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GLACIAL KARST, WHY IT IMPORTANT TO RESEARCH
LEDENIŠKI PSEVDOKRAS

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Bulat R. Mavlyudov: Glacial karst

Glacial karst (GK) is combination of phenomenon and processes as a result of which specific surface forms and cavities inside ice are formed. Hummocky relief with abundance of lakes, channels and reservoirs inside ice and on ice-rock contact are typical for GK. GK development occurs under acting of physical process of ice melting instead of limestone dissolution in classical karst. However processes directivities and arising forms in both cases are similar at system level. As karst processes in ice origin very fast it is give possibility to use them as physical models for limestone karst. Vice-versa, we can understand GK better if we use results of limestone karst investigations. However in both cases only general regularity can be used because some specific features are typical for each kind of karst. GK shows in development of such forms in ice: internal drainage systems (moulins, shafts, cascades, vadose galleries and phreatic channels, siphons, griphons) and under ice (vadose and phreatic channels), dry and water fill dolines on clean ice and on ice covered by moraine (debris-covered glaciers), glacier caves. Stages of GK development completely correspond to stages of limestone karst development. But because of glaciers motion it is possible to observe all stages of GK development on the surface of the same glacier from decrepit (at glacier tongue) up to early (in upper part of ablation zone). GK has large significance in glaciers evolution. GK is widely spread in all temperate and polythermal glaciers of the world. The accelerated glaciers degradation in present time gives a task of mandatory analysis of GK because of many glaciers can disappear very soon.

Keywords: glacial hydrology, debris-covered glacier, karst of glaciers, internal drainage systems, glacial karst evolution, similarity of glacial and calcareous karst.

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Bulat R. Mavlyudov: Ledeniški psevdokras

Ledeniški psevdokras je skupek procesov, katerih rezultat so značilne površinske oblike in jame v ledenikih. Za ledeniški psevdokras je značilen grbinasti relief z jezeri in kanali v notranjosti ledenika in ob stiku led-kamnina. Procesi, ki ustvarjajo ledeniški psevdokras in kras v karbonatih in evaporitih se razlikujejo, vendar so oblike, ki nastajajo v obeh sistemih, podobne. Procesi v ledu so hitri, zato je ledeniški psevdokras lahko primeren fizični model krasa v apnencu. Po drugi strani lahko s poznavanjem krasa v apnencih bolje razumemo ledeniški psevdokras. Seveda govorimo le o splošni podobnosti med fenomeni, medtem ko se oba tipa "krasa" v podrobnostih razlikujeta. Stopnje razvoja ledeniškega psevdokrasa se ujemajo s stopnjami rasvoja v apnenčastem krasu. Zaradi gibanja ledenika lahko razvojne stopnje ledeniškega psevdokrasa spremljamo vzdolž ledenika, od jezika do ablacijske cone. Ledeniški psevdokras je razširjen v ledenikih zmerne klime (temperate glaciers) in v politermalnih ledenikih.

Ključne besede: ledeniška hidrologija, pokriti ledenik, ledeniški psevdokras, notranji drenažni sistem, podobnost glacialnega in apniškega krasa.

*Author uses the term Glacial karst, which denotes features on the glacier surface and inside the glacier that result from the melting of ice. Other terms are used for his phenomena, like *Glacier pseudokarst* (see John Gunn (ed.), Encyclopedia of Caves and Karst, Fitzroy Dearborn, 2004)

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INTRODUCTION

In XIX century there was no karst division into separate kinds by rocks structure. Limestone on continents is the most widespread rock, which have direct or indirect influence on people life. Superficial and underground karst forms have begun to study mainly in limestone areas. Other kinds of karst rocks occupy smaller areas on the earth, therefore karst phenomena in them were studied less often. Glaciers are situated only in mountains and in Polar Regions, because features of their superficial relief and cavities have investigated later. We considered history of glacial caves research earlier (Mavlyudov, 2004a).

HISTORY OF GLACIAL KARST STUDY

Researchers were interested with perennial ice in calcareous cavities. But as caves in glaciers were considered as caves with ice in limestone these absolutely various cavities by genesis have received the uniform name «ice caves» and quite often studied by the same researchers (Balch, 1900). But nevertheless many scientists quite understood difference between these caves and specially accented attention on it (Browne, 1865, Listov, 1885). But about similarity of karst phenomena in glaciers and in limestone scientists began to speak only at the end of XIX century (Sieger, 1895). He said that porosity, solubility and weakened planes to the same degree characterized both for ice and limestone. Similar forms for glaciers and limestone are: karrens, natural shafts, moulins, caves, galleries, dolines, depressions without runoff etc. He found conditions necessary for relief formation on glaciers that similar to karst relief: flat glacier surface with small quantity of crevasses and slow ice movement. Moraine cover on ice surface protects it from melting but ice ablation occurs with large intensity only on walls of crevasses and moulins. At the end of XIX century this phenomenon was known for glaciers of Europe, America, New Zealand and Polar areas. Sieger considered that it is necessary to collect additional information for explanation of this karst analogy in limestone and ice.

