

Part II-2 Karst processes in the area of Siberian platform

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Wide occurrence of carbonate, sulphate and saline deposits in the area of Siberian Platform determines the extensive development of karst, which encompasses about 25% of the studied territory. Karst is widely developed in carbonate, gypsiferous and saline deposits of Cambrian, Ordovician, Silurian and Devonian age in the Siberian Platform and in the encircling mountain folds composed of deeply-metamorphozed carbonate formations of Archeic and Proterozoic. As an example, the pattern of karst occurrence in the Irkutsk amphitheatre is presented in Fig.1.

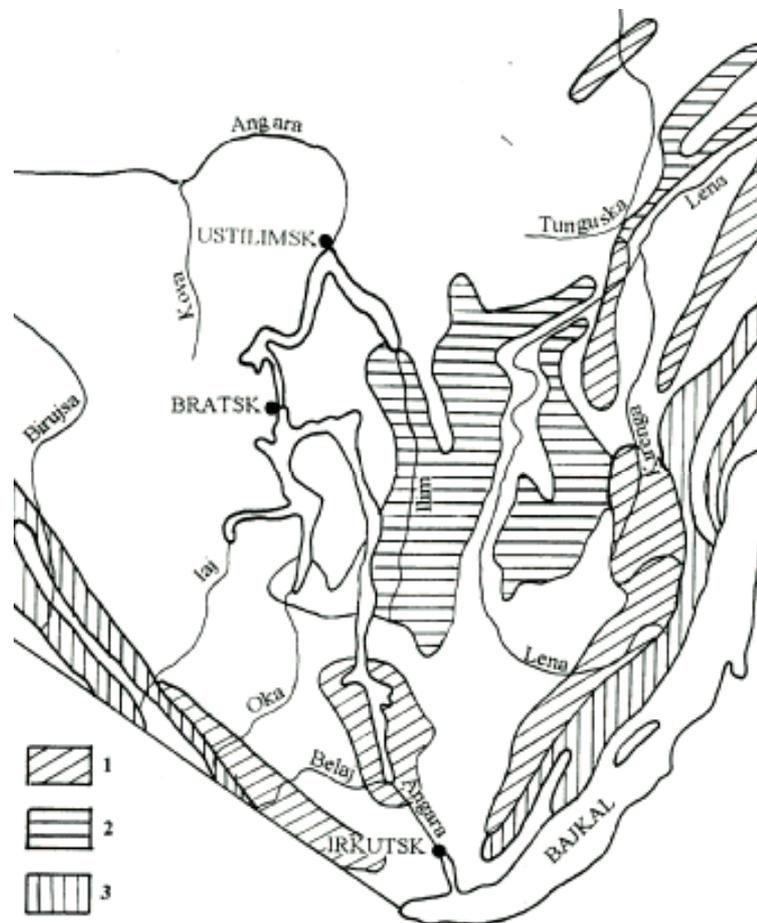


Fig. 1. Scheme of the occurrence of different karst types within the Irkutsk amphitheatre of Siberian platform.

1 - gypsum karst areas associated with sulphate-anhydrite rocks of Middle-Upper Cambrian; 2- carbonate karst areas associated with normal sedimental rocks of Paleozoic; 3- carbonate karst areas associated with metamorphized carbonate rocks of Proterozoic.

The character and conditions of the karst development in the region are rather diverse (Palshin et al., 1970, 1976; Vologodsky, 1975; Trzhtsinsky et al., 1977; Eraso et al., 1995; Filippov, 1983, 1986; Trzcinsky, 1996, Ovchinnikov et al., 1999, et al.). Majority of the extensive karst development is observed in gypsiferous formations of Lower Cambrian within the Angara-Lena foredeep. Most intensive karst occurs in arched structures, highly fissured rock formations of anticlinal domes and along the steep sides of river valleys. The extension of karst processes into the depth varies depending upon local conditions from tens of metres to 200-300 metres, reaching in places the depths of 1~3 km.

The development of karst occurs in all geographical zones ranging from low-humid forest-steppe areas in southern Priangaria to northern highland taiga regions marked by the continuous permafrost occurrence.

