

Morphology and dielectric properties of fish scales

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Scanning electron microscopy of scales of the fish *Catla catla* show a surface architecture made up of three distinct regions. The scales have high dielectric constants and exhibit pyroelectricity and dielectric hysteresis.

A large variety of fishes display beautiful silvery sides. Fish scales generally consist of layers of collagen and organic and bony materials¹ (Figure 1). The nature of the reflectors in fish scales has been a subject of considerable interest for some time. The reflecting properties are associated with the presence of arrays of crystals of guanine and hypoxanthine, which act like tiny mirrors arranged in special stacks. In view of the presence of layered organic and inorganic matter in fish scales, we examined some features of the scales, especially their dielectric properties.

Fish scales of the cycloid type, obtained from *Catla catla* (family Cyprinidae) were washed with distilled water and dried at 300 K for 15 days. Scanning electron micrographs were taken using a Cambridge Stereoscan-150 scanning electron microscope. The scales were also examined under polarized light in a Leitz Wetzler Orthoplan-Pol polarizing microscope. Thermogravimetric analysis of the scales was carried out using an Ulvac Sinku-Riko thermal analyser-1500. Silver paste electrodes were employed on either side of the scale to

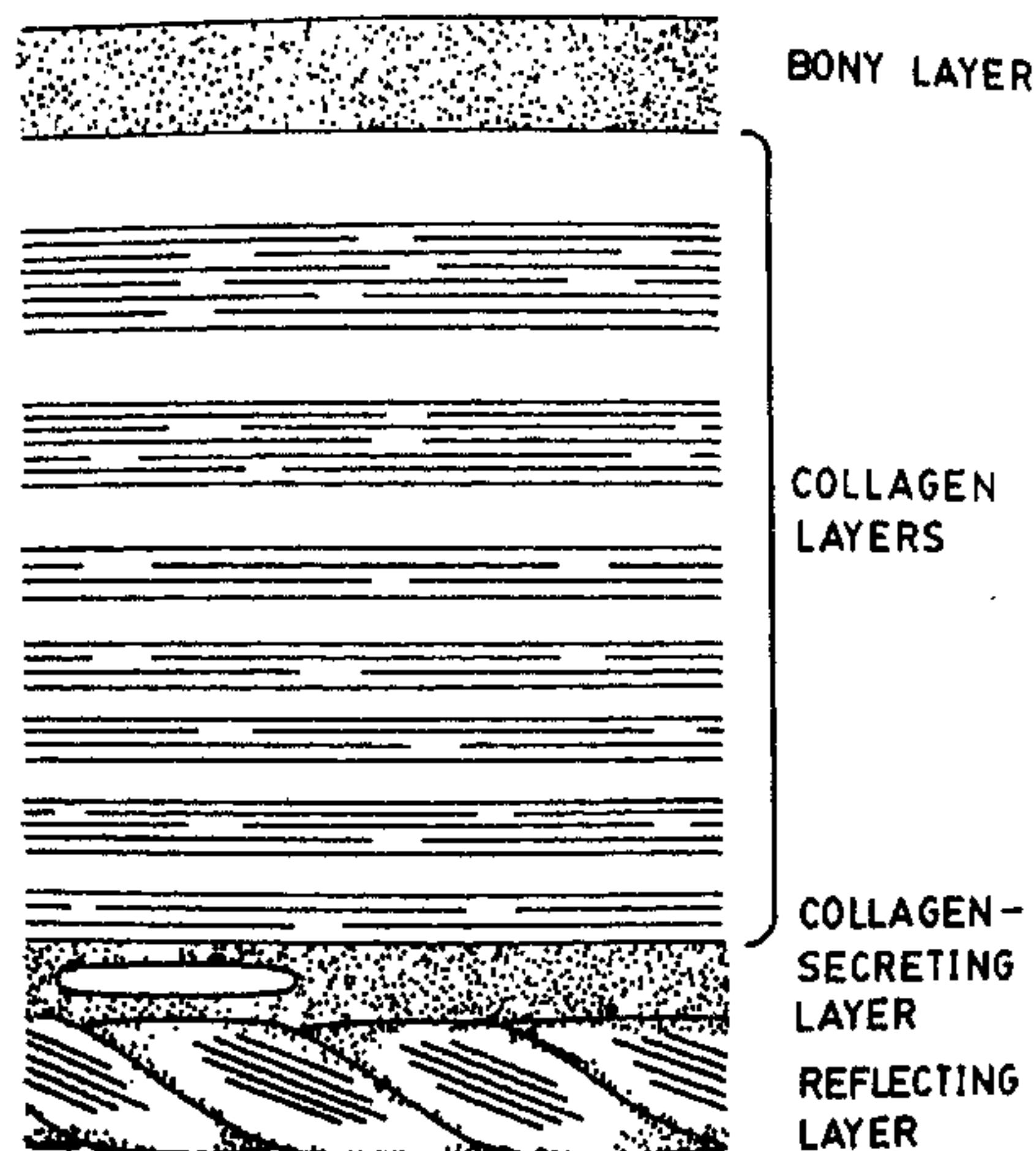


Figure 1. Schematic of fish scale in cross-section.

measure dielectric, pyroelectric and ferroelectric properties. The capacitance of the scale was measured as a function of frequency (1–100 kHz), with a signal strength of 0.5 V rms at 300 K, using a Hewlett-Packard multifrequency LCR meter, model 4274 A. The pyroelectric current was measured by employing a direct method due to Byer and Roundy. Ferroelectric hysteresis loop studies were carried out at 50 Hz using a Sawyer-Tower circuit.

