning and perhaps there will be an opportunity in one of the later papers to raise the subject of uniformity and distribution again. Meanwhile, has Corte any information about the relationship of the length of the fibres to the work that he was doing?

MR. H. W. EMERTON: In case there is any misapprehension, may I say that my comments on the representativeness of 1 mm^2 referred to the phenomena to which we drew particular attention.

MR. D. ATTWOOD: There are many excellent photographs in this paper and the wire side surface photograph of newsprint (Fig. 4) is interesting in that there is obviously a cavity of about 0·008 in. across. It is not apparent from the photograph how this hole was formed, whether by a random process or by the indentation of a wire knuckle.

We have found that it is very difficult in studying surface photographs at this magnification to distinguish between wire mark and random variations. Random variations can be reduced by averaging and we have produced a photographic technique to do this.*

Of two illustrations shown, the first is a typical surface photograph of newsprint about $\frac{1}{5}$ in. across produced by oblique illumination (Fig. 8*a*). Some indication of wire mark is seen relative to the machine-direction. When the randomness is reduced by the averaging technique, an extremely clear picture of the wire mark is obtained (Fig. 8*b*). It should be stressed that the second illustration was produced directly from the surface photograph: it is not a true photograph of a particular piece of paper, but a photographic average.

*This technique is described in *Paper Tech.*, 1961, **2** (5), T 191–T 198 in a paper by J. R. Parker and D. Attwood and the illustrations referred to appear in the article by the figure numbers quoted.

The effect of the impression of the twill wire can be clearly seen, particularly the indentation of the warp knuckles forming the diagonal pattern.

This technique is applicable also to beta-ray transmission photographs. A further figure (Fig. 1) shows a typical beta-ray photograph, the light areas corresponding to low substance. When the technique is applied to the beta-ray negative, the randomness is reduced and shows a very regular pattern of

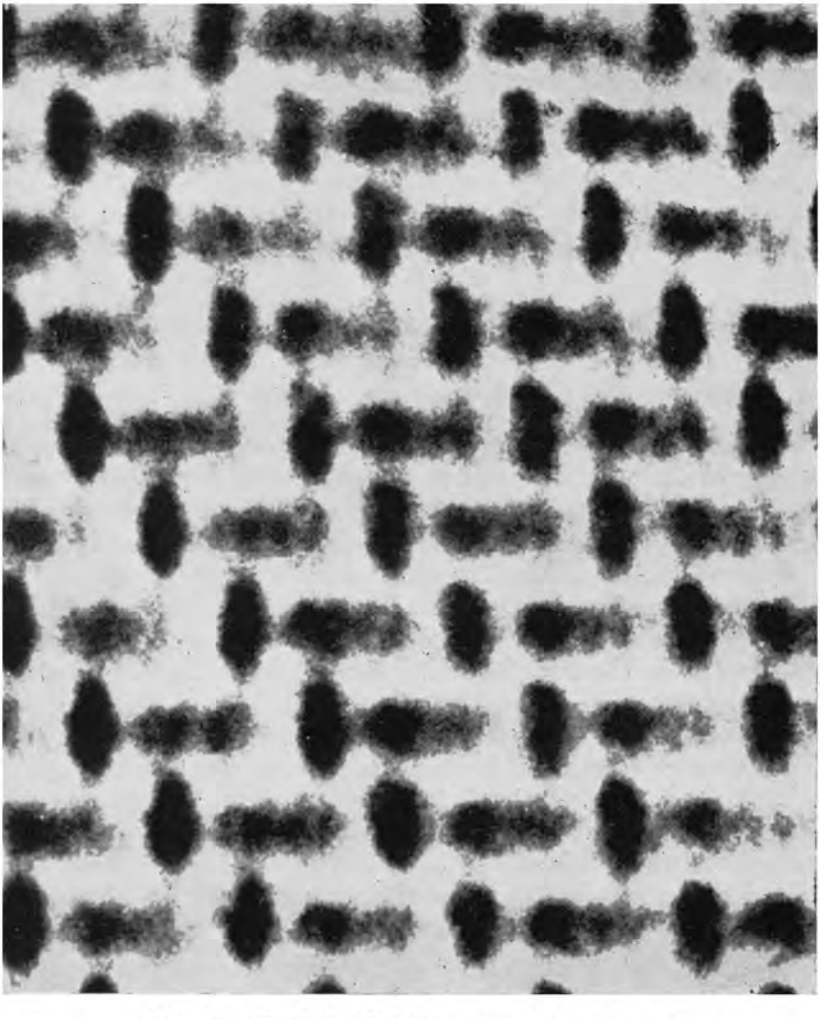

Fig. D1—Multiple print of beta-ray print negative basis weight variation corresponding to the wire pattern (Fig. 6*b*). The regular twill pattern then shows up—one up, two down—and exceptional agreement even in the small scale can be seen. For instance, in the light areas corresponding to the weft knuckles, these are seen to be lighter at the left side and, in fact, an examination of a twill wire shows that the weft knuckle does stick up more at this point (Fig. D1).