Famous Russian geographer A. A. Kruber (1915) wrote that «karst phenomena origin in gypsum, in salt, in ice, but, firstly, these rocks in comparison with limestone occupy considerably smaller areas, and, second, the phenomena in named rocks represent some specific features in comparison with phenomena in limestone». Thus, Kruber did not distinguish karst phenomena in limestone, gypsum, salt and ice.

The first who in Russia has used for glaciers term GK was geographer S.V. Kalesnik (1935, 1939). He comes to conclusion about GK existence after study glaciers in headstream of Naryn River (Tien Shan) during 2nd International Polar Year. Describing dolines and moulins at tongues of some Central Asian glaciers (on Zerafshan Glacier, on Petrov's Glacier, on Pamir glaciers etc.), Kalesnik wrote that «apparently, here before us is *glacial karst* that is especially probable on glacier tongues, in areas of maximal ice melting and maximal concentration of subglacial water. Because GK originate in plastic material this is a reason why all crevasses origin after collapse of ice above subglacial tunnels are masked, soldered and alloyed».

Term GK with reference to geomorphology is present in monumental work devoted to quaternary glaciation (Charlesworth, 1957) in which it is spoken about GK wide spreading on glaciers in different parts of the world, which differ by small surfaces inclination and slow movement. For ice with moraine cover cryoconite holes, dolines and depressions with moulins and without them, karrens, caves and under surface rivers, blind and dry river valleys are typical. All of these forms have the duplicates in limestone. He distinguishes GK and karst only by ice plasticity and by presence of moraine cover on ice.

In the other book Kalesnik (1963) give other name for this phenomenon – *ice karst.*

Repeatedly GK concept in glaciology is entered a little bit later (Clayton, 1964). In opinion of the author for GK a plenty of dolines and depressions (frequently filled by small lakes), tunnels and caves, disappearing waterstreams, blind valleys, large springs, natural ice bridges and arches, karrens, separate ice blocks and residual sediments (ablation tillites) are typical. He saw full analogy of forms in ice and limestone. Therefore he has automatically transferred development laws of limestone karst to GK. There are 4 same conditions necessary for GK and limestones karst origin, which were precisely formulated in the middle of XX century (Thornbury, 1954), but were known earlier (Kruber, 1915).

It was supposed that GK was widely distributed on dead edges of North American glacial sheet in time of its degradation (Clayton, 1964). In our opinion fast destruction of glacial sheets, which edges at last glaciation were terminated on land, depends on wide GK development (Mavlyudov, 2005, 2006).

During many years after Clayton's publication term GK in glaciology was almost not mentioned. Usually considering relief on glaciers tongues recently began to use term «debris-covered glaciers» (Nakawo, Young, 1981). Cross relief and huge lakes quantity are typical for such glaciers. Generalization of publications about GK was made in one of glaciology reports (Benn, Evans, 1998). But it begins since Clayton only.

In work (Benn, Evans, 1998) it is marked that moraine sediments on ice restrict ice melting and it concentrates mainly in places where moraine cover is broken: on moulins walls and on slopes of dolines and lake depressions. Depressions slopes become too abrupt to keep of rock debris so clean ice here is usually exposed; intensity of ice melting here is maximal. Ice melting on walls (backwasting) – one of the most important components of ablation in lower glaciers parts covered by moraine such as Khumbu (Nepal) or Tasman (New Zealand) (Iwata, *et al.,* 1980, Kikbridge, 1993 and others). Importance of ablation localization in vicinities of depressions and crevasses on retreating debris-covered glaciers tongues just also had result, in opinion of authors, occurrence of term GK. Certainly, GK and limestone karst are not identical processes. Fissures in calcareous areas extend by calcium carbonate dissolution, and on glaciers crevasses extend preferably by ice melting. In the first case it is chemical process, in the second – physical.

Very detailed description of sedimentary and erosive processes and relief forms connected with each stage of GK development was given for edges of outlet Kötlu Glacier, Myrdalsjökull in Iceland (Krüger, 1994).

In work (Benn, Evans, 1998) it is shown that GK may occur at tongues of surging glaciers when after fast motion glacier tongue remains motionless for a long time.

TERMINOLOGY OF GLACIAL KARST

Recently GK study have progress as a result of creation of the international commission «Glacial Caves and Karst in Polar Regions» (GLACKIPR) in structure of IUS (Actes, 1995, Eraso, Pulina, 1992, 2001, Proceedings, 1991, 1992, 1998, 2002, 2003, 2005). Big part of symposiums materials connected with GK study. In 1994 question of commission renaming was discussed. Term «cryokarst» in the name of commission has received biggest (but not common) recognition in comparison with term «karst». It has resulted that 3-5 commission symposiums occurred under the name «Glacial Caves and Cryokarst in Polar and High-Mountains Regions». However ambiguity of term «cryokarst» has resulted that since 6th symposium in 2003 the commission has returned to the former name. It is not necessary to forget that the term «cryokarst» is the European analogue of the term «thermokarst» (Monroe, 1976), i.e. it is more applicable to frozen rocks than to glaciers.