X-ray powder diffraction patterns of dry scale showed that it is amorphous (Figure 2). On heating the scale, there was considerable weight loss due to the loss of water around 400 K, and again around 600 K due to the loss of guanine and other organic matter, as seen from the thermogravimetric curve (Figure 3). There is a further weight loss around 900 K, eventually giving rise to the inorganic residue consisting of hydroxyapatite, as confirmed by X-ray diffraction (Figure 2) and infrared

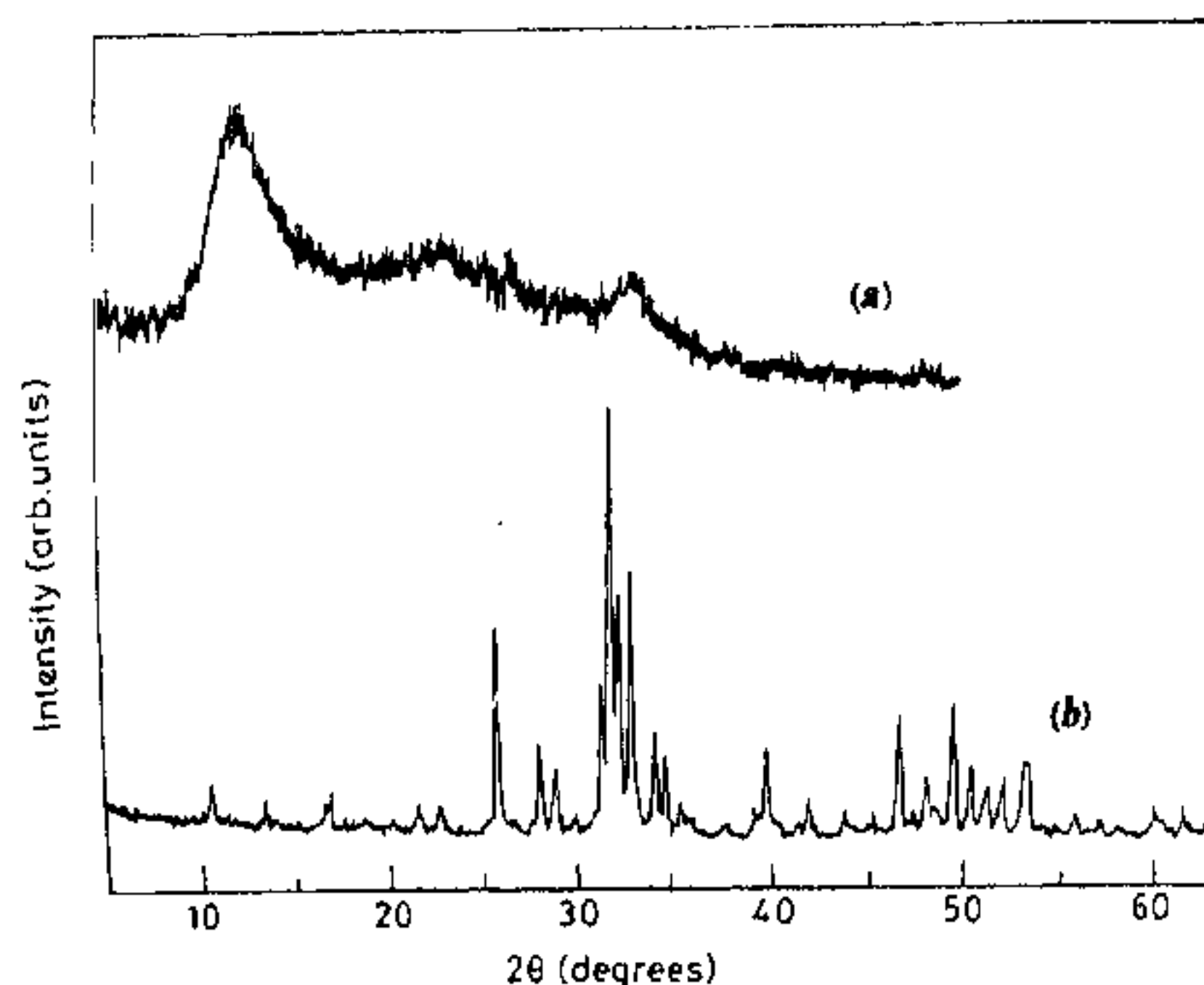


Figure 2. X-ray powder diffraction patterns of fish scale (a) dried at 300 K, (b) heated to 900 K.

