GLACIAL KARST AS POSSIBLE REASON OF QUICK DEGRADATION OF SCANDINAVIAN GLACIER SHEET

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Abstract

On the basis of analysis of reasons of edge destruction of Scandinavian glacial sheet which covered extensive flat areas in Russia, such as accelerated ice melting from above, below and within, calving in fresh-water lakes, ice movement, etc., we suppose that glacial karst development was the reason of quick sheet degradation. The glacial karst at edge areas of sheet could develop in lake and dry stages. On the basis of processes researched on glacial karst in modern areas of its development a conclusion was made that intensity of glacial edge destruction by glacial karst might be comparable to destruction intensity of sheets edges by calving.

Ледниковый карст как возможная причина быстрого разрушения Скандинавского ледникового щита

На основании анализа причин деградации края Скандинавского ледникового щита, который в России покрывал обширные равнинные территории, такие как ускоренное таяние льда сверху, снизу и изнутри, образование айсбергов в пресноводные озера, растекание покрова, пульсации и др. высказано предположение, что причина его ускоренной деградации связана с интенсивным развитием ледникового карста. Ледниковый карст на краю щита мог развиваться как в озерную, так и сухую стадии. На основании изучения процессов, происходящих в современных районах развития ледникового карста, сделан вывод о том, что интенсивность разрушения края ледникового щита ледниковым карстом могла быть сравнима со скоростью разрушения края щита за счет откола айсбергов.

Introduction

Glaciation in the past differed from modern glaciation. It had oscillations during a long period of time. Sometimes glaciation expanded up to considerable dimensions when glaciers covered huge areas of continents. Sometimes it was considerably reduced when glaciers situated only in northern regions and in high mountains.

The ice sheet glaciation of continents is, certainly, of greatest interest. It differed from modern glaciation of Greenland and Antarctica because in the past glaciers frequently spread from mountain ridges very far onto adjoining plains. It concerns Laurentide and Scandinavian glacial sheets. It imposed certain prints on glaciers structure and on their internal drainage systems.

Let's consider features of destruction of glacier sheet edge using example of last Scandinavian glacial sheet. We are interested with its southeast part, which has far spread into land. During maximum development of the Scandinavian glacial sheet in its southeast part ELA was at height about 100 m (Charlesworth, 1957). Ablation zone set off glacial sheet on periphery as narrow strip and its area during the maximal development of the Scandinavian glacial sheet did not exceed 10% in total glacier area (Khodakov, 1978). Removal of ice and snow by melting in this period was compensated by ice flow from central part of sheet so its edge remained in one place. Similar peripheral system of arrangement of ablation areas is marked on modern glacial sheets of different sizes: from small domes and caps (North East Land in Spitsbergen archipelago) up to continental glaciation of Greenland and Antarctica.

Glacial karst develops in limits of ablation zones of many modern glaciers. Alongside with it exists there is an assumption that at edges of glacial sheets (Scandinavian and Laurentide) glacial karst was advanced (Charlesworth, 1957, Clayton, 1964). In stage of glacial sheet growth glacial karst, most likely, played an insignificant role in life of glacial sheet as it developed only at its peripheries. There are reasons to assume that glacial karst value might strongly increase during degradation of glacial sheet. We shall try to estimate how far and in what degree glacial karst had influenced the glacial sheets destruction, whether it was the only influence, how quickly it might have occured and what areas are to mention.

Glacial karst

Similarity of processes of formation and development of internal drainage systems of glaciers to karst drainage systems and also similarity of superficial forms of glaciers and a karst areas allows to speak about glacial karst – a complex of internal drainage systems of glaciers and original superficial forms, which are similar to forms of a calcareous karst (Benn, Evans, 1998).