The peculiarity of karst development in Siberia is that it occurs in the seasonally-freezing and perennially frozen rock formations. The permafrost does not make karst process impossible, but only retards it. Development of the frost karst theory is still in its initial stage. There are two hypotheses on the development of karst: first, the karst processes develop throughout the whole thickness of permafrost layer. According to S.S.Korzhuyev's opinion, the karst process develops merely in the zones of circulation of supra-, intra- and subpermafrost groundwaters. Peculiarity of the karst processes in frozen rock formations is that they arise and intensively develop under the negative-temperature conditions. The physical-chemical processes such as corrosion and migration of elements are benefited by the presence of liquid phase water within frozen rocks even under the deeply negative temperatures. This leads ultimately to thawing-through of the frozen rocks.

Development of the frost karst is marked by some discrepant conditions. On the one hand, the modern climate conditions do not benefit to the development of karst, on the other hand, the frozen rock formations concentrate the surface flow, the low temperatures promoting the increase of the overall carbonate content in karst waters. The frost karst is characterized by domination of subsurface forms of karst occurrence which develop all-the-year-round and do not depend upon the seasonal temperature variations. According to L.D.Miroshnikov's opinion, the degradation of permafrost is the cause of localization of karst development, confining it to the areas of tectonic faults, where the groundwater circulation and formation of through taliks are promoted.

The development of karst causes large changes in the topography of the territory and orientation of modern erosion-denudation processes. On the karst rock formations of the Putoran plateau foot no permafrost is available; abundant mixed wood forests with motley grass exist here instead of tundra and sparse growth of trees. Most likely, the intensive karsting of carbonate rocks here, accompanied by heat emanation, prevents the occurrence of permafrost. The abundance of permafrost may be observed also in the areas of karst development in Spitsbergen (M.Pulina, Postnov, 1989).

In the territory of the Siberian platform the carbonate karst is in dominating occurrence; the gypsum and saline karst, being more dynamical, are of a less

occurrence in this area. Saline karst dominates in Yakutia, particularly in the basin of Vilui river, being represented here even by superficial forms, i.e. by deep (30 to 100 m) sinkholes, occupied by saline lakes with steep bank slopes. The intensive development of karst is evidenced by the occurrence of numerous saline water springs with the total rate of yearly debit about 500 l/s and mineralization of 310~317 g/l. There are no superficial forms of saline karst occurrence within the Irkutsk amphitheatre since the salt-bearing rock formations lie deep here. However, the high-mineralized saline springs also exist here (the Ilim-river basin, south of Priangaria).

The occurrence of sulphate karst is characteristic for the Angara-Lena region; it is associated with the gypsum-anhydrite rocks of Lower Cambrian and the low of the Upper-Lena series of Upper Cambrian. The old age superficial forms of karst occurrence are represented by large sinkholes (25 to 60 m in diameter and 5 to 25 m depth), as well as by caverns.

The carbonate karst is associated with limestone and dolomite deposits of Cambrian and Ordovician, it is most extensively developed in the Sayan region, inducing the formation of large sinks in the Irkut submountain depression. The evidence of ancient karst processes can be observed in high tracts of the interstream areas Olkha-Shinikhta and Olkha-Irkut, in basins of rivers Malaya Belaya, Bolshaya Belaya, Kitoi and in other places. This area is marked by large depressions and sinkholes filled with silicic-argillaceous breccias, refractory clays and kaolins from Troshko and Khaita deposits. Along with the ordinary sinkholes of 60 m depth and up to 100 m width, large kettles (400×120 m) were identified here by Vologodsky. Abundant subsurface caves appear here in the areas of descending water circulation in the areas of slacking slopes, pits Kurtuiskaya (80 m depth) and Razdolninskaya (63 m) may be considered to as the example. Caves of this kind exist also in other paces, due to which no surfacial streams exist within the interfluve areas. Considerable loss of water (up to 150~300 l/s, by Vologodsky) is characteristic for big rivers of those regions such as Kitoi, Belaya and Malaya Iret.

Morphologically the karst occurrence is typified by sinkholes, caverns, blind valleys and karst trenches. Superficial karst forms are represented mainly by sinkholes of corrosional, corrosion-erosional and corrosion-gravitational origin; the karst forms of corrosion-suffosional and polygenetical nature are of a less abundance here (Palshin et al.1976, Trzhtsinsky et al, 1977,et al.).

