ROLE OF CONTINENTAL GLACIATIONS IN KARST DEVELOPMENT OF RUSSIAN EUROPEAN NORTH

Shavrina E.V.[(1)]*, Malkov V.N.[(2)], Gurkalo E.I.[(3)]
[(1)] State natural reserve «Pinezskij»; [(2)] ZAO «Arhangelskgeolrazvedka»; [(3)] «Technoecology»
*E-mail: *elenashavrina@mail.ru*

Absract

On European North of Russia favourable combination of unique geological conditions and features of natural-historic development has resulted in formation of a peculiar and unique complex of denudation-accumulation relief. Its development was conditioned by long-term effect of geological processes first of all karst and glacial ones. The appearance of terrain relief built up to the moment of degradation of the last Late Valdaj sheet glaciation. In the modern period (last 9 thousands years) the inherited development of underground and surface relief progresses predominantly influenced by karst and karst-connected exodynamic processes. On example of Belomorsko-Kuloiskoye plateau the geological history of karst development is considered and influences of a glacial sheet on a karst is shown. Classifications of superficial karst forms of a relief are given.

Роль континентальных оледенений в развитии карста европейского севера России

На Европейском Севере России благоприятное сочетание уникальных геологических условий и особенностей естественно-исторического развития привело к формированию своеобразного и неповторимого комплекса денудационно-аккумулятивного рельефа. Его развитие было обусловлено долгосрочным воздействием геологических процессов, в первую очередь, карстовых и ледниковых. Облик рельефа территории сложился к моменту деградации последнего поздневалдайского покровного оледенения. В современную эпоху (последние 9 тыс. лет) унаследованное развитие подземного и поверхностного рельефа продолжается, преимущественно при действии карста и целого ряда сопряженных с ним экзодинамических процессов. На примере Беломорско-Кулойского плато рассмотрена геологическая история развития карста и показано влияния ледникового покрова на карст. Приведены классификации поверхностных карстовых форм рельефа.

Karst throughout Russian European North had undergone a long development in conditions of continental glaciations and permafrost. The geologic activity of Pleistocene continental glaciations rendered considerable effect on development and distribution of surface and underground karst forms.

Constitution of karst relief and its features are determined by structure of karst containing geological formations, tectonic structure, neotectonic motions, history of relief development and young processes of relief forming. Karst relief forms and evolves due to karst and other exogenic denudation processes (fluvial, nival, glacial processes, abrasion, etc.). Compared to other types of relief karst relief is subdivided into surface and underground types. The main distinguishing feature of karst is its capacity to self-development and combination – paragenesis of karst forms with fluvial, nival, glacial forms of relief.

In Arhangelsk region karst containing formations cover an area of 106220 км^2 or about 36,3 % of all region area (continental zone without arctic islands). Under terrigenous deposits layers karst rock cover an area of about 50-52 % of the region. On Kanino-Timan highlands karst formations cover about 19287 км^2 or about 22,7 % of its area.

Taking into consideration the structure specific of kast containing profile, homogeneity or unhomogeneity of composition of soluble mineral matrix there are following lithologic types of karst in considered area: 1) carbonate; 2) sulfate; 3) carbonate-sulfate; 4) mixed carbonate; 5) mixed sulfate. Two last types are usual for terrigenous rocks with limited content of soluble layers, soluble cement, and also for combination of thin layers of soluble and insoluble rocks. In such case karst processe are mixed with suffosion and suffosion-sink processes.

Karst of European North of Russia is rather different and includes all combination of negative and positive forms of karst genesis as well as denudation phenomena of different scale, with which these forms have tight connection. All forms of surface karst are submitted: karren, dolines, depressions, circuses, gullys, dry valleys, karst lakes, etc. Apart from that rare and unique forms are found: potyazhiny, furrows, polygenetic broad gullies or karst-glacial valleys (fig. 1), fields of «shelopnyak» (*field with very big quantity of dolines in gypsum, editor comment*), buttes, towers, «opadi», poljes *(sometimes author give local names of specific local karst forms, editor comment)*.

In European North of Russia both inherited ancient and young karst types are spread. Visible differences in karst development in concrete regions are connected not only to features of last stage of relief development but also to all previous geologic history.

The history of karst development in Arhangelsk region could be divided into four phases.

The first phase began in the second half of Neogene when the terrain represented a peneplane with absolute altitudes up to 100 m (Spiridonov, 1978). Then in the late Pliocene there were terrain raisings with simultaneous regression of Polar sea basin and relief drying.

Fig. 1. Karst denudation valley filled by sediments

The third phase of karst genesis occurs on Late Pleistocene and prolonged for 110 thousand years. It includes Mikulin time transgression - 30 thousand years, cold Early and Middle Valdaj - 69 thousand years, Late Valdaj continental glaciation - 11 thousand years. During Early and Middle Valdaj a network of valleys, dolines and depressions relief were formed. In massifs depth karst draionage systems developed.