In Russian glaciology term GK of Kalesnik is not used any more. In glaciological dictionary (Kotlyakov, 1984) this term is absent. In karstology for description of glacier caves firstly was used the term «thermokarst» (Maksimovich, 1963), but subsequently this term began to name areas with thaw dolines in frozen rocks. In karstological literature the term «pseudokarst» more frequently used (Andrejchuk, 1992). However this term ignore similarity of the processes in ice and in soluble rocks and also full coincidence of their karst forms. Some attempts of introduction of new term for description of processes in ice were undertaken. For example term «glaciokarst» was offered (Andrejchuk, 1992). But this attempt cannot be named successful as this term for a long time is used for designation of karst in limestone, originated under glaciers or activated by glacial meltwater (Monroe, 1976).

As now study of glaciers relief that similar to karst began increase, it is quite obvious, that has ripened necessity for term describing formation of this specific relief. For our opinion it would be reasonable to use term Glacial Karst (GK). This term shows that phenomena in glaciers are very similar to phenomena in karst rocks. The word «glacial» (but not ice) means features of this type of karst is formed not simply in ice but namely in glaciers. On analogies, calcareous karst it will be necessary to name «karst of limestone massifs» or «limestone karst».

CYCLE OF GLACIAL KARST DEVELOPMENT

On available representations (Clayton, 1964) by analogy to karst in limestone (Kruber, 1915) cycle of GK development consists of three stages: young, mature and decrepit. Basing on works (Cvijich, 1909, 1918, Kruber, 1915), we have added in cyclic evolution of GK delopment one more stage – early stage (Tab. 1) (Mavlyudov, 2004b). On the same glacier it is possible to find all stages of GK development from the earliest up to decrepit stage (Fig. 1). This is one of essential distinctions of GK from calcareous karst. Especially well it can be seen in tongues of retreating glaciers (from the ice edge) where it is possible to see gradual transitions from decrepit stage of GK through mature to stages of youth and early. On active glaciers the set of these stages will be incomplete. Frequently on such glaciers it is easy to find only early or less often – young stages of GK development.

Briefly we shall consider each stage of GK development.

EARLY STAGE.

For this stage of GK development is typical almost full absence of superficial forms and weak channels development inside glaciers. Glacier surface here is completely free from moraine. Besides, this area is situated closely to snowline (ELA) and may completely or not completely be clear out from snow in separate years. At presence firn there may be channels as in it thickness (originate at vertical infiltration of meltwater jets), and on firn/ice contact. However these channels are insignificant. As catch areas of superficial water streams are still insufficiently extensive, large internal channels here may not form yet. Dye tracing of water carried out closely to ELA have shown that water moves from here up to glacier tongue with very small velocity. Time of water movement was about some weeks (Bingham *et al.,* 2005 and others). It says about small channels opening in the upper part of glacier ablation zone. Nevertheless these channels exist, that allows allocating this stage of GK development. This stage may develops in the lower part of accumulation and in the upper part of ablation areas not only there, where there are water streams on glacier surface and crevasses in ice, but also where water inflows from areas adjoining to glacier or drain from lakes situated on rock/ice contact.

Tab. 1 – GK development cycle (Clayton, 1964) with author changes

	Stages GK development			
	Early	Young	Mature	Decrepit
Karst forms	Channels in snow, firn, on contact ice/ firn, small moulins, widen crevasses, englacial channels	Moulins, shafts, englacial and subglacial channels	Dolins, caves, tunnels, water channels	Karst windows, depressions, котловины, uvalas, residual ice blocks
Drainage	Mainly surficial	Partly surficial, partly internal	Mainly internal	Internal, surficial (after ice disappear)
Ice thickness, m	150-400 and more	50-150	10-50	0-10
Surficial moraine deposits, thickness, m	Absent	Absent, except median moraines, some centimeters	Some centimeters, later > 1 m, unstable	From 1.5 to > 3 m, stable
Vegetation on moraine deposits	No	No	First weakened grass; subsequently bushes	Grassy and wood vegetation
Lakes, cleanliness of water, density of population	Rare lakes, in cracks, cold, transparent, without life	Enough rare, cold, transparent, without life	In dolins, cold, silty, without life	In dolines, depressions, uvalas and poljes; isolated from ice by moraine sediments; warm and clean; fresh-water plants and animals
Glacier movement	Active	Inactive	From small activity to motionless	Immobile

