Hydrogeological Classification of Volcanogenic Structures

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Abstract: Volcanogenic structures cover quite big area on our planet. They are widely spread in young plicate areas: Alpine and Pacific Ocean ones. They also appear in rejuvenated plicate areas of Paleozoi, rift zones, island arcs and on the ocean floor. At the beginning of our planet's evolution volcanogenic structures have been spread almost everywhere.

This article deals with the typing of volcanogenic structures in accordance with the following features: their location on land, on the bottom of the world ocean and in the transition zone land-ocean; their interaction with other hydrogeological structures; landscape climate, composition of volcanogenic structures, age (time of their formation); location of ground water. The above-mentioned factors on the whole determine the variety of hydrogeological conditions of volcanogenic areas including the formation of ground water, their resources, composition and regime.

Keywords: Groundwater Governance, transboundary aquifer, governmentality, nature of power, Guaraní aquifer system, Regional Consultation Mechanism

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Riassunto: *Le strutture vulcaniche coprono un'area abbastanza grande del nostro pianeta. Sono ampiamente diffuse in quelle zone giovani plicate: Alpine e dell'Oceano Pacifico. Esse appaiono anche in aree plicate ringiovanite del Paleozoico, zone di rift, archi insulari e sul fondo dell'oceano. All'inizio dell'evoluzione del nostro pianeta le strutture vulcaniche erano distribuite quasi ovunque.*
Questo articolo riguarda la classificazione delle strutture vulcaniche sulla base delle seguenti caratteristiche: la loro localizzazione sulla terra, sul fondo dell'oceano e nella zona di transizione terra-mare; la loro interazione con altre strutture idrogeologiche; il clima, il paesaggio, la composizione delle strutture vulcaniche, l'età (tempo della loro formazione); localizzazione delle acque sotterranee. I suddetti fattori, nel complesso determinano la varietà delle condizioni idrogeologiche delle aree vulcaniche tra cui la formazione di acque sotterranee, le loro risorse, la composizione.

Introduction

A volcanogenic basin is a structure formed with the flows and coverings of volcanic lavas and the volcanic rocks accompanying them (tuffs, piroclastics, etc. and sedimentary deposits). Volcanogenic edifices represent formations imposed on other kinds of hydrogeological structures which in their turn form the foundations of volcanogenic basins. Void volume in them was formed as a result of eruption. Their water-bearing systems also include water sedimentary volcanogenic rocks, underlying or overlapping effusions. Vast territory of our country promoted the development of regional research including hydrogeological one. That is why theoretical, methodological and applied research of regional hydrogeology have been variously and deeply developed (I. K. Zaitsev, N.I. Tolstikhin, 1964; V.A. Kiryukhin, 2006).

Typing of Artesian Basins

Location of volcanogenic basins on the planet

There are three groups of volcanogenic basins in accordance with their location: volcanogenic structures of continents, those of transitional area land-ocean and those of the ocean. Volcanogenic basins are mostly spread on land in Alpine area confined to geosynclines of the Mediterranean and the Pacific ocean. On the continents they form volcanogenic girdles some hundred and even thousand kilometers along Kamchatka, Cordilieres, Andes, Apennines, the Lesser Caucasus, Sikhote Alin. These volcanogenic structures are various as concerns their size, capacity, forms and content. Columbian plateau is the biggest volcanic field on the earth with its size up to 360.000 km^2 and capacity of 4-5 kilometres. Volcanic basins of Alpine area are **characteristic** of active volcanism, powerful warm flows and active gas and hydrothermal activity. Volcanic basins of

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comparatively small size and capacity are observed in rejuvenated folded Paleozoic areas. These are **Altay Sayanskaya**, Tien Shan and other folded areas. Here volcanism has been over for long, volcanic structures form small volcanic basins several kilometers long. Gas and hydrothermal activity in these regions is connected with zones of active tectonic activities.

As mentioned above modern rifting is observed in two biggest tectonic zones: Baikal and Eastern African ones some hundred kilometers long each. Besides rifting is observed in Rein graben, Californian rift, most part of which is hidden under the Californian bay and only partly on the surface of land. Volcanism in rifts is revealed unevenly, sometimes there are small structures of some dozens square kilometers. Chains of young volcanoes along rifts are observed more often. Volcanic activity takes place on separate sites and gas and hydrothermal processes are fixed with numerous outputs of mineral and thermal sources with water of various composition.

Volcanic basins of the transition area continent – ocean are usually linked to island arcs and within oceans form specific volcanogenic structures producing rift zones in middle ocean ridges and forming volcanic isles in different points of the world ocean. Volcanogenic structures have been in fact formed during all stages of our planet's evolution.