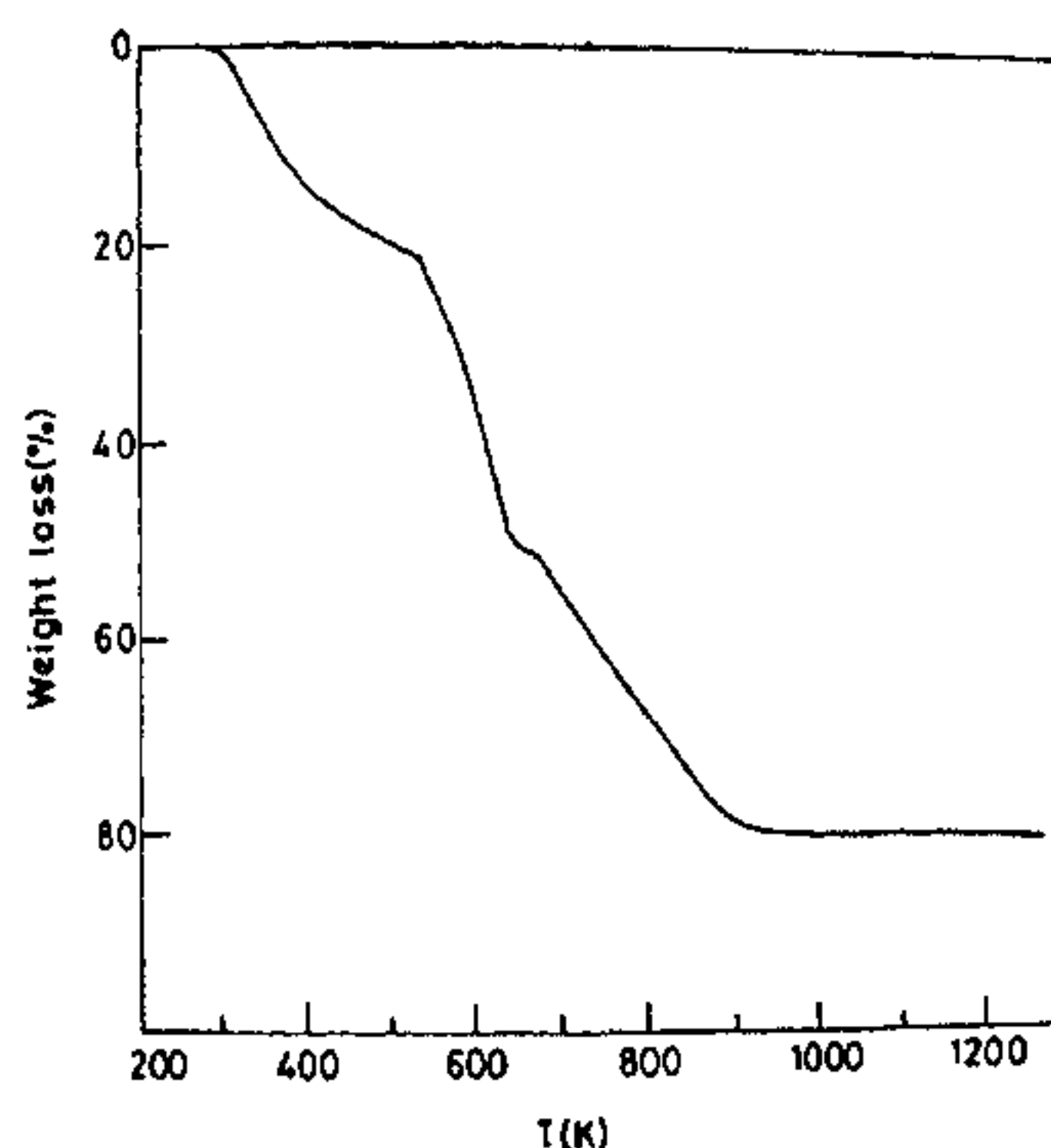


Figure 3. Thermogravimetric curve of scale dried at 300 K.

spectroscopy. Scanning electron micrographs of the scale showed the existence of three distinct regions (A, B and C in Figure 4a); region B is shown blown up in Figure 4b. Domain-like regions were also seen in region B (Figure 5) in a polarizing microscope with the polarizer and analyser crossed.

