GROUNDWATER HYDROGEOLOGY

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Contents

Summary

The subject and essence of hydrogeology, as a branch of science, is presented. Classifications of groundwater according to its occurrence, peculiarities of regime and origin, and conditions of spreading are given. Infiltration, condensation, sedimentation and simple theories of groundwater origin are briefly considered. The main physical properties of rocks, causing conditions of groundwater formation and accumulation, namely, porosity, moisture content, water yield, saturation deficiency, and permeability are characterized. The main law of groundwater filtration (Darcy law) and its applicability are described. Considerable attention is paid to assessing groundwater resources and reserves, and their classification. It is emphasized that groundwater is not only a mineral resource but also an important component of the hydrological cycle and the natural environment.

1. Introduction

Hydrogeology is a science that studies groundwater, conditions of its occurrence and movement, regularities of distribution in the Earth crust, interaction with mountainous rocks, and also conditions and possibilities of their practical use. Hydrogeology is a geological discipline. Groundwater is studied based on analysis of the Earth's crust as it is not possible to understand the water in the Earth without also understanding the geology. At the same time hydrogeology is a constituent part of hydrology in a wide sense, as the object of its investigations is the underground component of the hydrosphere. Hydrogeology is therefore often called “groundwater hydrology”.

Even in the second and third millenniums BP, groundwater was intensively used for drinking and domestic water supply, particularly in countries with an arid climate, where deep and complex drainage galleries were constructed, e.g. in the Middle East, Central Asia, China, etc. Aspects of groundwater origin were considered in many projects and philosophic works of the ancient Greek and Roman philosophers (Miletsky, Plato, Aristotle, Kar, Seneka, Pollio, etc.). The first quantitative concepts of groundwater formation due to infiltration of atmospheric precipitation were formed by French scientists P. Perro and E. Marriott in the middle of the eighteenth century based on the study of water balance in the Seine River.

Russian scientists M.V. Lomonosov and later V.I. Vernadsky made significant contributions to the science of groundwater formation. In the second half of the nineteenth century the works of A. Darcy (1856), A. Dobre (1887), I. Gaase (1885), E. Zuiss (1902), J. Dupui (1857), A. Tim (1887), I. Slikhter (1899), and in the twentieth century the works of J. Teise, M. Masket, N. Zhukovsky, F.P. Savarensky and many others, were of great importance for developing the main trends in hydrogeology and its formation as a science.

At present, theoretical and applied parts of hydrogeology can be singled out. Theoretical parts include:

- hydrodynamics (investigation of groundwater movement, regularities of hydrodynamic regime and resources);
- hydrogeochemistry (principles of chemical elements migration in the underground hydrosphere and processes affecting groundwater chemical composition;
- hydrogeothermy (investigation of thermic properties and processes of heat transfer by groundwater);
- paleohydrogeology (origin and development of the underground hydrosphere, investigation of groundwater functions in geological processes);
- regional hydrogeology (regularities in groundwater distribution in the Earth crust, types of hydrogeological structures, formation of different groundwater types).

Applied parts include:

- assessing groundwater resources (types of groundwater development areas, conditions of formation and methods for assessing groundwater resources of different types);
- hydrogeology of mineral deposits (hydrogeological aspects of shaft-sinking and conditions for exploiting mines of different types);
- melioration hydrogeology (hydrogeological investigations for projecting meliorative systems, optimization of water and salt regime in meliorated terrain);

- engineering hydrogeology (hydrogeological investigations for protecting and building engineering constructions of different types);
- ecological hydrogeology (groundwater protection, hydrogeological aspects of protecting the natural environment).

Two different classes within the groundwater of the planet's underground hydrosphere, in its most common form, can be identified: 1) water in a free state able to move independently, and 2) water in a combined state not able to move independently without transition into a free state. Gravitational water is the most widely known and widespread example of a free state. Groundwater is called gravitational if its movement occurs under the effect of gravitational force or a gradient of hydrostatic pressure.

In the second case, water is deemed bound if it is combined with particles of landmass in the rocks or rock-forming mineral constituents. Tightly bound water is, in turn, subdivided into tightly bound, osmotic and capillary.

2. Groundwater classification

There are many groundwater classifications. This is because of the complex and variable natural conditions affecting groundwater formation and distribution, and also different practical requirements. Groundwater is classified by origin, lithological composition and geological age of the water-bearing rocks, different hydrodynamic characteristics and filtration parameters, temperature, chemical composition and other indications.

The most widely used classifications are those in which the three main zones of groundwater are singled out according to occurrence, head, peculiarities of regime and origin: water of the aeration zone, zone of complete saturation, and zone of groundwater in a supercritical state. The aeration zone (often called vadose zone in American literature) embraces the upper non-saturated part of the rocks from the surface to the groundwater level of the first aquifer. Aeration zone thickness changes from a few tens of centimeters in flat plains to -250 m or more in intensively separated interfluvial territories of mountainous regions. The thickness of the aeration zone in any area depends on the local relief, the level of its separation, atmospheric precipitations, the depth of the water-impermeable layer, lithological composition, and the types and thickness of soils and rocks constituting the Earth surface. Aeration zone can be absent over vast territories, and groundwater, reaching the surface, forms swamps and peaty ground. Water in the aeration zone, usually temporary, is formed in periods of recharge and occurs near the surface in poorly permeable rocks (loams, clays). The close connection between groundwater and atmosphere is apparent throughout the aeration zone. Rain and snowmelt water percolates into the depth and recharge groundwater resources. When groundwater occurs at a depth less than 3 m, it evaporates through the aeration zone. Intensity of infiltrating atmospheric precipitation through the aeration zone and groundwater evaporation depend mostly on the structure and lithological composition of the aeration zone. Thus, for instance, if sandy rocks constitute the aeration zone, then most of the rain and melted snow percolates to the groundwater level. If clayey and loamy rocks constitute the aeration zone, then melted snow and rainwater create surface flow, and only a small part of it recharges the groundwater.