The density of sinkholes is generally less than 10 units per 1 sq.km, in some areas, however, reaching 200~600 sinkholes per 1 km² (e.g. in southern Priangaria). The number of sinkholes per 1 km² appearing within a year is considered as an index of stability of karsted territories. Karst troughs are abundant in Priangaria, Mid-Lena region, Lena-Aldan plateau etc. Genetically they are related to the areas of slope release, block-like landslides and the phenomenon of "rassedanie" (dispersion) of the interstream (interfluve) areas (Trzhtsinsky, 1974).

The underground caves occur primarily due to leaching; in certain cases they are caused by erosion and gravitation processes; generally these caves occur along river valley slopes. Caves of this kind originate under the erosional and drainage influence

of rivers. Here the caves of corrosion-erosional and corrosion-gravitational origin may be outlined.

To the corrosion-erosional type the largest caves of the region belong, such as Khudugunskaya, Balaganskaya, Nizhneudinskaya, Botovskaya, Karakolskaya, Olekminskaya, as well as numerous smaller ones (commonly 20~50 m in length); these were formed within the zones of horizontal groundwater circulation. The multi-level structure is typical of these structures, associated with changes of drainage basins and karsting due to deepening of the river valley. The caves are of the horizontal and gently-sloping tend towards valleys. In individual cases the caves correlate with the levels of river terraces; in other cases, however, their stage-like occurrence is likely to be related to the lithology of rocks and multi-level mode of karst water occurrence. The initial stage of formation of "cyclic" caves is probably associated with full head pressure of groundwaters; completion of their formation relates to subaerial conditions. The stage-like structure of caves depended on the cycles of the recent uplifts, occurring synchronously with the rhythms of time-evolution of the relief.

The caves of corrosion-gravitational origin and pits are confined to the area of the erosion-karst denudation, the major part relating to the fractured zones, deep troughs caused by block-like landslides, i.e. to the zones of surface and subsurface runoff. The caves of relatively simple elongated form, widening towards the bottom, originate along the fractures within the massive limestones; the caves of more complicated forms occur in the case of lithological non-uniformity of rock formations. These caves are marked by most dynamical character of development and are relatively young (Upper Pleistocene/Holocene). This is evidenced particularly by their small catchment areas.

The intensive economic development in East Siberia has considerably enhanced the karst processes with their detrimental impacts upon the environment (Pulina, Trzcinsky, 1994). In particular, activation of the karst processes has been induced by creation of the man-made reservoirs (for example the Bratsk and Ust-Ilimsk reservoirs) which entailed considerable changes of natural conditions along their karsted shore areas (The Problems of Protection ..., 1993; Ovchinnikov et al.,1999; Trzhtinsky, 2002). These changes have imposed the accelerated rates of karst deformations, including the development of collapse sinkholes and subsidence trenches. Many of these caused the damage to buildings and constructions; some shore zone areas have become unsuitable for industrial and even agricultural use. The creation of reservoirs has considerably changed the hydrogeological conditions in the region, for example, flooding of the earlier dry slopes, occurrence of new aquifers, changes in hydrogeodynamical parameters.

The experimental studies of leaching of karsting rocks on location (in the shore zone) and in laboratories (Filippov, 1981; Trzhtinsky, Filippov, 1981) show a low dependence of the leaching rates of sulphate and limestone-dolomitic rocks upon their composition, being determined primarily by the hydrodynamic zonality and filtration rates. For example, the leaching rates of crystallized, fibrous and bituminous gypsum,

as well as dolomite and mixed limestone-dolomitic rocks show a 10%~30% difference, depending primarily not on the chemical composition but on the structure-texture characteristics, presence of microfractures, terrigenous inclusions and other structural imperfections.

The comparison of sulphate and carbonate leaching by hydrodynamical section gave more contrast results. For example, the leaching rate of gypsum within the zone of varying saturation is marked by 3.4 to 7.7 times decrease in comparison with the aeration zone and 12.5 times in the zone of complete saturation, while the leaching rate of dolomite increases due to a lower solubility, with longer solvent-to-rock contacts, being 2.7 times higher in the zone of varying saturation than in the aeration zone.