In Late Valdaj epoch surface karst formation has stopped prior to the beginning of glacier melting and its decay into separate tongues and caps of dead ice. During the melting of rests of glacier sheet (13-9.8 thousand years BP), there were conditions for intensive wide surface and underground karst formation. Together with formation of a new cavities spreading, dipping and overwork of existed pre-glacial karst forms took place.

In Onego-Belomorskaya karst area mainly carbonate karst is found. Buried karst massif lies on considerable depth under a cover of Quaternary deposits; its thickness can exceed 50 m. It is presented by filled depressions and valley forms. Filled mesoforms are also present: dolines, ditches, depressions, ravine gullies, ponors, sinks etc. The density of mesoforms is about 30-50, maximum 90-270 per km^2. At hydrological level karst is present as karst springs, karst lakes of different size, often with water-level change and periodically disappearing lakes.

Karst formation in limits of Dvinsko-Mezenskaya karst area is connected predominantly to sulfate rocks. The surface terrain karst holds 500-700 forms per km^2, in places of extreme karst development it exceeds 1500 forms per km^2, maximum - 2800 forms per km^2. On Belomorsko-Kuloiskoye plateau especially its southeast part the effect of continental glaciations on karst development left a series of unique features, which do not appear, on neighboring terrains.

The modern appearance of relief defined the position of terrain on the joint on one hand of Poltinskij and Pinezskij glacier tongues of Severodvinsk glacier front (lobe) of Scandinavian glacier center, on the other hand Kuloj tongue of Mezenskaya glacier front (lobe) of Barents-sea glacier center. The maximums of two last glacier tongues development were time-shifted by 10 thousands years (Malkov *et al.*, 2001). Therefore in the average flow of Sotka River there was a nunatak, which was not covered by continental ice (Malkov *et al.*, 1987). In limits of nunatak weakened karst and erosion-denudation processes did not stop even during the progressive phase of glaciation. To west from nunatak there are belt of peripheral glacier accumulation with karst basis and marginal moraine massif with composite combination of segments of glacier morphosculpture. In a peripheral zone of glacier by exaration subglacial gullies and valleys were formed by cutting into the karst basement. The plains and adjoining stripe of relief have clear marks of karst formation origin before decay of glacier sheet (Shavrina, Malkov, 2000).

Some parts of old depressions and poljes was slightly opened, filled by deposits but has kept its dissection karst bottom. Other part of relief forms stayed uncovered and were included into the structure of valley relief. Many small karst forms were filled and transferred into buried or half-buried conditions. There are exaration relief segments built by gypsum rocks and covered from above by caps of dead ice. Ice melting lead to karstification of the fissured gypsum rocks and formation of unique «shelopnyak» fields that are located at side zones of valley forms of karst (Fig. 2).

Fig. 2. «Shelopnyak» fields in valley of Chuga River

«Shelopnyak» is a combination of singular, linear surface and transition elements dissecting an open surface of karst rocks occupying large space and built by general forming process. Elements of «shelopnyak» field are: doline-like, tubular-like, pit-like fissure and cleft hollows and also dividing them different kinds of partitions. «Shelopnyaks» are connected with erosion-glacial, denudation-valley, and karst-denudation inside-valley relief. The greatest concentration of «shelopnyak» formations is found in belt between rivers Chuga and Ugsenga. Belt width reaches 5-8 km, in some places it is about 0,5-1,5 km. The segments of «shelopnyak» in bare karst are islands among the hummocky glacier relief. The thickness of glacial deposites change from 0-2 m up to 5-6 m.

Karst buttes represent residual rock ledges cut away from a basic massif as a result of karst-formation and general denudation. All forms are connected with sulfate karst. Buttes of meso-level are dated back to zones affected by dammed basins and are subdivided into three kinds.

Buttes-pillars are situated in sides of large depressions on collapse-block slopes. From above pillars have a smooth washed shape. Less often pillars situated on isolated ledges at the valley bottom, where they have pointed shape and remnants of destroyed caves.

Buttes-towers are completely separated from basic massif and have sharp or washed sides. Standing in groups towers have upper surfaces at one level. Usually on the top there is a vegetation-soil layer on crumbly sediments that allows rare trees to grow. In case of destruction of vegetative layer the top of a tower becomes pointed shape and begin quick destroyed. In a classic form buttes-tower are found on the bottom of Eraskina depression (Fig. 3).

