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Wetting Front Instability in Porous Media (Alfred Wegener Medal Lecture)

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Normal porous media, like soils, exhibit liquid flow instabilities that are very different from what is observed in a Hele-Shaw cell. Unfortunately, the latter is often used as the basis of our understanding in the case of soils. In Hele-Shaw cells, the instability is less developed and shows as "fingers" merging into a hand. On the other hand, in a soil, the "fingers" are replaced by "columns" that remain distinct. With fingers, surface tension enters Laplace's equation through the radius of the saturated tip, whereas with columns, it is not the diameter of the column but the much smaller pore radii which are relevant. At present, the phenomenon is fairly well understood: With fingers, the liquid viscosity is often important and hysteresis is not; with columns the opposite usually holds. In nature, columns tend to remain at the same position in the soil. This persistence is responsible for rapid water and solute transport with potential pollution of ground water. As the column enters the soil, its tip consists of a narrow wetting zone followed by drainage. Both the drainage profile and the lateral diffusion of water are well described by Richards' equation. Lateral diffusion eventually stops because of hysteresis, maintaining columns of constant width which do not merge into a hand. The wet zone cannot be described by Richards' equation as the wetting requires understanding of the flow at the pore scale, i.e., solving the Navier-Stokes equations, leading to a Hoffman-Tanner type of flow behavior.