A DELEGATE: Would Mr. Emerton comment on the kind of microscope he used?

MR. EMERTON: This is not a particularly special microscope. The specimen had been prepared by making a replica in clear plastic material.* One ends up with a substantially plain specimen of metal with a tone variation sandwiched between clear plastic. There is no confusion of the image.

DR. J. GRANT: Is there any special significance that the fibres from the early stages of beating show an increase in transparency in the case of the unglazed sheet, but not in the glazed sheet? Is this fortuitous?

MR. D. PAGE: There were no fibres in the pictures shown: all you saw were pictures of metal.

MR. EMERTON: There is no question of transparency: the fibres were not there. The replica technique used reveals only the surface form.

DR. J. A. VAN DEN AKKER: It is known that the gloss of paper is irreversibly diminished by exposure of the sheet to high humidity—an effect that might be related to changes in the configuration of the fibres dried under restraint. Have you used your technique to observe the effect of high humidities on the surface of fibres that have been dried in contact with a plate?

MR. EMERTON: We have not done this. It is clearly a valuable thing to do.

PROF. J. D'A. CLARK: A much greater area of fibres in contact with the polished plate after only 5 min beating does not necessarily denote greater fibre flexibility gained in that short beating time. It was probably due rather to the development of fibrils, which drew the structure closer together and hence caused greater pressure on the plate. An excess of tension so developed with longer beating was finally large enough to cause the sheet to part from the plate after the compacting effect of this tension had passed its maximum.

Svensk Papperstidn.*, 1959, **62 (9), 318–332

MR. T. H. FAREBROTHER: I should like to show one or two slides that relate to the supercalendering effect Mr. Emerton has already illustrated.

The first three slides are photomicrographs of the topside surface of a rotogravure magazine paper taken by oblique top illumination. They show an identical area of the paper in three conditions, the first 'off-dryer' (Fig. D2*a*), the second after laboratory supercalendering (Fig. D3*a*) and the third after 40 min soaking in water and redrying (Fig. D4*a*). The increased smoothness and glossiness of surface produced by the supercalendering is very marked, but more interesting is the degree to which the surface returns to the 'off-dryer' condition after the soaking and redrying. The only noticeable difference from the original condition is a slight reduction in the surface contours.

The reversible nature of supercalendering

Mechanical printing (top side) in three states

All six micrographs record one identical field

The machine-direction of the specimen is aligned parallel to the side of the page

Surface configuration (Fig. D2*a*, D3*a* and D4*a*) was recorded by top illumination in the machine-direction and at 20° to the paper surface

Look-through (Fig. D2*b*, D3*b* and D4*b*) was recorded by transmitted illumination

Magnification $\times 15$

The other three pictures (Fig. D2*b*–D4*b*) show the same three conditions of the paper, but by transmitted light. The supercalendering is seen to suppress most of the visible detail of the look-through such as the rather spotty appearance and the dark fibres and some new features appear, notably the bright translucent fibres. By soaking and redrying, the original appearance is again restored in great detail, although with some loss of contrast.

The main interest in these experiments is the finding that the visible effects of supercalendering may be reversed almost completely by soaking and redrying, though it should be mentioned that some measured physical properties such as bulk and smoothness showed quite appreciable residual effects from the supercalendering.

MR. P. E. WRIST: In Buchanan's micrographs of strained paper, was the shadowing done before straining or after straining?