Now there are different approaches to term «glacial karst»: 1) areas from glacier tongue up to area of median moraines melt out from ice as glacial karst are considered (Clayton, 1964, Krüger, 1994); areas, where it is possible to find dolins (Kalesnik, 1935); sometimes for these areas term «debris-covered glacier» is used (Nakawo, Young, 1981); 2) glacier areas where it is possible to find moulins (Badino, 2002), i.e. the site of a glacier as a rule is higher than its debris-covered part; 3) glacial karst develops within the limits of all ablation zone (Pulina, Pereyma, Piasecki, 2002) but basically to superficial forms. We agree with last named approaches to term glacial karst, i.e. it is advanced within the limits of all ablation zone but sometimes it is possible to find some features of glacial karst even somewhat higher then ELA.

Occurrence on a specific relief on ice surface is connected with plenty of negative forms of different orders in dimensions (from cryoconit holes up to dolins, depressions and poljes) that are typical for glacial karst. Especially intensive is hilly (hummocky) relief with plenty of well expressed dolins and depressions (frequently with small lakes in them), disappearing water streams and blind valleys, natural ice bridges and arches, moulins, tunnels and caves inside ice, large springs, separate blocks of ice and residual sediments (ablation tillits), which are advanced in tongue parts of glaciers (Charlesworth, 1957, Clayton, 1964). The greatest intensity of glacial karst is marked in areas of inactive glaciers strongly covered by moraine. Stages of glacial karst development are described in previous works (Clayton, 1964, Kruger, 1994, Mavlyudov, 2005).

Existence of several scenarios of glacial karst development is possible: lake and dry.

Lake scenario arise at dammed glacier edges by dead ice which is ends in a lake situated near glacier, by end moraine ridge or rock bar (Fig. 1).

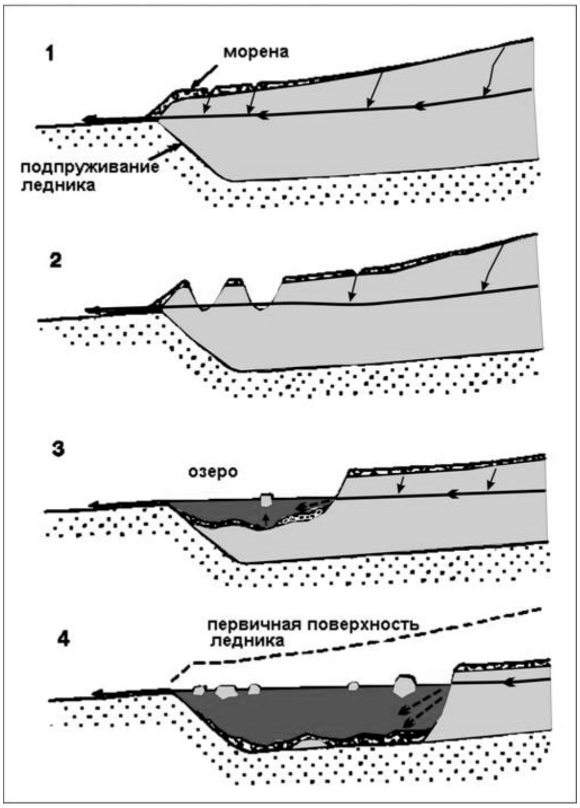

Fig. 1. Lake scenario of mature stage of glacial karst. Glacier tongue is dammed by rock bar (Kikbridge, 1993); gray – ice, black – water, points – glacier bed, dotted line – initial glacier surface

In limits of hummocky relief in depressions on glacier surface there are plenty of small lakes. Despite of large thickness of moraine cover (up to 3 m) abrupt lake shores cannot keep moraine sediments therefore bare ice here was exposed. Lake basins quickly expanded in breadth and depth and at last reach up to dammed water level. After that water stood approximately at one level in all large hollows on glacier surface. Lakes growth up in sides to certain stage by backwasting when together with ice melting calving also began. Huge number of internal lakes strongly increased the contact area of ice with water (except when glacier front water began to contact with coast of lakes and with walls of subglacial channels connecting lakes). Lakes deepening occurred by calve off and floating of ice blocks at water surface. It leads to increasing of calving in peripheries of big lakes. Growth of lake basins and combined lakes into one system might become a reason of fast destruction of glacial sheet edges. As a result of combination of numerous small lakes there can occur a uniform reservoir, which subsequently joined the lake situated at glacier margin. It leads to increasing of marginal lake area and growth of coastal line length of calving front.