A completely saturated zone embraces the upper part of the Earth crust from the level of the first aquifer, i.e. from the lower boundary of the aeration zone to a depth where temperature and pressure of the water reach critical values, according to the available concepts. In this zone pores, fissures and large voids are completely filled with free gravitational water and water is physically connected with the surface of mineral rock particles. Only areas of oil-and-gas fields are excluded. Within the zone of complete saturation, starting from a depth of 1.5 to 2 km, physically bound water is transformed into a moving state. In lower parts of this zone, where temperature exceeds 200 to 300 ^{o}C, only water in a crystal lattice of minerals remains in a bound state. The thickness of a complete saturation zone is usually a few kilometers. Material from the Kola super-deep well indicate that at a depth of 12 km there are conditions characteristic of a completely saturated zone. In areas of present-day volcanism, the lower boundary of complete saturation is at a considerably smaller depth. Thus, in some areas of contemporary volcanism steam-hydro-therms with temperatures close to critical values (300 ^{o}C and more) have been revealed at depths of 1500 to 2000 m. Below this, there is a zone with a supercritical groundwater state. The thickness of this zone within the continents amounts to 20 to 30 km and more.

In the area of permafrost (northern regions of Eurasia and America, Antarctica, and some high-altitude areas), a cryolite zone is singled out as an independent element of the underground hydrosphere. It usually embraces the whole aeration zone and the upper part of the complete saturation zone. Thickness of the cryolite zone, depending on local climate conditions, geological structure and geothermal conditions of rocks in the upper part of the Earth crust, can vary from the first meter to 1000 to 1500 m or more. The main mass of groundwater in the cryolite zone is in a solid state. Free gravitational water in the cryolite zone is restricted to areas of melted rocks, particularly under riverbeds.

Different rocks, according to their lithological peculiarities and geological age, constitute the saturation zone. They can be described from the viewpoint of accumulating groundwater, its percolation through the rock thickness, water yield in wells and pits, water bearing and water confining (impermeable) characteristics.

Water bearing rocks are those containing free water—it can pass through their thickness with relatively ease under gravity. This category includes pebbles, grit-stones, poorly cemented conglomerates and sandstones, sands, aleurolites, limestones, and fissured magmatic and metamorphic rocks.

Water confining (impermeable) rocks are those that only weakly allow water to pass (filtrate) or not at all, under natural conditions. They include the following: clays, heavy loams, dense peat, clay shells, argillites, rock salts, gypsum, marls and also all the dense and unfissured magmatic and metamorphic rocks. Depending on the character of voids in water bearing rocks, groundwater is subdivided according to the voids and pores in the material:

- sands, pebbles and other sedimentary and clastic rocks,
- fissured rocks,
- closely-cemented rocks (granites, sandstones),

- rocks broken by cracks, and
- karst——soluble rocks (limestones, dolomites, gypsum, etc.

In the aeration zone, a soil layer, perched water and water of a capillary fringe are usually singled out according to the conditions of occurrence and peculiarities of the water regime.

Water of a soil layer is usually formed near the land surface. Its thickness is usually from a few tens of centimeters to 1 to 2 m. The degree of soil layer saturation and soil moisture regime is determined by such factors as liquid atmospheric precipitation, snow melt, irrigation, condensation, evaporation, etc. Over-saturated soils are usually formed in places where groundwater is shallow, where water of the capillary fringe is constantly within the soil layer. The main type of soil water flow is vertical moisture transfer under the effect of capillary-sorption and gravitational forces, plus transpiration by vegetation.

Perched water is a local and usually temporary phenomenon formed by gravitational water accumulating on a confined layer of the aeration zone. Young and relatively thin inter-layers and lenses of poorly permeable rocks (clays, loams, buried soils, etc.) can form such a water confining layer. Perched water is most typical in ground with a thick aeration zone, such as interfluvial spaces, piedmont plains, and arid zones with a deep groundwater level. The most favorable conditions for perched water formation are found in areas with relatively high amounts of infiltrating atmospheric precipitation and also in intensively irrigated areas.

Water being retained above the surface of the first aquifer as a result of groundwater rise constitutes the capillary fringe. Its thickness is determined by the granulometric composition of the aeration zone and it can vary significantly. The availability of a capillary fringe and its thickness to a large extent determine the soil moisture regime in the aeration zone and soil layer, and water supply for vegetation.

Aquifers and aquifer complexes are distinguished, according to groundwater distribution in the saturated zone. An aquifer is a relatively seasoned single- or different-aged rock mass saturated with free gravitational water, and acting as a hydrodynamic unit. An aquifer can comprise one or several water bearing layers, of different or similar age and lithological composition. These layers, or horizons, may be unconfined, interlayer (confined, sometimes unconfined), or artesian water, each being a hydrodynamic unit. Usually it occurs at a relatively small depth from the surface on the first confining bed and is a constantly aged and regionally spread aquifer. These two designations, "constantly aged" and "regionally spread", determine the difference between an unconfined aquifer and perched water.

Water between two regionally aged water-confining rocks is called interbedded groundwater. As a rule this water is confined. However, sometimes a water-permeable interlayer is not fully saturated with water and then the interlayer water is unconfined. In those cases where the layer of confined interbedded water is higher than the land surface, water may emerge at a spring. An interbedded confined aquifer at pressure greater than atmospheric is called an artesian aquifer. Aquifers located one above another and closely interconnected are called an aquiferous complex.

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Biographical Sketch

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