

planes perpendicular, and at various intermediate angles, to the original planes. Exactly the same results were obtained from these thin sections.

The primary purpose of a gypsum plate in optical mineralogy is not merely to increase the birefringence (the quarter-wave mica plate is more commonly used for that) but to indicate elongation. The apatite minerals are optically negative. Prismatic crystals are length-fast, tabular crystals are length-slow (5). The "blue rim" produced on the articulation surfaces of domestic animal bones when the section is placed so that the edge of the articulation surface is perpendicular to the slow ray of the gypsum plate suggests an alignment of tabular crystals oriented with the basal planes parallel to the surface of bone-to-bone contact. The strong enhancement of (002) reflections from the articulation surfaces corroborates the optical evidence.

We hypothesize that the alignment noted is a reaction to stress in the weight-bearing bones of domestic animals which, through poor nutrition or lack of exercise or both, possess insufficient bone matter when compared with the healthier wild animals. McConnell's figure 2 seems to support this hypothesis—the lack of large-scale orientation effects reflects the lack of stress in a fetal tooth. It might be worthwhile to compare the teeth of individuals of different cultural environments with our techniques, although since we have concentrated on the effects produced in the weight-bearing bones, and especially in the articulation surfaces of such bones, we do not know whether dental enamel would reflect similar stresses.

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The Thoreau-Reynolds Ridge, a Lost and Found Phenomenon

McCutchen's D-line (1), formed where relative motion exists between a surface film and the underlying liquid, was described as early as 1854 by Henry David Thoreau (2). The D-line is an abrupt change in surface curvature near the top of a small ridge raised by viscous shear stress at the edge of the film; it can be observed when a layer of oil spreads across a water surface, or where liquid flows under the edge of a raft of surface contaminants. It was discussed in the scientific literature first by Osborne Reynolds in 1881 (3), and later by other authors (4–8). So many times was it rediscovered that in 1936 *Nature* published a brief historical summary and commented, "When the rising generation of physicists see the Reynolds ridge, they should recognize it at once as an old friend" (9).

This expectation has been disappointed. The textbook (5) cited in the summary in *Nature* is now almost unobtainable, and modern texts do not mention the subject. Consequently the rediscoveries have continued (1, 10), the most recent one by McCutchen, who unwittingly ignored the earlier work.

It should not be ignored. Thoreau (2) understood, broadly, what happened at a D-line and had an inkling of its physical mechanism. His descriptions of the phenomenon as it occurs in nature remain some of the best available.

Reynolds' discussion (3) is longer, an unhurried essay that has a gentle Victorian charm. His efforts to understand the mechanism were only partly successful, because he needed a hydrodynamic concept that had not yet been thought of. Reynolds could not understand how the fluid at the surface could flow along at undiminished speed until, abruptly at the D-line, it almost stopped. He thought that viscosity ought to make the stopping occur more gradually. Missing was the idea of the boundary layer: that the direct effects of viscosity are confined to a thin layer of liquid immediately under the contaminant film, and extend only a minute distance upstream of the film's leading edge. Without the idea of the boundary layer Reynolds was forced into obscure speculations about surface tension to explain the narrowness of the D-line.

At least two of the later authors (5, 7) knew that the surface film dragged with it only a thin layer of the

liquid beneath. But they seem to have learned about the boundary layer only from their experiments: they neither mentioned it by name, nor used the results of boundary layer theory. Like Reynolds, they needed to know that the viscous shear stress on the film tends to infinity at its leading edge. It is this stress peak that accounts for the sharpness of the D-line.

Perhaps the explanation is now complete enough so that the phenomenon will be remembered, and the earlier accounts will receive the attention they deserve as science and as good reading.

A different but closely related phenomenon has the appearance of an ascending Reynolds ridge (4, 6, 11): a contaminant film spreading over water will climb a vertical wetted surface, such as the wall of the container. The ascending edge produces what looks like a ripple, but interferometric measurements have shown this to be a round-cornered step rather than a true ridge. Except in contrived cases the water layer is very thin, both it and the film move very slowly, and the viscous forces are dominant everywhere. Reynolds' objection to an abrupt change in the speed of the surface now holds, and there is no D-line.

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