Buttes-humps are isolated hilly rock ledges of a whole or destroyed rock massif. They rise 10-12 m above the bottom of valleys (depressions) and are very rare. The karst buttes-hills are forms of macrorelief and appear on interception of valleys of different orders or at bifurcations in valley entry. Macro-buttes indicate a long period of karst evolution in conditions of multi-stage development of a relief. The size of macro- buttes changes in following limits: diameter 100-700 m, length 150-740 m. What concerns the height they could be divided into two groups: from 10 up to 15 m, and from 15 up to 30 m.

Due to abundant subglacial and melt water runoff Late Valdaj glaciation has rendered grate effect on underground karst development. This runoff moved in existing and new-formed network of karst-denudation valleys and has supplied concentrated feeding and intensive growth of existing caves and formation of the new forms (Malkov *et al.*, 1987). Some caves under influence of glacier pressure and valley side cutting were open and in a different degree destroyed. Other caves have stopped their growth after ice completely melts. A number of large caves developed with maximum effect and confluence of several galleries at different hypsometric levels. The formation of the majority of caves went in water pressure conditions (guided phreatic). It was conditioned both by general under-glacial caverns position and reaction of earth crust to distribution of continental glaciation (Malkov *et al.*, 1987).

There are original systems of small-sized caves of «shelopnyak» level (on 2-3 m deep from surface). Caves were formed under the glacier but now are drained and are largely destroyed. On occasion in valley side zones there are small-sized gravitational caves and cavities developed above karst cavities as a result of their roof collapse.

The accelerated development of Late Valdaj age caves was prolonged up to a standard degradation of glaciation and isostatic raising of terrain what caused a reorganisation of water feeding and increasing cavities drying.

Such considerable and different effect of continental glaciations before was marked only for karst of Canada, where it is exhibited mainly in carbonate rocks (Brook, Ford, 1978; Ford, Williams, 1989). Nevertheless for sulfate rocks of southeast of Belomorsko-Kuloiskoye plateau all consequences of development of a paragenesis karst - continental glaciation marked in Canada are detected. In European North as well as on karst terrains of Canada «the glacier-karst interactions are set in a queue from temporary conservation of preglacial karst up to its full destruction; from exception of any after-glacial karst up to its fastest development» (Ford, Williams, 1989).