Comparison of the rates of karsting of gypsum and dolomite under laboratory and on-location conditions shows that the leaching rate of dolomites is by 2~3 orders of magnitude lower than that of gypsum. The homogeneous limestone rocks have the 2/3 times higher leaching rates than dolomites and mixed rocks. The sulphate rocks are most responsive to variations of hydrodynamical conditions; with higher filtration rates the leaching rates of sulphate rocks may increase by 2 orders of magnitude. It has been proven by experiments that a highest rate of intensification is characteristic for sulphate karst. In the areas of gypsum-anhydrite deposits of the upper area of the Bratsk reservoir the suffosional pattern of deformation changed for karst-induced one entailing the formation of new sinkholes and pits of up to 30 m depth and up to 7,000 m³ volume (Wika et al., 2000) (Fig 2). Origination of large-size sinkholes, a typical effect during the early period of the reservoir existence, was due to rejuvenation of paleokarstic features. Development of sinkholes in later years was caused primarily by variations of water table induced by water level changes in the reservoir. Also, the signs of carbonate karst activation are observed, however, with a lower intensity.

The zones of sulphate and carbonate karst activation are respectively 4~6 km and 0.5~1.0 km wide. The maximum rates of appearance of new collapse forms are observed along the shore zone of 1.0 km and 0.3~0.5 km widths respectively, where they range between 5.9 and 3.5 collapses per 1 km² per year. Figure 3 shows the larger stability of the territory against karsting with a larger distance from the reservoir shores (Maximovich, 1961). In recent years the activation of karst processes is caused by variable impacts of the groundwater backing due to variations of the water level in the reservoir.

In general, the main role in activation of karst processes belongs to variations of the hydrogeological conditions. Impounding of the reservoir with the 100 m water level rise resulted in the increase of the thickness of the existing aquifers and origination of new ones in the backwater zone. In the areas of occurrence of carbonate and sulphate-carbonate deposits of Lower Cambrian the maximum hydrostatic head is 23-28 m. Flooding of the highly fissured rock areas of the former aeration zone with its high filtration character has sharply increased the rock wateriness here. Carbonate



Fig.2. Recent karst hole.

and sulphate-carbonate rocks of Lower Cambrian are characterized by the largely uneven wateriness due to the large non-uniformity of filtration characteristics of the karst-fissured container rocks. The variation coefficient of the specific yield of boreholes here is 162%, however, an appropriate decrease of the rock wateriness with increasing distance from the reservoir may be observed.

Within the shore zone of up to 2.0 km width marked by the maximum influence of heading-up, very high specific yield of existing boreholes (the average values varying from 5 to 25 l/s) dominates. The rock wateriness decreases substantially with increasing (>2 km) distance from the reservoir, the maximum value of specific yield of boreholes not exceeding 0.5 l/s. Also, the similar relationships within the section can be observed. The zone of high rock permeability is confined to the depths of 30~50 m below the reservoir's basement.

Formation of the backwater was accompanied by the infiltration of fresh groundwater into the reservoir shores which entailed the leaching of gypsum-anhydrite rocks and their loss due to the lowering of the water level in the reservoir and consequently the lowering level of groundwaters and increasing of their travel rates.