The dielectric constant and the loss tangent of the dried scale are plotted as functions of frequency (1-100 kHz) at 300 K in Figure 6. Both quantities decrease with increase in frequency. The dielectric constants at 1 kHz and 100 kHz are quite high, 49 and 23 respectively; the dielectric constant at 1 MHz is 19. What is interesting is that the scale is pyroelectric at 300 K. Quantification of the pyroelectric coefficient is, however, difficult owing to the occurrence of decomposition above 300 K. To our surprise, we found that the scale exhibits a well-defined dielectric hysteresis loop at 300 K (Figure 7) with a saturation polarization P_s of $4.1 \times 10^{-7} \text{ C cm}^{-2}$ and a coercive field of 6000 V cm^{-1} . The loop persists till 360 K. The hysteresis loop is

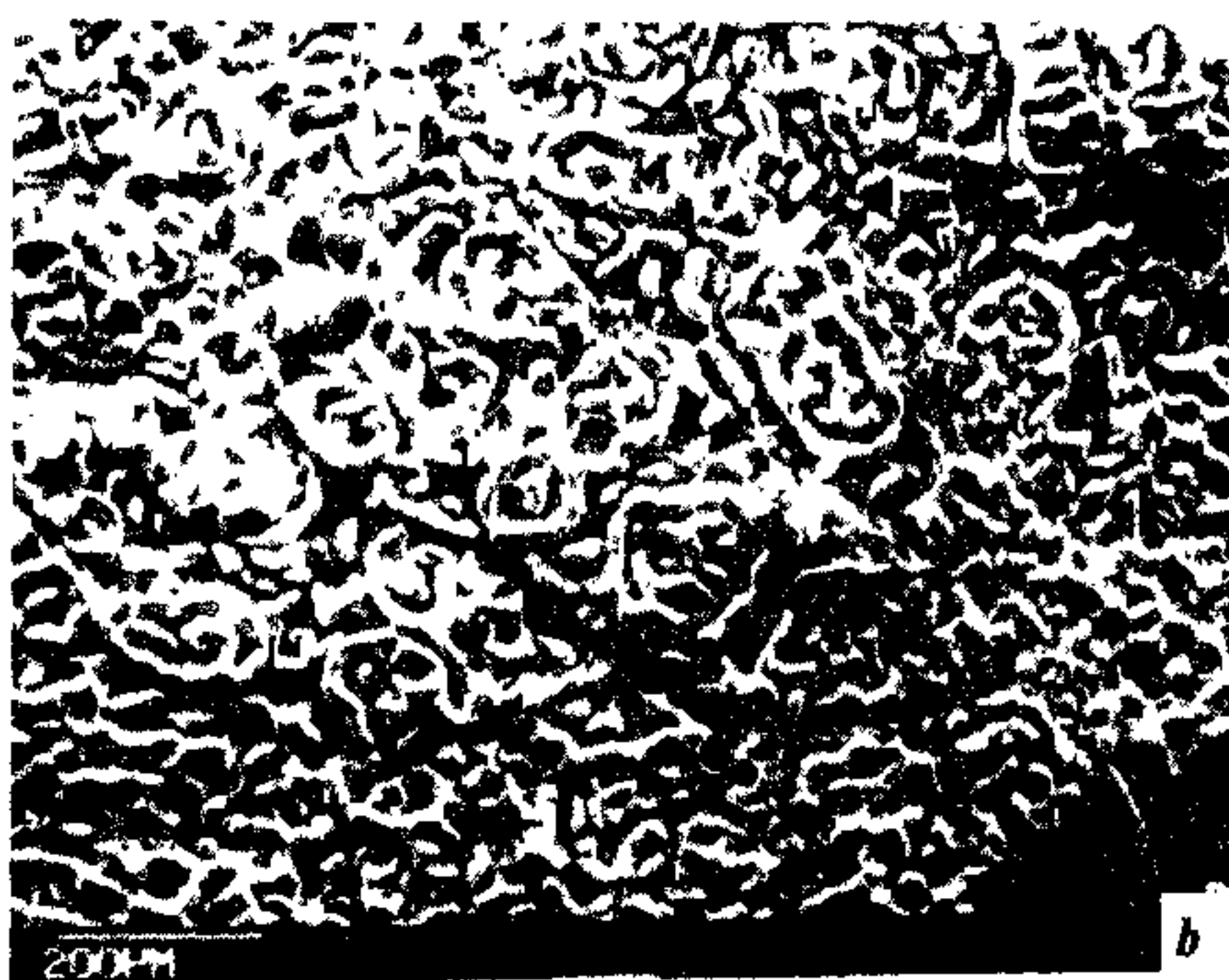
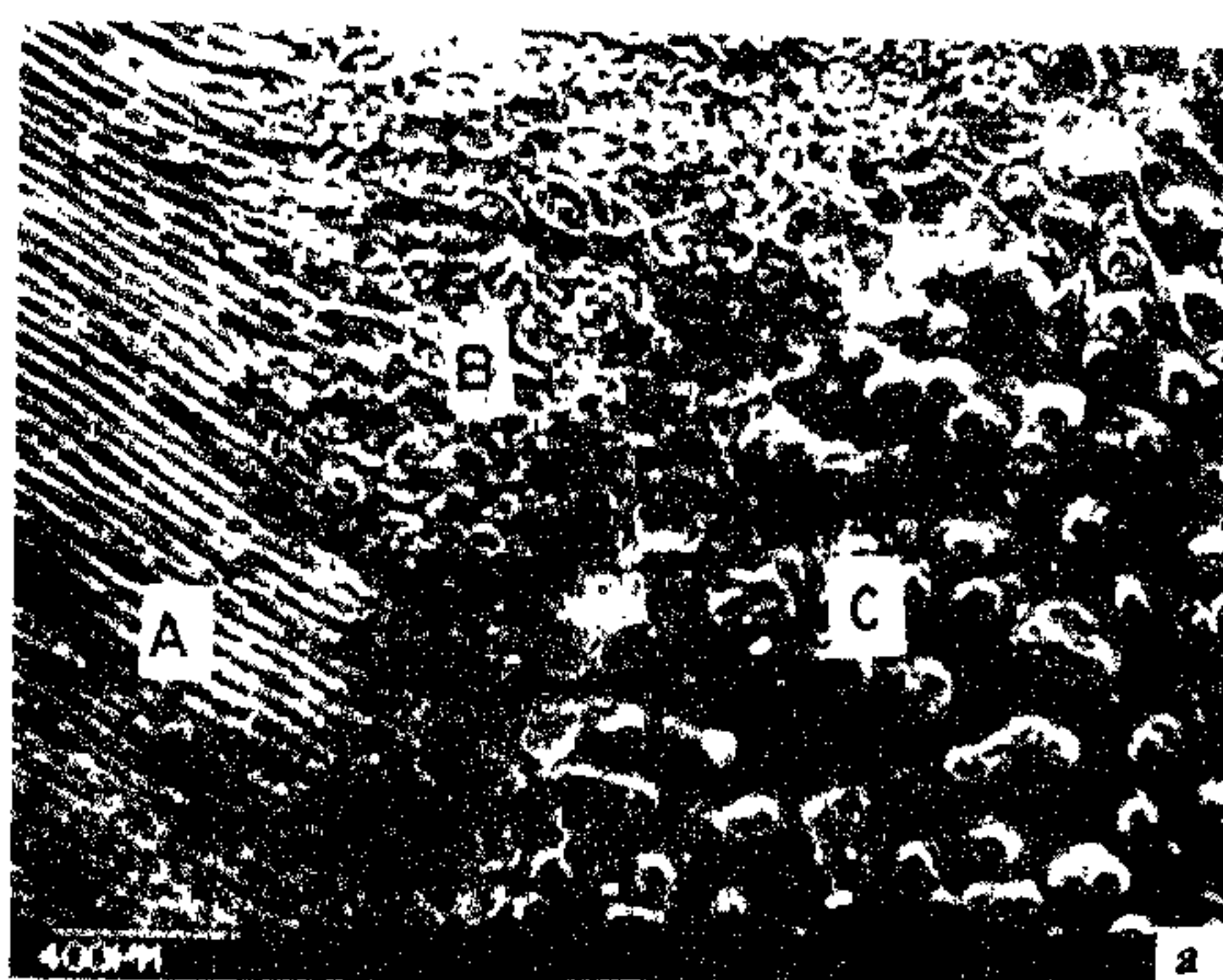