In case of dammed edges of glacial sheet by end moraine small lakes on glacier surface combined forming firstly larger lake on glacier surface and subsequently marginal glacier lake (Fig. 2).

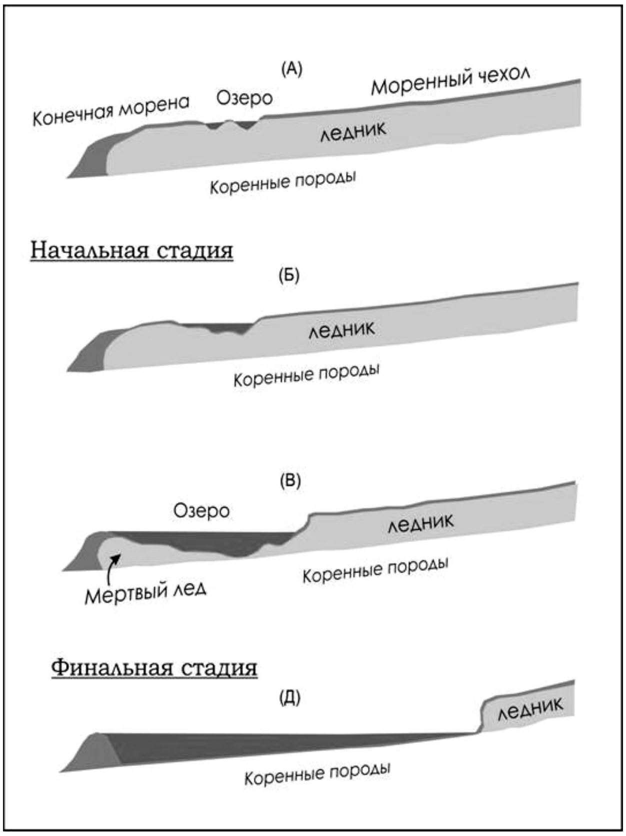

Fig. 2. Lake scenario of mature stage of glacial karst. Glacier tongue is dammed by end moraine (Yamada, 1998); light gray – ice, black – water, intermediate - moraine

Modern analogues of this stage of glacial karst development are marked on Northern Inyltchek Glacier (Tien Shan) (Mavlyudov, 1995) and Tasman Glacier (New Zealand) (Kikbridge, 1993), on Trakarding Glacier reach up to 12 m/year (Kikbridge, 1993). Degradation intensity of Northern Inyltchek Glacier tongue by glacial (Himalayan) (Yamada, 1998) etc. Increasing of lakes diameter on Tasman Glacier in second half of 20 centuries karst exceeds speed of glacier tongue retreating by calving (Mavlyudov, 1995).

Dry scenario. For debris-covered areas of glaciers presence of many moulins and depressions with ice walls is typical. At depressions bottom only small lakes are formed which do not have common level. In spite of the fact that moraine cover protects ice surface from melting there is intensive melting on depression and moulin walls. Numerous cracks arise on depressions periphery and by them ice collapsed in depressions where quickly desintegrated (Fig. 4).