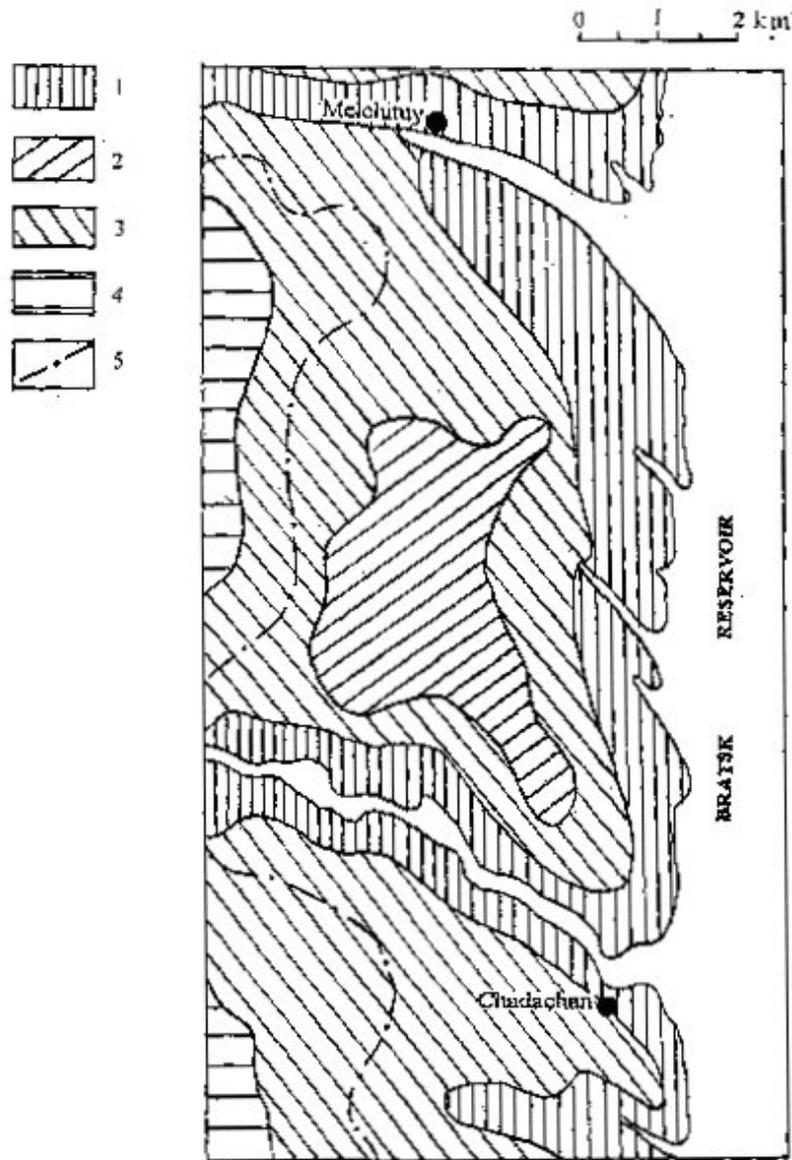


Fig.3. Zoning of the Rassvet - Ust-Altan tract of the Bratsk reservoir shore area in terms of their sustainability against karst processes (based on the data of V.M. Filippov).

Areas: 1- rather unsustainable (formation of 10-1 sinkholes per 1 sq.km per year); 2- not sustainable (1~0.1); 3- low sustainable (0.1~0.001); 4- sustainable (<0.01); 5- zone of forecasted karst activation under the reservoir's influence.

Since the time of the initial impounding in 1967 the intensity of karst processes did not diminish but tends to expand its area of influence.

The technogenic intensity of carbonate karsting is much lower; however, the maximum danger in the areas of carbonate karst occurrence comes from the joint influence of karst, landslide and suffosion processes, which approach the impacts of gypsum karst. In the shore areas of the reservoir the activation of karst processes is

most prominent. The karst-suffosional processes, however, may be intensified also by other kinds of technogenic impacts. For example, in the BAM area numerous small and middle-size (ranging from 0.5 m to 8.0 m in diameter and up to 2.5 m in depth) sinkholes of suffosional nature appeared due to opening of the karsting rock beds by cuttings, quarries etc. Origination of sinkholes was the result of intensified infiltration of surface water into the exposed rock beds, and suffosional transfer of products of the karst-induced destruction into corrosion-tectonic joints. The development of karst is associated with enhanced leaching process, which is more intensive than in similar areas with undisturbed turf cover.

The analysis of leaching rates shows that the karsting rocks will hold the inherited character of karst activation at least until the next century. In the shore areas the cave-like hollows will develop in the areas of gypsum-anhydrite rocks in the zone of influence of groundwater backing.

The probability-statistical prognostication of karst development is the most effective method of local karst prognosis in the southern area of East Siberia. On the basis of permanent investigations the karst dynamics, karsting degree and activation of processes, the probability and frequency of the occurrence of sinkholes and their size can be predicted; it enables also to make the territory zoning in terms of its sustainability. The phenomena of such kind take place currently in the area of Khadakhan settlement; here the horizontal cavities stretch for approx. about 20 m into the gypsiferous rock massif (Fig. 4).



Fig.4. Leaching of sulphate rocks in the area of variable water level of the reservoir.

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The analysis of conditions and factors contributing to activation of karst within the zone of reservoir's influence enables to suppose that the intensity of sinkholes formation will not vary during the next 15~20 years. Sharp fluctuations of the water level in reservoirs will result in considerable intensification of the origination of sinkholes.

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