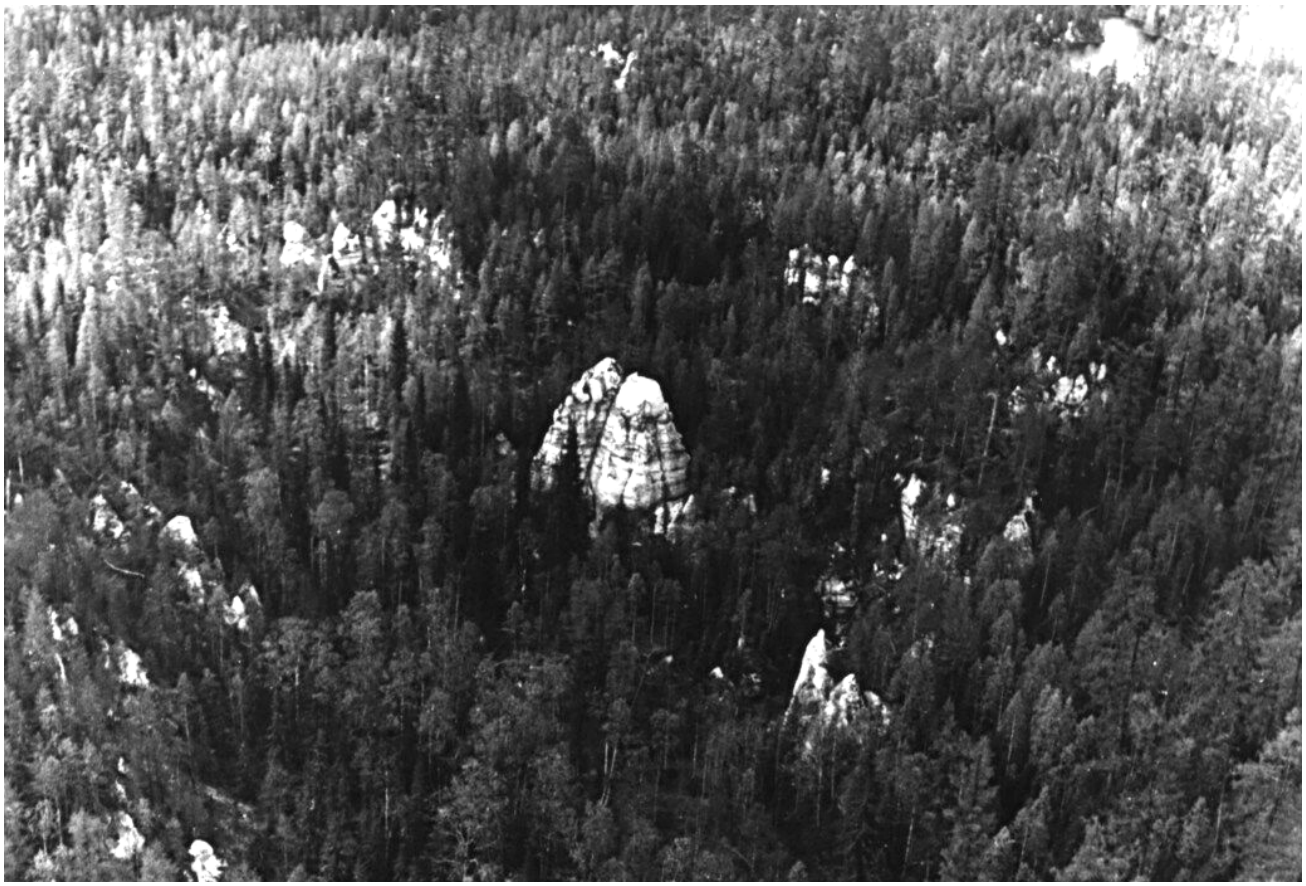

Fig.3. Buttes-towers, Eraskiny Lakes

The fourth stage of karst genesis occurs in Holocene. During which following events took place: a degradation of permafrost zone, origin of river runoff, cutting of an erosion network, level falling of after-glacial watershed lakes and their almost complete swamping, development of forests, rhythmic sequence of cold and warm periods. Thus different tendencies of karst development came into play. In surface relief linear and plan macro-forms moved into stage of weakening and degradation. A part of meso-forms inherited from late Ice Age period became active in their development. Other part of meso-forms was filled and began its existence in a passive state.

On considered stage linear meso-forms and microforms and also a large number of hotbed meso-forms were appeared. Due to their youth this formes are characterized by active karst processes. In underground karst occured a general decrease of water, concentration of active processes in karst-erosive links of water systems, formation of young vadose cavities and destruction of upper levels of underground relief. Affected by continental glaciations karst in the European North in its development undergone a series of denudation condition, characterized by increase of karst scale and evolutionary maturity. In this connection five main stages of karst denudation are pointed out for the region: 1) covered-closed; 2) covered; 3) semi-open; 4) open; 5) uncover-buttes.

Covered-closed stage. Karst massif lies on considerable depth (more than 10-15 m) under a cover of friable deposits. Depending on a permeability and the thickness of deposits, karst features on surface could be absent or seen by contours of buried forms. In buried rock massifs ancient dead or partially rejuvenative and also rejuvenative and generate forms are present. On segments of neo-tectonic raisings in a band of denudation cuttings karst-erosive elements are developed, which make the absorption of a linear drainage.

Cover stage. The friable sediment cover is disturbed by old and young growing karst forms. They envelop the rock massif, pierce the sediments cover and come out on the surface. The depth of a massif position is greater than the depth of surface forms. At the bottom of forms as a rule there are no elements of active karst processes such as ponors and sinks. By decrease of friable sediment cover thickness on areas of buried and half-buried karst cover stage changes for cover-screen stage. It differs by high density of karst forms, instability of morphological features and size of forms, oscillation of altitude of a boundary valley edge, availability of elements of activation.

Semi-open stage. Karst massif is covered with a friable cover of not significant thickness. Karst forms of active and passive nature are intensively developed. They vary in size and morphological constitution. The existing forms cut into upper part of karst massif therefore at the bottom and in the sides usually rock outcrops are seen. In a karst relief usually numerous micro, meso and macroforms are found with elements of activation or phase activations or passive karst developments.

Fig. 4. Tunnel gallery in Golubinskij Proval Cave

Open stage. Karst massif lies at ground-level and cut by karst forms on all depth. The friable cover is not complete, very small in area - up to 2,0 m sometimes up to 0,5 m or is not exist. The presence of a soil is typical. Karst in form of karren have limited presence. Typical forms in the area of ancient continental glaciations are «shelopnyaks» and «shelopnyak fields» of composite structure.

Uncovered-buttes stage. Present on sites of differentiated stratum-denudation relief, where karst massif lies at different altitudes and derivates ledges on ground-level, such as buttes, buttes-tower and hills. Friable cover is not thick in some places is broken. On subhorizontal surfaces cave forms of different safety are exposed. Formation of this stage is shown the most ancient karst relief sites.

Conclusions

Thus in European North of Russia favourable combination of unique geological conditions and features of natural-historic development has resulted in formation of a peculiar and unique complex of denudation-accumulation relief. Its development was conditioned by long-term effect of geological processes first of all karst and glacial ones. The appearance of terrain relief built up to the moment of degradation of the last Late Valdaj sheet glaciation. In the modern period (last 9 thousands years) the inherited development of underground and surface relief progresses predominantly influenced by karst and karst-connected exodynamic processes.

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