

Porosity

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Porosity is a measure of the void spaces in a material, and is measured as a fraction, between 0–1, or as a percentage between 0–100%. The term *porosity* is used in multiple fields including manufacturing, earth sciences and construction.

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Porosity in earth sciences and construction

Used in geology, hydrogeology, soil science, and building science, the porosity of a porous medium (such as rock or sediment) describes the fraction of void space in the material, where the void may contain, for example, air or water. It is defined by the ratio:

$$\phi = \frac{V_V}{V_T}$$

where V_V is the volume of void-space (such as fluids) and V_T is the total or bulk volume of material, including the solid and void components. Both the mathematical symbols ϕ and n are used to denote porosity.

Porosity is a fraction between 0 and 1, typically ranging from less than 0.01 for solid granite to more than 0.5 for peat and clay, although it may also be represented in percent terms by multiplying the fraction by 100.

The porosity of a rock, or sedimentary layer, is an important consideration when attempting to evaluate the potential volume of water or hydrocarbons

it may contain. Sedimentary porosities are a complex function of many factors, including but not limited to: rate of burial, depth of burial, the nature of the connate fluids, the nature of overlying sediments (which may impede fluid expulsion). One commonly used relationship between porosity and depth is given by the Athy (1930) equation:

$$\phi(z) = \phi_0 e^{-kz}$$

where ϕ_0 is the surface porosity, k is the compaction coefficient (m^{-1}) and z is depth (m).

A value for porosity can alternatively be calculated from the bulk density ρ_{bulk} and particle density ρ_{particle} :

$$\phi = 1 - \frac{\rho_{\text{bulk}}}{\rho_{\text{particle}}}$$

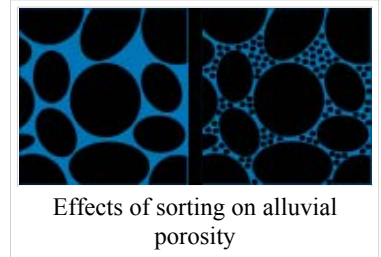
Normal particle density is assumed to be approximately 2.65 g/cm³, although a better estimation can be obtained by examining the lithology of the particles.

Porosity and hydraulic conductivity

Porosity is indirectly related to hydraulic conductivity; for two similar sandy aquifers, the one with a higher porosity will typically have a higher hydraulic conductivity (more open area for the flow of water), but there are many complications to this relationship. Clays, which typically have very low hydraulic conductivity also have very high porosities (due to the structured nature of clay minerals), which means clays can hold a large volume of water per volume of bulk material, but they do not release water very quickly.

Sorting and porosity

Well sorted



(grains of approximately all one size) materials have higher porosity than similarly sized poorly sorted materials (where smaller particles fill the gaps between larger particles). The graphic illustrates how some smaller grains can effectively fill the pores (where all water flow takes place), drastically reducing porosity and hydraulic conductivity, while only being a small fraction of the total volume of the material. For tables of common porosity values for earth materials, see the "further reading" section in the Hydrogeology article.

Porosity of rocks

Consolidated rocks (e.g. sandstone, shale, granite or limestone) potentially have more complex "dual" porosities, as compared with alluvial sediment. The rock itself may have a certain (low) porosity, and the fractures (cracks and joints), or dissolution features may create a second (higher) porosity. The interaction of these porosities is complex and often makes simple models highly inaccurate.

Porosity of soil

Porosity of surface soil typically decreases as particle size increases. This is due to soil aggregate formation in finer textured surface soils when subject to soil biological processes. Aggregation involves particulate adhesion and higher resistance to compaction. Typical bulk density of sandy soil is between 1.5 and 1.7 g/cm³. This calculates to a porosity between 0.43 and 0.36. Typical bulk density of clay soil is between 1.1 and 1.3 g/cm³. This calculates to a porosity between 0.58 and 0.51. This seems counterintuitive because clay soils are termed *heavy*, implying *lower* porosity. Heavy apparently refers to a gravitational moisture content effect in combination with terminology that harkens back to the relative force required to pull a tillage implement through the clayey soil at field moisture content as compared to sand.

Porosity of subsurface soil is lower than in surface soil due to compaction by gravity. Porosity of 0.20 is considered normal for unsorted gravel size material at depths below the biomantle. Porosity in finer material below the aggregating influence of pedogenesis can be expected to approximate this value.

Soil porosity is complex. Traditional models regard porosity as continuous. This fails to account for anomalous features and produces only approximate results. Furthermore it cannot help model the influence of environmental factors which affect pore geometry. A number of more complex models have been proposed, including fractals, bubble theory, cracking theory, Boolean grain process, packed sphere, and numerous other models. See also Characterisation of pore space in soil.

Types of geologic porosities

Primary porosity

The main or original porosity system in a rock or unconfined alluvial deposit.

Secondary porosity

A subsequent or separate porosity system in a rock, often enhancing overall porosity of a rock. This can be a result of chemical leeching of minerals or the generation of a fracture system. This can replace the primary porosity or coexist with it (see dual porosity below).

Fracture porosity

This is porosity associated with a fracture system or faulting. This can create secondary porosity in rocks that otherwise would not be reservoirs for hydrocarbons due to their primary porosity being destroyed (for example due to depth of burial) or of a rock type not normally considered a reservoir (for example igneous intrusions or metasediments).

Vuggy porosity

This is secondary porosity generated by dissolution of large features (such as macrofossils) in carbonate rocks leaving large holes, vugs, or even caves.

Effective porosity (also called *open porosity*)

Refers to the fraction of the total volume in which fluid flow is effectively taking place (this excludes dead-end pores or non-connected cavities). This is very important for groundwater and petroleum flow, as well as for solute transport.

Dual porosity

Refers to the conceptual idea that there are two overlapping reservoirs which interact. In fractured rock aquifers, the rock mass and fractures are often simulated as being two overlapping but distinct bodies. Delayed yield, and leaky aquifer flow solutions are both mathematically similar solutions to that obtained for dual porosity; in all three cases water comes from two mathematically different reservoirs (whether or not they are physically different).

Macro porosity

Refers to pores greater than 50 nm in diameter. Flow through macropores is described by bulk diffusion.

Meso porosity

Refers to pores greater than 2 nm and less than 50 nm in diameter. Flow through mesopores is described by knudsen diffusion.

Micro porosity

Refers to pores smaller than 2 nm in diameter. Movement in micropores is by activated diffusion.

Measuring porosity

Several methods can be employed to measure porosity, including the volume/density method (pore volume = total volume - material volume), water saturation method (pore volume = total volume of water - unsaturated water), water evaporation method (pore volume in cubic centimeters = weight of saturated sample in grams - weight of dried sample in grams, mercury intrusion porosimetry (several non-mercury intrusion techniques have been developed due to toxicological concerns), and nitrogen gas adsorption (nitrogen gas condensation in pores is measured either by volume or weight).

See also

- Petroleum geology
- Poromechanics
- Bulk density
- Particle density

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