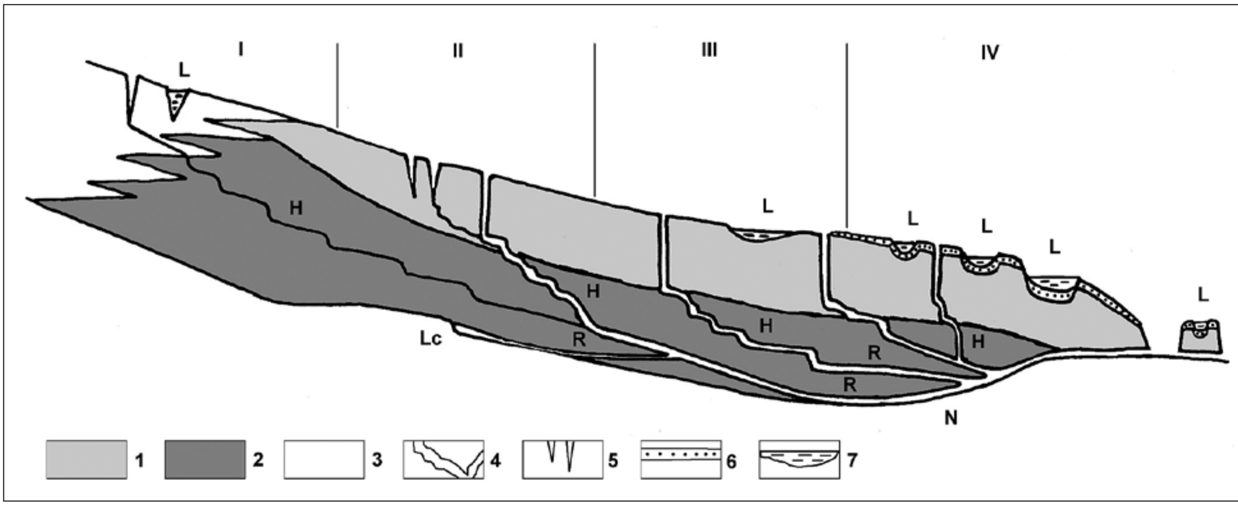

Fig. 1. Scheme of glacier with internal drainage system; on the right – massif of dead ice. 1 – cold ice layer; 2 – temperate ice layer; 3 – snow and firn; 4 – englacial and subglacial channels; 5 – glacial crevasses; 6 – moraine cover; 7 – lake water. H – vadose englacial channels (Hooke channels); R – freatic englacial channels (Röthlisberger channels); N – subglacial channels (Nye channels); Lc – linked-cavities channels behind bed ledges; L – lakes. I-IV – GK stages: I – early, II – young, III – mature, IV – decrepit.

YOUNG STAGE.

Boundaries of this stage distribution on glaciers are upper part of ablation zone above and a zone of occurrence of median moraines on ice surface – below. On active glaciers this stage may occupy almost all ablation area. On less active glaciers area of young stage may occupy half of ablation area. On almost motionless glaciers young stage can be found out only in the uppermost parts of ablation area (Fig. 2). As catch areas here are extensive enough, large superficial water streams may be formed. It promotes development of large channels in internal drainage. Occurrence of median moraines often promotes stream localization along moraines and formation of large water-streams. It leads to formation of developed systems of an internal drainage. Dye tracing of water streams has shown, that water velocity through channels beginning in this zone, are comparable to velocity in superficial water-streams and may reach 1 m/s (Stenborg, 1969 and others). Our speleological researches have shown that channels sizes inside ice are great enough: pits have depth up to 100 m and more, pits diameter may be up to 10 m and more, galleries width may be 0.3-4 m, height of galleries – from 2 up to 20 m. The channels sizes directly depend on volume of water-streams absorbed in ice. Superficial

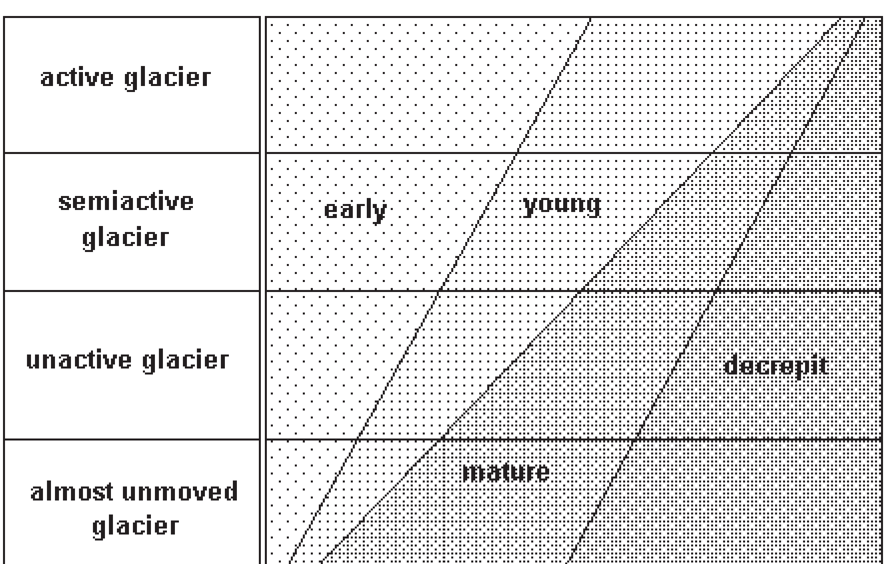

Fig. 2. Relationship of sizes of various zones appropriate to different stages of GK development on glaciers with different activity degree.

forms are submitted basically by closed lake depressions on ice, which are not numerous. Their number may grow in places of crevasses formation.