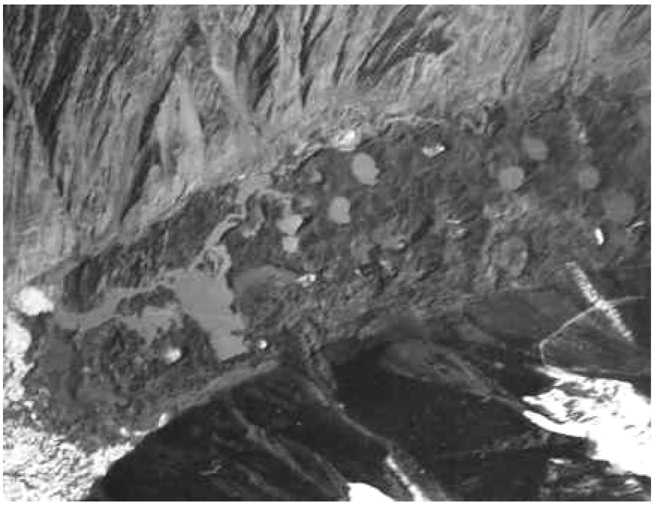

Fig. 3. Intensive glacial karst development at Nothern Iniltchek Glacier tongue (glacier width about 1 km); lake scenario of mature stage

As all water moves through ice big quantity of englacial and subglacial channels origin. Channels increasing occurs as due to influence of water streams, which especially increase during floods and due to movement of air flows. Collapse of cavities vaults results in occurrence with new depressions in superficial relief and to increasing of contact area of subglacial streams with ice. The failure of moraine material in subglacial streams promotes its carrying out for limits of ice massif.

Fig. 4. Depression with rounded crevasses and big quantity of icebergs at the tongue of Bashkara Glacier, Caucasus, 2005

Modern analogues of the dry scenario of glacial karst are revealed on Southern Iniltchek Glacier (Tien Shan) (Mavlyudov, 1999), Fedchenko Glacier (Pamir) (Spengler, 1936), Kolka Glacier (Caucasus). Diameter growth rate of arising depressions may be enough high (on Kolka Glacier up to 50-100 m/year).

The reasons of glacial sheet degradation

As it is known last glaciation on the European Plain reached its maximum about 18 thousand years BP. During next approximately 7 thousands years a deglaciation occurred (Aseev, 1974; Faustova, 1994). At this time the Scandinavian glacial sheet has disappeared. Its length from icedivide to southeast was more than 1200 km that corresponds to average speed of ice edge retreating about 170 m/year. In work (Aseev, 1974) rates of glacial sheet edge retreating about 100 m/year is shown. Large sizes of rates of glacial sheet edge retreating need for explanation a speed of superficial ice melting about 30-35 m/year. That is physically impossible, so we have to search for other reasons such as lakes influence situated near glacier, katabatic winds etc. (Humlun, Houmark-Nielsen, 1994).

At the same time as deglaciation of Scandinavian glacial sheet was accompanied, as well by the periods of glacial sheet activation, real significances rates of glacial sheet edge retreating were considerably higher.

According to work (Faustova, 1994) «after 13 and till 10 thousands years BP deglaciation mainly had the regressive character following from the analysis of marginal formations. Rates of deglaciation grew from 150 up to 200-700 m/year (Fig. 5).

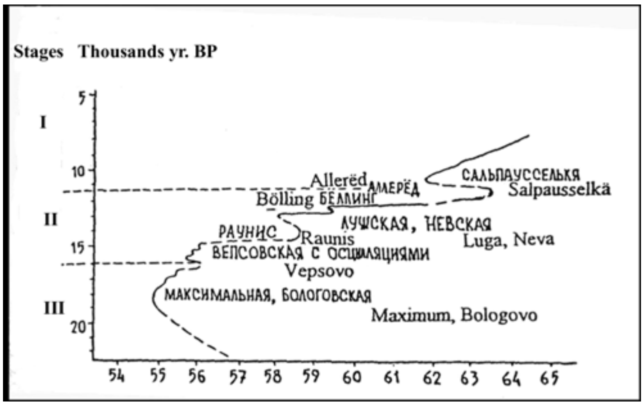

Fig. 5. Deglaciation rates of Scandinavian glacial sheet (Faustova, 1994); I, II, III – stages of deglaciation; lower scale – latitude