Hydrogeological interaction of volcanogenic basins with other kinds of hydrogeological structures.

Volcanogenic flows can go down slopes at the distance up to 85 kilometers from the site of eruption. Volcanic covers can occupy the areas of hundred and more square kilometers. Moreover as a result of numerous eruptions multi-layered structures are formed containing both lava and permeable sedimentary rocks. During the eruption rocks of the substratum represent the ways of movement for volcanic lavas and gas and hydrothermal products. Later artesian and non-pressure water-bearing systems are formed. Infiltration systems come from the surface of the earth. Deep water can penetrate in the lower part of artesian basin reaching deep parts of the substratum. In accordance with the power of volcanogenic cover and hydrogeological conditions different **water-bearing** systems are formed with flows both from top to bottom and from bottom to top. Depending on the type of volcanogenic basins (slope, volcanic cones, plateau, grabens, depressions, etc.) the water-bearing character of volcanogenic structures can change. There is water of different kinds as concerns the conditions of flowing (transversely-ground, pore layer, fracture vein, cavernous water) and their origin (infiltration, condensed, volcanic, sedimentary water, etc.). It can circulate both in the cover of volcanogenic sediments and in their substratum.

Specific hydrogeological conditions take place on the sites of buried volcanogenic structures. Volcanic bodies can at first be located on the surface. During the evolution of the region they can be overlapped with rather powerful sedimentary rocks. In this case such structures are called **volcanogenic** artesian or artesian volcanogenic ones. Artesian water usually play leading role in them while lava water become more or less independent.

Lavas, formed during the volcano eruptions fill low relief forms, thus the foot of volcanic basin has complicated character. It is usually uneven and buried valleys, depressions, grabens and other negative relief forms take part in its formation. Volcanic edifices can also be located on the positive relief forms as slopes, watersheds, summits and plateau.

The relief of volcanogenic basin roof is also uneven and various. These are mostly plateau-shaped upland and mountains, flat and convex shield-shaped surfaces, cones of extinct volcanoes, plinth terraces in the river valleys, built with valley basalts, sometimes more or less eroded summits and mountain watersheds, wide-ranging lava plateau. Exceptions are also possible, for example in Transcarpathia along with Vygorlat Gutinskaya volcanogenic ridge there are hills as well.

Main morphological types of volcanogenic basins are valley, depression, summit, watershed, slope and complicated ones. Valley volcanogenic basins are located on the bottom and on the river valley terraces. Sometimes they completely block the valley. In these cases upwards from the volcanogenic basin in the valley powerful alluvial lake sediments are formed and artesian basin of closed type can appear. Sometimes the lake water formed over the volcanogenic basin breaks through it or at its border with host rocks. In this case over the basin on the terraces powerful lake alluvial sediments are preserved (for example in the Selenga river valley in Mongolia). Volcanogenic basins of valley and depression types are present in Transbaikalia in Tunkin depression. Ground water of such volcanogenic basins are replenished at the expense of atmospheric precipitation and overflow from the foundation rocks of the volcanogenic structures.

Volcanogenic basins of summit and watershed types form on the mountain summits or watershed areas. Lower parts of mountain slopes and their foundations are built with rocks underlying volcanogenic basins. They are usually well drained. Their supply depends on atmospheric precipitation or on melting of glaciers if volcanogenic basins are covered with glaciers (e.g. Elbrus). Discharge of volcanogenic basins takes place on the edge of mountains as sources which often appear at the contact of volcanogenic structures and substratum rocks. Summit volcanogenic basins are located in Eastern Sayan, Big Caucasus (mountains Elbrus and Kazbek), in Selengin Dauria.

Role of Permafrost.

Volcanic structures building complicated volcanogenic basins overlap both negative and positive relief forms, i.e. both mountains and valleys are hidden under them. Supply of basins is mostly provided at the expense of atmospheric precipitation and melting of glaciers.

Landscape climate conditions considerably define water balance and regime of ground water of volcanogenic structures. Among the factors leading to this effect the most important are precipitation regime, slope and orientation of land, vegetation, soil cover sediments, conditions of atmospheric water absorption, slope height, permafrost conditions. Each of the above-mentioned factors has its own effect on formation and distribution of underground drainage. Thus for example in humid areas the resource of ground water is much more than in arid ones. Alpine deserts practically deprived of atmospheric and ground water have been detected in some world regions. The area slope determines which part of drain should be directed in superficial or underground way. Slope orientation distributes water atmospheric feeding which goes from the seaside. Windward slopes usually have some several hundred millimeters more per year than downwind ones. Vegetation to a large extent defines water balance of ground water and top water. This situation is controlled by the process of transpiration. Soil cover sediments in volcanogenic areas are not common everywhere. In places of their location they regulate the inflow of atmospheric precipitation in water-bearing systems. Infiltration absorption of bedrock depends on the level of their erosion. Permafrost conditions have great effect on the hydrogeological characteristics of volcanogenic structures. There are three types of