MATURE STAGE.

This stage is typical for parts of glaciers covered by moraine (Fig. 3). In the upper part of this stage zone moraine cover does not exceed 1/3 of glacier surface but in the middle part moraine covers ice completely. Thus in direction to glacier tongue thickness of moraine cover grows up to meter and more. At moraine cover thickness lower then 10 sm there is ice-melting activization due to stones heating (Nakawo, 2000). This is expressed in growth of quantity of meltwater on glacier surface. When moraine thickness exceeds 10 sm reduction of ice melting begins. At moraine thickness more than 0.5-0.7 m ice melting practically completely stops. For upper part of mature zone wide development of superficial water-streams and internal channels are typical. For lower part of mature zone superficial water-streams are not usual and for glacier surface smoothed hummocky relief is typical with plenty of dolines and depressions, many of which are occupied by lakes. Ice melting occurs here basically on lakes slopes. Lakes water is heated up much more strongly than ice covered by moraine (Sakai *et al.,* 2000). For this reason lakes quickly grow.

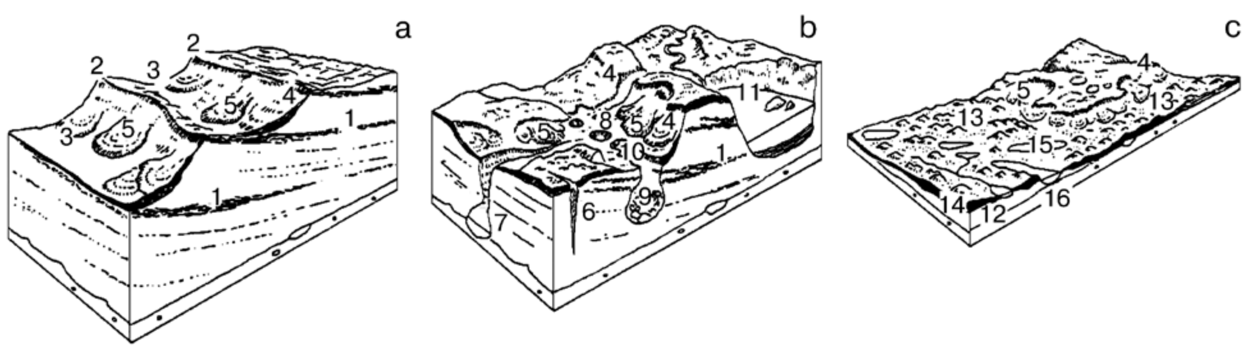

Fig. 3. Block-diagram showing development of mature and decrepit GK stages (Krüger, 1994). a-b) mature stage; c) decrepit stage. 1 – strips of rock fragments in glacial ice; 2 – ridges with ice core; 3 – through-shape valley; 4 – melting escapes of clean ice; 5 – rock fragments flow (colifluction); 6 – crevasses expanded by melting; 7 – subglacial channels; 8 – dolines; 9 – collapsed arch of tunnel; 10 – doline expanded by melting and collapse; 11 – lake extending due by melting on slopes; 12 – dead ice; 13 – hummocky plain, free from ice; 14 – superficial glacial sediments; 15 – lakes; 16 – subglacial sediments.

Quite often this stage, which is well expressed in relief on glacier surfaces, is named as GK (Krüger, 1986, Benn, Evans, 1998). In dependence of dammed degree of glacier tongues GK development may realized both by lake or dry scenario (Mavlyudov, 2005). Lake scenario of GK mature stage develops where glacier tongue is dammed by rock bar or end moraine. It conducts to formation of extensive lakes connected by numerous englacial and subglacial channels. Subsequently small lakes merge into one large lake. After that development of karst process departs on second plan and as the first acts calving.

Absence of glacier tongue damming leads to GK development under dry scenario when lakes exist at different levels. Expansion of lakes depressions occurs on ring crevasses by ice collapse (Fig. 4). As a result of GK activity glacier will disintegrate completely (at lake scenario) or will broken into separate blocks of dead ice (at dry scenario).

Fig. 4. View on collapse of dry scenario of mature stage of GK. Bashkara Glacier, Central Caucasus, 2005.

DECREPIT STAGE.

This stage develops on tongues of motionless glaciers or within the limits of isolated dead ice massifs (Fig. 3). Thickness of moraine cover changes from 1 to 3 m. Numerous windows are typical even at continuous ice cover. Except dolines and small depressions larger depressions – uvalas and poljes here are typical also. Water streams wandering under ice provide fast ice destruction. Wide directions range for water streams provides formation of big quantity of caves with small water streams. Galleries expansion in caves includes also action of airflows. Because of small ice thickness caves galleries are not compressed by plastic deformation. But for galleries are typical vaults collapses. In process of GK development area of glacier ice decrease. It continues until complete ice disappearance.