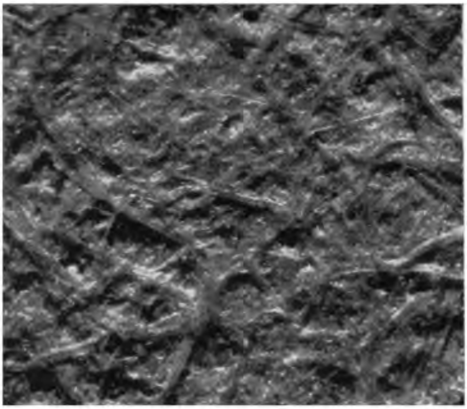

Fig. D2a—Surface detail in the off-dryer condition

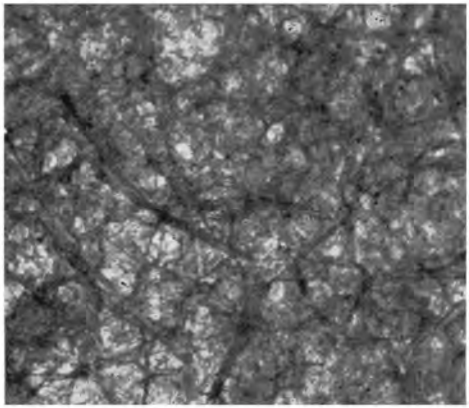

Fig. D2b—Look-through in the off-dryer condition

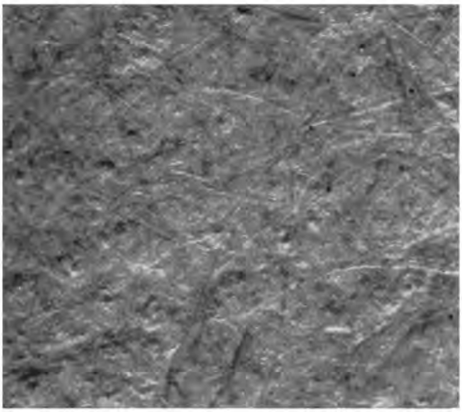

Fig. D3a—Surface detail after moderate laboratory supercalendering

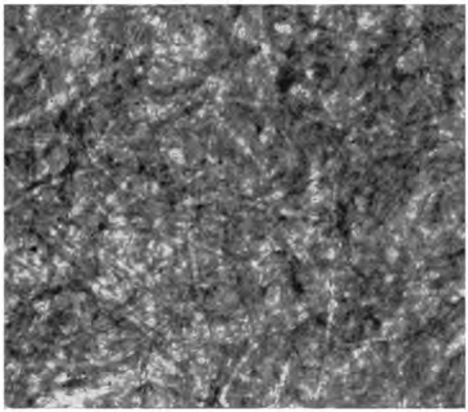

Fig. D3b—Look-through after moderate laboratory supercalendering

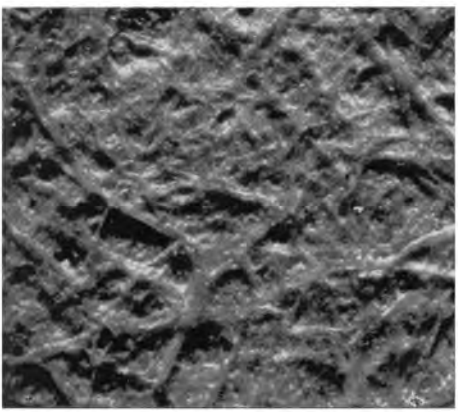

Fig. D4a—Surface detail after soaking and redrying

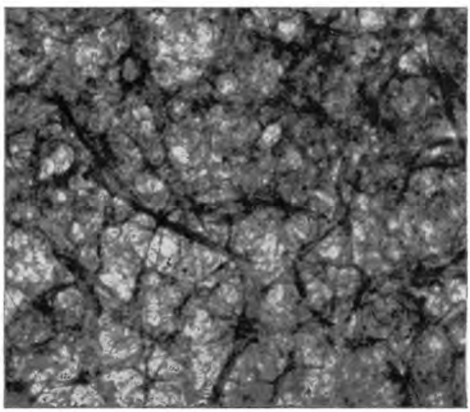

Fig. D4b—Look-through after soaking and redrying

MR. J. D. BUCHANAN: It was done after straining. The specimens were not completely ruptured. We applied the arresting mechanism on the Instron tester, which prevented the full separation of the specimen, though the maximum load had been exceeded.

A DELEGATE: How would you estimate the length of the fibrils forming the bond?

MR. BUCHANAN: In Fig. 14 (p. 106), they are 1–2 microns long.

THE CHAIRMAN: Is it right to say they form the bond or part of it? One has only observed them after the event.

MR. BUCHANAN: Agreed. In the central section of the debonded area in question, the surface is not wrinkled and was probably in close contact with the debonded fibre. Here, the fibrils must have been flattened, but towards the edges of the bond they were free.

MR. J. A. S. NEWMAN: The micrographs show fibrils between fibres at bonded points. More fibrils appear on the wetter beaten fibres. Could these fibrils be formed by the action of the bonds being strained—that is, the fibrils are more easily torn from the surface of beaten fibres, because of the internal damage done to the fibres by beating?