volcanogenic basins in accordance with it. The first type is characterized by common low-powered permafrost thickness and island location. Under these conditions fresh water are formed. The fresh water zone appears to be frozen. Meanwhile subpermafrost water happen to be brackish or salty. Volcanogenic structures of the third type are completely frozen to their base. That is why ground water is observed only in rocks substratum. In alpine regions where snow and ice caps on mountain summits are common feeding of ground water can be carried out at the expense of melting of accumulated snow and ice. Frozen summits and glaciers are common in Andes, Cordilleras, Island, Antarctica, Greenland, Kamchatka, Tchukotka, etc.

Material composition of volcanogenic structures

Volcanic rocks play the leading role in composition of volcanogenic basins. Their composition can be different in accordance with the eruption conditions. There can be upland plateau basalts (South of the Far East seaside, Armenia, Kamchatka), mountain slopes, built with liparites, dacites (Lesser Caucasus, Sikhote-Alin), volcanic valleys, grabens built with rocks of middle composition (Amuria, South of Kamchatka).

Material composition defines the conditions of occurrence, permeability, mechanical and other features of volcanic rocks. In accordance with the silica content effusive rocks are subdivided into ultrabasic (40-45%), basic (45-53%), middle (53-64%) and acid (64-80%). In description of the above-mentioned types proportions of calcium, potassium, sodium oxides and alumina are also taken into consideration. On this basis tholeiitic, lime alkaline or aluminous and alkaline lava rocks are subdivided.

Lava properties depend considerably on the acidity level. Basalt lava are formed at the highest temperature (1200-1300^{0}C)and have low viscosity, which provides for rapid loss of water and gas. Eruptions are accompanied by magma fountains several hundreds meters high which leads to accumulation of a great amount of volcanic bombs and fragments of different size.

The temperature of formation of andesitic and dacite lava is much lower (800-1000^{0}C). As a result of great viscosity they give away volatile fluids with difficulty. Their eruption is accompanied with powerful explosions producing explosive debris – piroklasts. The amount of piroklasts formed at volcano eruptions is 6 times higher than the amount of erupted lava (V.A. Aprodov, (1982)). Liquid lava of basalt composition form vast covers, extended flows and flat shields. At the explosion of acid and viscous lava the explosive material is erupted at great speed at a distance of several dozens kilometers from the eruption site.

Volcanic structures usually have complicated composition as lava formations, piroklasts and sediments of various genesis (alluvial, lake, swamp, sea, etc.) chaotically alternate in them. At transfer of the eruption center along the fracture linked with the volcano, elongated volcanic ridges occur. Ring structures (various volcanic cones, tops and craters) are formed at a ring fracture even more often.

Cavitation distribution in volcanogenic rocks is rather specific. The type and rate of eruptions, composition of volcanic material change with time. Magma eruptions alternate with accumulation of vulcanites and terrigenous deposits. That is why strata of volcanogenic formations have complicated and uneven composition.

Let us consider the features of porosity distribution in volcanic rocks of Neogene-Quaternary age developed in Lesser Caucasus, South of the Far East, Kamtchatka and Kurils.

Acid volcanic rocks are usually more viscous and dense compared with other varieties while their porosity and fracturing is less. In acid volcanic rocks platy jointing prevails while in basalts vertical and steeply dipping fractures do. At the same value of common porosity the lava with thick columnar and big blocky jointing have much more open cracks than lava with breccia and ball jointing. Tuffs and tuff breccias usually stand out for lesser porosity than volcanic rocks. The biggest cavitation is typical to slag species of basalts, acid and middle varieties of volcanic rocks with pumiceous texture.

The water permeability of Pliocene-Quaternary volcanic rocks is determined mostly by their horizontal fracturing. In pore volume capacitive store of ground water are formed while it moves along cracks, with the exception of some slag and pumiceous varieties of volcanic rocks of extremely high porosity.

Frequent eruptions lead to formation of 5-10 (seldom more) water-bearing horizons in the section of the volcanic strata of Pliocene-Quaternary age. The high water-bearing horizons of such complicated volcanogenic strata are characteristic of free level. Water-bearing horizons of middle part and the strata base are pressure. In separate cases they are the most watery (Ararat volcanogenic basin).

With depth the level of water content of the host rocks usually declines. Such forms as lava flows are the most common forms of bedding of Neogene-Quaternary volcanic rocks. They reach 85 km at length while their height ranges from few to 150 m. Lava volume at one single eruption is 3-12 km^3.