Figure 4. Scanning electron micrographs of (a) scale dried at 300 K, (b) the central region B.

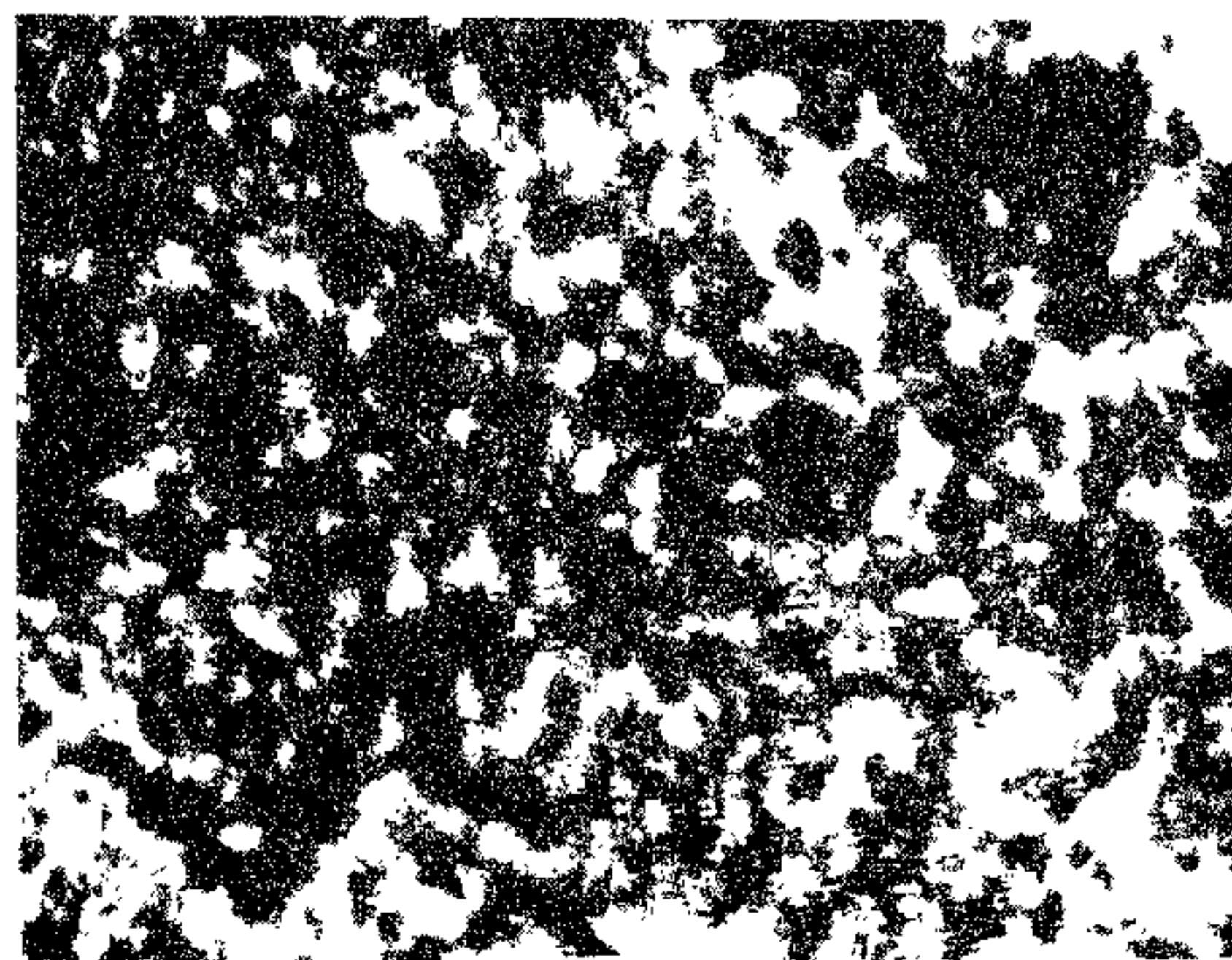


Figure 5. Region B of scale viewed under a polarizing microscope.