DR. W. GALLAY: It seems to me that we have been presented with strong evidence that failure of the union between fibres very frequently takes place, not in the bond, but rather in the intrafibre structure away from the bond. This is not surprising, since, from analogies with other systems, as I pointed out some years ago, one would expect the intrafibre bond to be stronger than faulted regions with the fibres. Whether we obtain lamellae or fibrils of different lengths or diameter hanging on after two adjacent fibres have parted at the crossover region could merely reflect the state of the structure adjacent to the bonds.

DR. VAN DEN AKKER: In the case of the fibre pulled from the web, could it have been directly involved in the rupture or was it remote from the fracture?

MR. BUCHANAN: It extended across the fracture and could be traced right over the broken zone, with its end still bonded to the other side. It is a very long fibre.

DR. VAN DEN AKKER: Did you see this in any regions removed from the fracture?

MR. BUCHANAN: This was an unusual event. We purposely chose it, because it gave a very good range of types of debonding. Close to the fracture in this sheet, many debonded areas similar to this could be found, but none of them extending back as far as this particular one did. It was only because this was one of the last fibres to be deposited in the sheet mould that the debonding extended back so far.

PROF. A. H. NISSAN: If the length of these little struts and columns between the two structural elements were, say, of the order of 0·1 micron, would you not expect that area to be transparent, even though it is so thoroughly interconnected by strings as to constitute almost, but not quite complete 'bonding'?

MR. BUCHANAN: I think Page might answer that better than I could.

MR. PAGE: I am reserving my comments about the whole question of the fine structure of bonding until this afternoon.

MR. C. A. CHESTER: I would like to refer back to the effects of calendering, whether machine calendering or supercalendering, to the damage done to the surface bonds during that process. There is an increase in the smoothness, but undoubtedly damage to the surface bond. Has Emerton come across this effect? Were his specimens completely untouched after calendering, because I believe that, although the increase in smoothness may be beneficial for some printing processes, the damage done to the surface bonding may be very detrimental and may not show up in smoothness tests. The damaged bonds may be flat under static conditions, but they may cause fibre lifting during printing, when a vertical stress is applied.

MR. EMERTON: The answer is that this particular method does not give sufficiently high results to resolve the detail of bonded areas, so our pictures shed no light on bonding. Clearly Buchanan's technique would throw light on it.

MR. UNDERHAY: Farebrother showed in his slides the reversion of the calendered state. Has he gone further, calendered again and reproduced the same effect—and is that sort of thing capable of being produced indefinitely?

MR. FAREBROTHER: No, we have not examined this matter further.

MR. J. MARDON: Has Chester detailed experimental evidence upon the reduction of surface bonds by calendering? I would suggest one side of the sheet stays about the same and the other side is improved.

MR. CHESTER: Yes, we have a certain amount of evidence and I am afraid it is rather conflicting—to be quite honest, it is still a complete puzzle. We found there is an effect that probably varies with the type of machine on which the paper is made. Some evidence shows that, on one particular Fourdrinier machine, the damage during calendering is apparent on both sides of the sheet; on another Fourdrinier machine that is apparently very similar, the damage occurs much more on the top side of the sheet. I think that the effect is pronounced enough to be worth study. One certain fact is that the number of fibres anchored at one end only to the surface of the paper increases progressively with increasing smoothness obtained by calendering. Of course, this applies only to uncoated paper.

PROF. G. JAYME: I am going to show this afternoon that calendering has a double effect. One is the pressing of microfibrils together to a fairly coherent mass; the other is that some very fine fibrils are at the same time torn out of the surface and lifted from it.

DR. S. W. KINGSNORTH: From our experience, we could expect the erratic changes in paper properties following supercalendering, observed by a previous speaker, to be associated with variability in moisture content in the sheet.

Referring to Emerton's interesting photograph of a fibre forming a spiral as it dried and straightening out again as it re-absorbed moisture, could he tell us the approximate moisture content at which the fibre resumed its straight form?

MR. EMERTON: It was impracticable to measure the humidity as the method of moisture gain was very crude here—sucking acid drops, then breathing over it! You will appreciate that we had little control over the pH value!

Written contributions

MR. F. M. CROOK: The photomicrographs are excellent and the technique most elegant. It has been our experience in microscopic examination of paper surfaces that they are very far from homogeneous and that the variations in surface texture within a single surface of one paper may be as great as the differences between either the back and wire side of a single sheet or those between the surfaces of two sheets that have been given different gradings for some surface property.

To what extent are the micrographs representative fields? How much personal choice was involved in selecting the areas photographed as being typical of the surface of the specimen?

MR. H. W. EMERTON: The fields were not selected by co-ordinates taken from tables of random numbers. Nevertheless, we believe that, so far as the phenomena described in our text and presentation are concerned, the fields are representative. Experienced microscopists are well aware of the dangers of generalising from the particular!