Porosity and fracturing of volcanic rocks declines down the flow. All this testifies to irregularity of permeability change not only of the section of volcanogenic strata but of the area of their distribution. Complicated form of lava flows influences rather convoluted pathes of water-bearing horizons

Age characterization of volcanogenic structures

Weathering process leads with time to gradual reduction of emptiness of volcanic rocks and filling of cracks and pores with weathering products. Reduction of water resistance of volcanic rocks is also promoted by tectonic process, progressive catagenesis process and magmatic activity. Thus with age filtration properties of volcanic rocks degrade, zone character of water accumulation becomes obscure while their hydrogeological features are more and more similar to features of metamorphogenic and intrusive rocks. This transition takes place at least during the first dozens of million years since the time of formation of volcanic rocks. According to S. Davis and R. de Wist (1961) all pre Cenozoic volcanic rocks of Southern Brazil, west of central part of India and Eastern regions of USA are poorly waterlogged and are similar to metamorphic and intrusive rocks as relates to their water-bearing properties.

Analysis of water content of effusive rocks shows that prevailing development of water types can be divided into three groups: lava water, fractured core water and karst water. Three types of water exist in volcanogenic structures of paleogenic age while water-bearing complex of upper chalk contains mainly lava and fractured core water. In complex of low chalk age fractured core water prevail with sporadic distribution of lava water. In water-bearing complex of Jurassic age and older lava water are not detected.

Characteristics of hydrogeological spatial domain

Under natural conditions three types of hydrogeological spatial domain are formed: latitudinal (geographical), altitudinal (mountain) and vertical (geological). Within each type different hydrogeological data can be considered: geodynamic, hydrogeochemical,

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temperature, etc. It enables to define patterns of their behaviour in water-bearing systems and directions of hydrogeological processes.

The third section has already dealt with the role of climate factor in the formation of resources of ground water. In every landscape and climate zone specific conditions of ground water formation are created. The main question is which is the balance between the amount of precipitations and evaporation. In humid climate precipitation dominate evaporation and create favourable conditions for ground water supply. In arid climate balance between the above-mentioned parameters becomes inverse and the conditions of water-bearing system supply are less favourable. Landscape and climate conditions affect many parameters of ground water: dynamics, chemistry, temperature, balance, regime and other characteristics of ground water (A.V. Kiryukhin, V.A. Kiryukhin, Yu.F. Manukhin, (2010)).

High altitude zone has in fact a clear zoning upwards. With increasing grades the amount of precipitations at first rises and then abruptly falls. Discharge of ground water of volcanogenic structures begins at some hundreds meters lower of watershed in marginal sources of temporary type. Gradually with lowering of relief the intensity of discharge increases. It is fixed as maximal at bases of slopes with high debit sources. The module of underground drainage with the lowering of relief usually decreases.

With lowering of relief gradual increase of mineralization of ground water takes place in volcanogenic basins. In their upper part there are conditions of intense water exchange where zones of fresh water are formed. Their character is usually carbonaceous, magnesium-calcium and sodium-calcium. Mineralization is 0.2-0.4 g /l. With lowering of relief mineralization of ground water increases and their composition becomes more complicated. Mineralization of ground water rises. Within central highland of Armenia in upland and foothill mineralization of ground water increases from 70 to 388 mg/l. Water contains most chemical components.

Processes of continental salinization develop in river valleys (Caucasus, Carpathians, Apennines, etc.). Water mineralization increases up to several mg/l and more and the water content becomes mottled: biocarbonate, sulphate, chloride. At the sites of development of saline deposits water mineralization increases up to 100 g/l and more with positive sodium and chloride composition. Such conditions take place in the river Razdam valley in the Lesser Caucasus in Gorla-Dubutin zone (Carpathians). Salty water appear only at seaside where intrusion of sea water activates with intense extraction of fresh water. Under conditions of powerful multi-layered volcanogenic thickness mineralization of ground water with depth gradually increases. Water of biocarbonate-sodium and chloride biocarbonate-sodium character and later of chloride-sodium character appears. Thus vertical hydrogeochemical layering takes place.

Specific hydrogeochemical conditions are observed in the regions of present volcanism with gas and hydrothermal processes. There are volcanic basins of fumarolic and solfataric types.

Temperature of ground water depends on climate and volcanogenic factors. Under conditions of severe climate and Permafrost temperature of ground water within active layer is several times lower than average annual air temperature in this place.

Present volcanic activity is characteristic of specific hydrogeological conditions connected with manifestation of gas, vapour, fumaroles, solfataras and other factors of gas and hydrothermal activity. Volcanism influence is revealed at several stages.

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