There are some variants of transition from one GK stage to another: 1) in active glaciers, 2) in motionless glaciers. In first case at stable position of ELA there is evolutionary displacement of GK stages boundaries in direction of glacier tongue. That is why area of young stage of GK development is displaced on glacier downwards turning into mature stage. By similar way changing of other GK stages occurs. All stages of GK development are formed approximately in one place of glacier surface during the long period. In this case boundaries of stage zones of GK development remain approximately on the same places. At ELA lowering there will be replacement of all zones boundaries in direction to glacier tongue.

Progressive movement of all GK zones boundaries in direction to upper glacier part will occur at glacier edges retreating and ELA increasing. When processes of GK formation will include all glacier surface, the further decreasing of glacier dimensions will result in size reduction or full lost of upper zone (early stage). So quantity of zones may be reduced gradual. After some time there will be only one zone (decrepit stage). Then the glacier will completely disappear.

In surging glaciers all events occurs by other way. In period before surge all GK stages will develop in glacier ablation area. During surge all GK structures will be completely destroyed. As ice melting during surge does not stop but existing ways of water throughflow will be destroyed during glacier motion, it may stimulate local water accumulation in englacial and subglacial reservoirs. It can lead to sudden water outbursts from under glaciers during surge. After surge GK structure begins to restore on all extent of ablation area. Firstly all ablation area will be in early and young GK stages. Intensity of GK development will increase in area of dead ice. It connects with features of local climate (warmest on glacier), moraine cover thickness on glacier surface, big quantity of crevasses, the crossed glacier surface that provides fast development of numerous lake depressions and their intensive growth. Therefore in the lower glacier part GK develops more intensively than in other glacier parts. It will result appearance firstly of two, then of three and, at last, of all 4 GK zones in ablation area. Increasing GK development in area of dead ice promotes accelerated ice degradation that prepares possibility for new glacier surge. It seems that calculated and real ice melting intensity under moraine cover differs very significant. Full destruction time of the Glacier Kolka tongue in the Caucasus after surge in 1969 was estimated as 25-30 years (Khodakov, 1978). But really glacier tongue has disappeared after 11 years. It means that GK increase ablation of debris-covered glaciers in some times.

Now we will outline channels evolution inside glaciers. Some authors (for example, Mikhajlev, 1989) tried directly apply schemes of karst cavities evolution to GK cavities. He considered that glacier caves as well as limestone caves evolve through following stages: crevasse-slot-hole, crevasse-channel, gallery, channel and collapse. In his opinion, the crevasse-slot-hole stage is characterized by occurrence of open fissures on glacier/bed contact and in glacier body in accumulation zone. Crevasse-channel stage is characterized by occurrence of narrow horizontal subglacial crevasses on contact with bed in accumulation area. Gallery stage is typical for ablation area with development of subglacial and englacial channels. Channel stage is usual for ablation zone with active development englacial and subglacial caves. Separate grottoes may reach 30-40 m length and 20 m height. Vaults collapses in subglacial caves conduct to formation of large dolines and depressions on glacier surface. Collapse-ablation stage is typical for moraine-covered part of glacier. Caves roof collapses and depression sizes growth are typical for this stage.

However we automatically may not transfer character of limestone caves development on ice. Against limestone caves, which mainly change in agreement with all these stages, in ice only channels at glaciers tongues can evolve through all this stages. Other channels may develop only up to gallery stage but then channels can completely disappeared because of secondary ice filling or under action of ice plastic deformation (creep). We know that later type channels on glaciers consist overwhelming majority.

GLACIAL KARST SPREADING

GK is enough widespread phenomenon. It was found on a plenty of glaciers all over the world: in Alaska (Clayton, 1964; Russel, 1893; Tarr, Martin, 1914), in Iceland (Krüger, 1994; Badino, 2002; Eraso *et al.,* 2002), in Spitsbergen (Gallo, 1977; Griselin, 1991; Shroeder, 1991, Krawczyk, Pulina, Rehak, 1997; Pulina, 1982, 1984, 1997; Mavlyudov, 2002; Mavlyudov, Solovyanova, 2003), in the north of Canada (Iken, 1972, Bingham *et al.,* 2005), in Sweden (Stenborg, 1968, 1969; Holmlund, 1988), in Caucasus (Mavlyudov, Solovyanova, 2005), in Alpes (Maroue, 1995, Piccini *et al.,* 2002), in Altai, in Central Asia (Kalesnik, 1935; Mavlyudov, 1994, 1995; Popov, 1936; Spengler, 1936; Badino, 2002), in Himalayan (Iwata *et al.,* 1980, Mavlyudov, 1992), in Andes (Aniya, 2001), in New Zealand (Kikbridge, 1993), Greenland and Antarctica (Eraso *et al.,* 1991) and in other places. Absence of any regions in the previous list simply means insufficient quantity of researches in this area. GK play important and possibly also an integral role during destruction of the majority of temperate and polythermal glaciers, especially if they are in retreating stage.