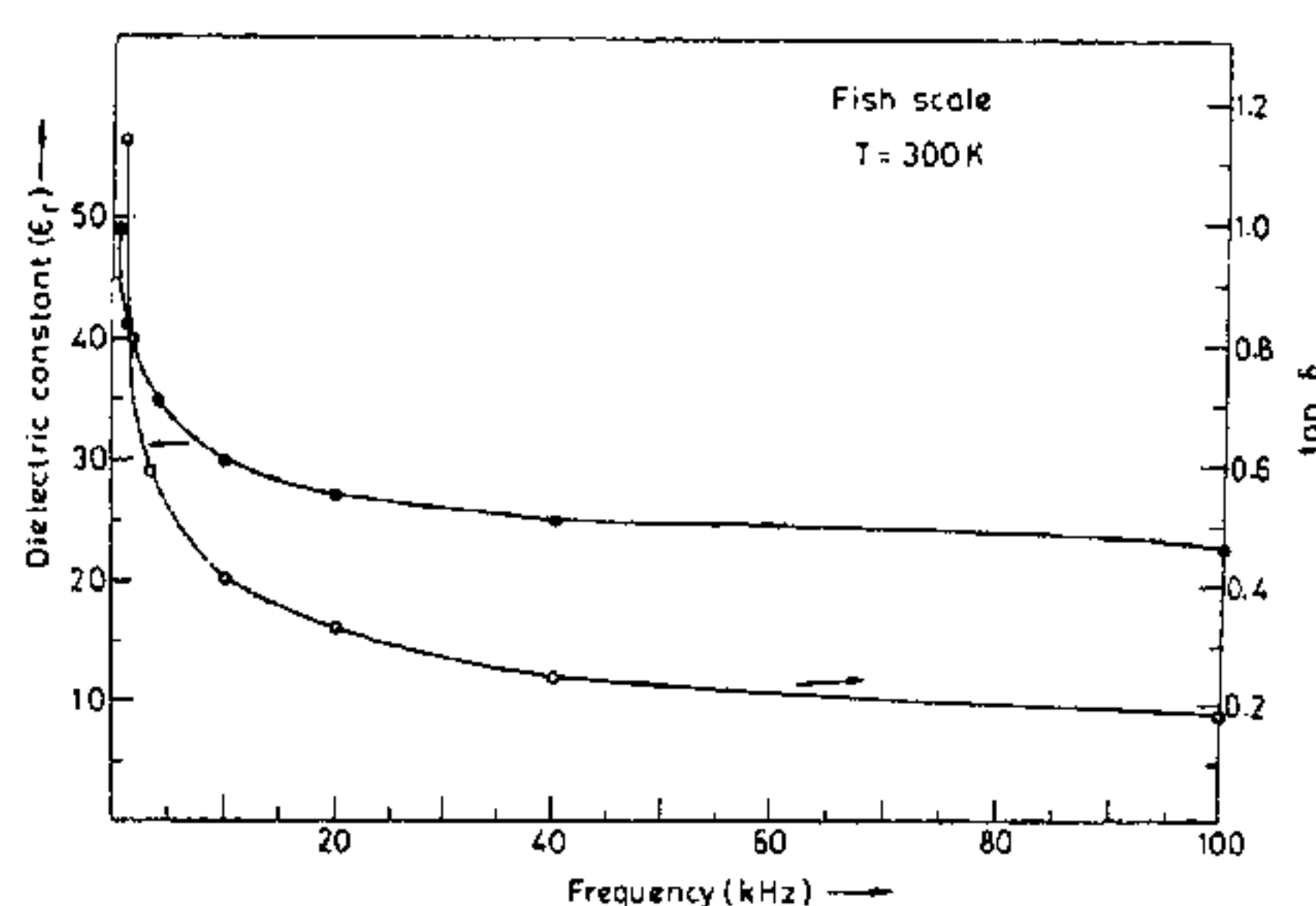


Figure 6. Frequency response of dielectric constant (●) and loss tangent (○) of scale at 300 K.

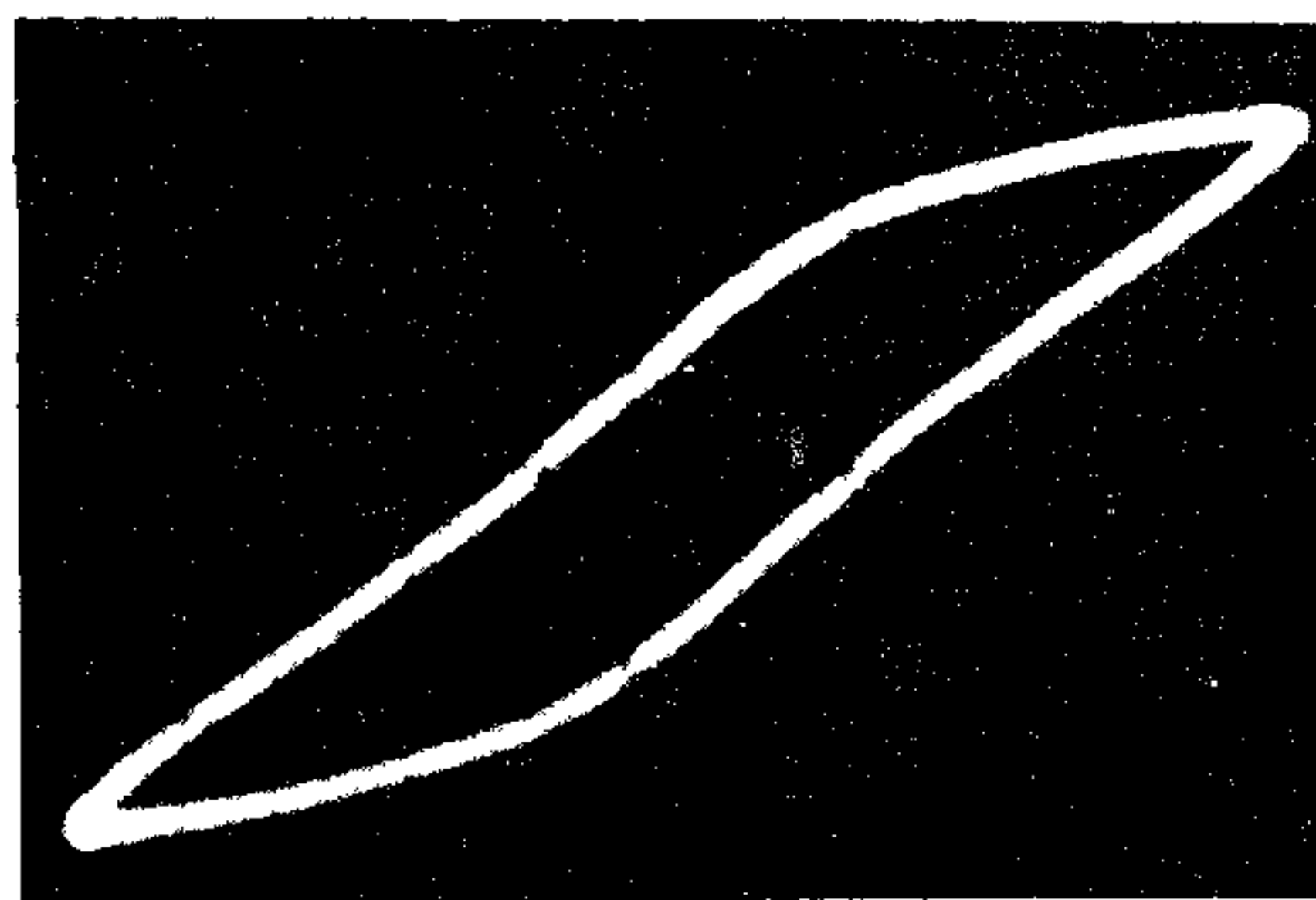


Figure 7. Dielectric hysteresis loop of the fish scale at 300 K.

reminiscent of ferroelectric materials. The disappearance of the loop around 360 K is likely to be associated with the loss of water, which is a major constituent of the scale (30–40%). Clearly, water plays a role in the polar structure of the scale. The dielectric hysteresis of the scale could have its origin in collagen, which is known

to be polar². Hair, biological tissues and such materials containing oriented collagen molecules are known to be piezoelectric as well as pyroelectric^{3,4}. The hysteresis loops found with fish scales could arise from the piezo-pyroelectric effects, since ferroelectric materials should necessarily be pyroelectric.