SIMILARITY AND DIFFERENCE OF GLACIAL KARST AND LIMESTONE KARST

Similarity GK and karst in soluble rocks is shown in convergence of cavities forms. Similarity of GK and karst is determined by identical conditions of cavities formation in soluble rocks and in ice. For cavities formation is need: 1) soluble rocks, 2) fissures and crevasses in rocks, 3) solvent of rock, 4) solvent movements and aggressiveness. Similarity of features of karst and GK also is shown in similarity of characteristics of both drainage systems. They have similar structure (arborescent channels form), an evolutionary cycles, seasonal prevalence of development, dependence on climate and rock conditions; they are singenetic to relief, divided into superficial and internal components.

Despite of processes difference of chemical rocks dissolution and physical ice melting both these process lead to identical results – loss of rock or ice layer on channels walls on contact with water-streams. Not consider kinetic of process of rock chemical dissolution by action of water streams and process of ice melting under action of water streams at molecular level we may speak about general similarity of this processes. This processes similarity is determined by similarity of curves of limestone dissolution and ice melting, which have linear character (Gabrovchek, 2000; Shumskij, 1955).

Formulas of carbonate concentration changes in water and of ice melting under action of water streams in time are almost similar (Eraso, Pulina, 1992, page 14-16). This similarity also defines forms of convergence in limestone and in ice. And as solvent in both processes is one substance – water, it defines similarity in hydraulic processes in both cases. This similarity underlies of possible data exchange between GK and karst in soluble rocks in the field of cavities origin and evolution.

Distinctions of processes occurred in limestone and in ice are determined, first of all, by various physical properties of ice and rocks. Density of ice is 917 kg/m^3, density of limestone – 2500 kg/m^3, heat conductivity of ice is 2.22 Wt/(m°K), heat conductivity of limestone – 0.9 Wt/(m°K), specific thermal capacity of ice is equal 2,12 KJ/(kg°K), specific thermal capacity of limestone – 2.5 KJ/(kg°K) (Shumskij, 1955, Dzidziguri *et al.,* 1966). As we see, the basic distinctions between limestone and ice are shown in rocks density, which approximately in 2.5 times is higher for limestone, and in heat conductivity which approximately in 2.5 times is more for ice. The last means that at identical heat arrival to both rocks, ice will heat up less than limestone. But it also means, that for cooling of ice and limestone on equal quantity of degrees, from the first it is necessary to remove approximately in 2.5 times heat more than from the second.

But the basic distinctions of processes occurring in limestone and ice are determined not by distinction in rocks thermophysical properties but by speed of their destruction. Therefore distinctions of processes in soluble rocks and in ice are determined by: speed of processes or speed of superficial and internal forms development; duration of evolution cycle; abort of development in winter time; presence of ice movement; presence of ice plastic deformations; ability for ice to heal of crevasses and cavities; influence of thermal conditions of ice; monolithness of ice, absence of some types of fissures in ice; difference of chemical process of rock dissolution from physical process of ice melting; channels displacement downwards on glacier during evolution.

Essential difference in physical properties of limestone and ice is shown in significant distinctions in behavior of drainage systems inside these rocks. But common structure of internal drainage systems in both rocks allows to speak about similarity of evolution of internal drainage in both rocks at a level of system.

The ideological affinity of glacial hydrology with karst hydrology and speleology means not only affinity in research methods of drainage systems in glaciers and limestone, but also affinity of theories describing drainage systems and their separate elements origin and evolution. For this reason many conclusions about GK structure and evolution are received by analogy to structure of drainage systems in limestone (Mavlyudov, 2006).

IMPORTANCE OF GLACIAL KARST STUDY

Internal glaciers drainage study is necessary part of nival-glacial systems researches (Krenke, 1982). GK has complex influence on glaciers. Investigations has shown that GK presence in glaciers cardinally changes physical ice properties, ice permeability for water, structure and chemistry of glacial runoff, character of sediments removing by water streams, separate characteristics of glaciers: water level position in different parts of glaciers, changes of cold ice layer thickness by ice warming around drainage channels. All these changes can be incentive reasons of numerous phenomena in glaciers: water outbursts, winter runoff, changes in speed of ice movement, glaciers surges, accelerated deglaciation. At some stages of glaciers evolution (in particular in deglaciation period) GK begins to control practically all processes in ice thickness and many processes on glaciers surface, becomes determining factor of glacier development.

Without taking into account GK influence on glaciers mistakes are possible in: 1) hydrological calculations; 2) hydrological processes modeling in glaciers; 3) results interpretation of majority of indirect methods of GK study (dye tracing of waters, runoff studying, definition of throughflow time, runoff chemistry, suspense sediments transport, cold ice layer thickness measurements etc.). If we do not know GK structure, it becomes not clear as water moves in ice thickness. If we shall not study GK: 1) an glaciers interior remain for us as «black boxes», 2) we shall irrevocably lose valuable scientific information based on character of internal glaciers destruction; 3) we shall not understand many processes in glaciers.