It is not clear whether the hysteresis loop exhibited by fish scales can be used to any advantage. However, the high dielectric constants of these scales at low frequencies (around 1 kHz) suggest that they could, in principle, be used for capacitor applications. Although the fish scale itself is not thermally stable, the hydroxy-apatite left after removal of organic matter could be useful as a linear-capacitor material.

1. Denton, E., *Sci. Am.*, 1971, 224, 65.
2. Fukada, E. and Yasuda, L., *Jpn. J. Appl. Phys.*, 1964, 3, 117.
3. Martin, A. J. P., *Proc. Phys. Soc. (London)*, 1941, 53, 186.
4. Shamos, M. H. and Lavine, L. S., *Nature*, 1967, 21, 213.

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Occurrence of vesicular-arbuscular mycorrhiza in *Casuarina equisetifolia* L.

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***Casuarina equisetifolia* is a fast growing and promising fuelwood tree. Vesicular-arbuscular mycorrhizal (VAM) fungi improve seedling growth by facilitating nutrient uptake. Two VAM fungi were found to colonize the roots of *C. equisetifolia*. These were identified as *Glomus fasciculatum* and *Scutellospora calospora*. Application of VAM fungi can be successfully used for plantation of this species especially in degraded soils.**

SELECTION and cultivation of fuelwood tree or shrub species suitable for waste, marginal or degraded lands are

important. Apart from the traditional fuelwood species, underutilized taxa are being investigated for growing in low fertility soils. *Casuarina* is gradually gaining popularity as a fast growing and promising fuelwood

tree particularly in coastal India. *Casuarina equisetifolia* L., introduced in the sixties of the last century, has been the most successful species of *Casuarina* because of its hardiness in degraded soils. Presence of N fixing symbiont *Frankia*, association of VAM fungi and their interaction with *Frankia*¹ has prompted scientists to investigate the species for wasteland utilization.

When available phosphorus levels in the soils are low, VAM stimulate significant increase in P uptake resulting in a dramatic increase in plant growth^{2,3}. It would facilitate fast growth and high biomass which are the desired traits in fuelwood plantations. Survey of the literature revealed that no systematic work has been undertaken on VAM association in *Casuarina* except for a report on occurrence of *Glomus mosseae* in *C. equisetifolia*¹.

Casuarina germplasm are being investigated under species × site trials for their potential as fuelwood trees for salt-affected sodic alkaline soils at Biomass Research Centre of National Botanical Research Institute, Lucknow. The present communication on the association of vesicular-arbuscular mycorrhizal (VAM) fungi with *Casuarina equisetifolia* is a part of the biomass studies on the role of VAM fungi in fuelwood tree establishment in alkaline soils.

Root samples along with surrounding soil were collected from one year old plants of *C. equisetifolia* growing in the research centre. Terminal feeder roots attached to lower order roots were collected, washed carefully and cleared with 10% KOH. The roots were then washed with 5N HCl, stained with trypan blue, mounted in lactophenol following the method described by Phillip and Hayman⁴ and examined under light microscope. The spores of VAM fungi were isolated from the soil surrounding the roots by wet sieving and decanting method of Gerdemann and Nicolson⁵. Identification of VAM fungi was made following the keys suggested by Trappe⁶ and Schenck and Perez⁷.

Two VAM fungi were found to colonize the roots of *C. equisetifolia* (Figure 1a). These fungi were identified as *Glomus fasciculatum* (Thax. sensu Gerd.) Gerd. and Trappe and *Scutellospora calospora* (Nicol. and Gerd.) Walker and Sand. Chlamydospores (Figure 1b) were subglobose to obovate or ellipsoidal or cylindrical, hyaline to light yellow to yellow, (41.2)-82.4-(123.6) µm, occulate opening in the subtending hyphae, one to two walled. The VAM fungus was identified as *Glomus fasciculatum*⁷. Chlamydospores were mostly globose, spherical, occasionally broader than long, hyaline to pale greenish yellow (144.2)-272.9-(401.7) µm, 3 to 4 walled, outer thick and smooth, attached to hyaline to yellow bulbous suspensor, 20.6-(41.0)-61.5 µm. Septa formed below the suspensor tip (Figure 1c). Germination shield often oval and present along the margin. The fungus was identified as *Scutellospora calospora*⁷.

The present study indicates the association of two