Only expensive ice drilling or study of glaciers water runoff regime usually give information about glacier internal structure. GK drainage channels researches allow us: a) to receive direct information about glacier structure, to make large crevasses survey, to establish presence and amplitudes of ice replacement on them after time of cavities formation; b) to take ice samples of any size from necessary depths for different purposes (definition of permeability, durability, water-saturation etc.); c) to determine morphometric characteristics of cavities. Analysis and mathematical processing of morphometric parameters of GK drainage channels allow to receive statistically steady parameters of channels sizes and content of cavities in ice of separate glaciers and their parts.

Analysis of plans and vertical cuts sections of separate cavities allows to determine main directions of crevasses and their connections with orientation of tension ellipsoid in separate parts of concrete glaciers. By statistical analysis of the data about length of rectilinear sites of drainage channels it is possible to determine sizes and a configuration of ice blocks, to establish density of hydrologically active crevasses inside these blocks.

Usually hydrological research is possible only in catch and outflow areas of glacial waters. Application of karstological (speleological) methods allow to carry out hydrological research also in internal water transit zone – directly inside drainage systems. Researches of them allow:

A) to establish position of water level (uniform hydrostatic water level, isolated conduits, «double porosity» with various filtration properties for crevasse zones and internal parts of ice blocks with small quantity of fissures and crevasses).

B) to establish structural and filtration anisotropy of glacier by realization of indicator experiments.

C) to establish character of water movement (free, pressure head, laminar, turbulent) in various parts of drainage systems to receive settlement characteristics of water streams inside drainage systems (stream velocity, water level, discharge, Reynolds and Fraud numbers and so on) and glacier in whole (filtration index etc.), to dismember hydrographers of springs (upwellings) at glaciers tongues (with allocation of dead volume in underground dammed and accumulative lakes) and curve of exhaustions (with allocation of various components of glacial runoff).

D) to coordinate seasonal changes of hydrodynamical parameters and temperatures of glacial water with data of meleorological and hydrological investigations on surface, with changes of springs discharges and with fluctuations of water levels in moulins and boreholes.

E) to receive differential values of GK activity for different seasons and hydrodynamical zones of glaciers.

GK study in future will allow to receive quantitative indicators of growth and dynamics of drainage channels in different glaciers and in different regions. With the help of these indicators in future, probably, it will be possible to make quantitative estimations not only for speed of origin and destruction of internal drainage systems, but also its role at different stages of glaciers evolution.

Further study of internal drainage will enable to explain mechanisms of such catastrophic glacial phenomena as outbreaks of glacial lakes and fast ice motion (surges). Detail study of an internal drainage will allow to understand GK evolution. It will enable to approach us to explanation of ancient glacial sheets destruction from quantitative positions.

Research of GK together with others glaciological researches will allow to look in a new fashion at a role of water in glaciers. It will enable to explain both properties of ice and feature of glaciers (movement, metamorphism, degradation features etc.).

Investigations of glaciers drainage systems, laws of their origin and evolution during ablation season and long periods of time, and also in connection with conditions and structure of glaciers enables to coordinate among themselves combinations of superficial and internal glaciers drainage systems. But also it is possible to solve inverse task: on basis of drainage systems study to understand conditions of separate parts and of whole glaciers. It will allow in the future on the basis of GK study including remote sensing methods together with the control of glaciers tongues positions to receive more full, wide and trustworthy information not only about a structure and a condition of many glaciers of a planet, but also character and tendencies of regional climate change.

Isomorphism of GK and karst allow to use achievements in research of one of karst type for finding out of development laws for other karst type. Calcareous karst is now enough well investigated. It means that laws of limestone karst development may be used for finding out corresponding laws in GK. And this «laws conversion» is possible without entering serious corrections (in view of time difference of drainage systems formation, and also in view of special properties of ice: fluidity and plasticity). It results now and will result in future progress in GK study including glaciers internal drainage. But it means also that many laws received at GK study may be used without very serious changes at researches of calcareous karst. It is especially tempting because of different speed of karst forms origin in limestone and ice (many hundreds thousands years for limestone karst and from several months to several years for GK). It means possibility not only directly observe origin of karst forms in glaciers of different regions with various climate, to carry out their exact measurements or even to put some types of experiments. It means GK may serve as natural model of calcareous karst. Certainly, not now, not in the future it will be impossible automatically to transfer laws of origin of separate forms from one karst type to another. But it does not mean that in general it will be impossible to take advantage from it. Hope therefore is quite competent that big interest, which has originate recently to GK study, in future will result in progress of calcareous karst study.

CONCLUSIONS

Thus forms and processes, which result in formation of karst relief (superficial and underground) on glaciers can named GK. Despite of some distinctions determined basically by ice properties, full similarity of superficial and internal karst forms in ice and limestone is observed. It means, that GK may serve as model for calcareous karst and on contrary. It is especially important as speeds of formation and evolution GK in millions times is higher than at calcareous karst. But we need take into account difference between ice and rocks and processes of chemical rocks dissolution and physical ice melting. GK also defines a lot of processes on glaciers: change in thermal ice conditions, maintenance of fast water delivery in ice thickness, water-contents changes in ice, ice properties changes, maintenance of glacier surges, outbursts of glacier-dammed lakes etc. Therefore GK study has the big prospects in future.

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