The highest rates of deglaciation were typical for alleröd». It means, that 11,8-11 thousands years BP when average July air temperature above glacial surface was below modern air temperature about 3ºC, average January air temperature was lower on 8ºC, average annual temperature - on 6ºC below modern temperature (Klimanov, 1994), glaciers retreated with greatest rates. Edges of many modern glacial sheets outside of limits of outlet glaciers in present period retreat very slowly, rates of displacement of ice edge usually does not exceed some tens meters per year. It means it is necessary to search for the reasons accelerating destruction of glacial sheets.

It is possible to assume some the probable reasons of acceleration of glacial sheet destruction: 1) accelerated ice melting (from surface, from within, from below); 2) calving in lakes; 3) change of a glacial sheet form (more quick ice movement, action of outlet glaciers) (Tabl. 1).

As we can see most significant contribution to destruction of glacial sheet edge was brought by calving, glacial karst and ice melting from glacier surface.

For glacial karst development at glacial sheet edge there were enough favorable conditions: slow ice movement and debris cover on ice surface.

Discussion

It is supposed that glacial karst can be widely distributed on dead edges of Northen American glacial sheet in time of degradation of last glaciation (Clayton, 1964). Thus the marginal part of glacial sheet was covered by enough thick layer of moraine sediments which, after complete ice melting, have formed widely widespread in areas of an ancient glaciation hummocky relief. The similar phenomena are marked and for Scandinavian glacial sheet (Aseev, 1974). Apparently, wide development of glacial karst in marginal parts of an inactive glacial sheet can promote its accelerated destruction.

Table 1

Contributions of different factors in deglaciation rates of Scandinavian glacial sheet

Reason	Mathematical character of action on glacial edge	Contributions in deglaciation rates, m/year	References
Ice melting from surface	+	30-50	Aseev, 1974; Khodakov, 1978
Ice melting by water streams	+	Not significant	
Ice melting from glacier bed	+	Not significant	Ходаков, 1978
Calving in lakes	+	200-300	Benn, Evans, 1998; Funk, Röthlisberger, 1989
Quicker ice movement	-	Not significant	Khodakov, 1978
Outlet glaciers	-	Not significant	
Glacial karst	+	200-300	

Till now value of glacial karst in glacial sheets destruction was underestimated. Presence of uncountable quantity of small lakes and also channels of internal drainage is typical for mature stage of glacial karst within the limits of marginal parts of glacial sheet. It can promote essential increase of contact surface of ice with water and air. Lakes water warmed up by sun and intensively destroyed ice thickness by sideways interaction with ice walls in lakes and in channels without dependence of ice surface protection by debris covers.

For intensive glacial karst development presence of a thick layer of morain cover on ice surface is necessary (Clayton, 1964). The reasons of moraine cover occurrence in glaciers tongues and at edges of glacial sheets researchers see in periodic stages of ice edges movement when the part of a ground moraine through faults was replaced into glacier body (Troitsky, 1970, Khodakov, 1978). It is usually considered that debris-covered ice melts in tens or even hundreds times more slowly than bare ice (Khodakov, 1978 Nakawo, Young, 1981). Really debris layer on ice surface essentially reduces superficial ice melting. However glacial karst development radically changes melting character of dead and inactive ice.

From considered above scenarios of mature stage of glacial karst development for glacial sheets the intermediate scenario is more favorable. It combines lake and dry scenarios, which might operate alternately. In period of wide development of glacial lakes the lake scenario of mature stage of glacial karst was developed. At this moment huge areas at glacial sheet edge were dammed by water of lakes situated near glacier. After lakes emptying the mechanism of dry scenario of mature stage of glacial karst development was brought into action.

In a case of damming of glacial sheet edges by end moraines small lake on glacier surface are aspired to combine together forming all over again larger lake on glacier surface and later large marginal lake. It is possible to assume that stages ridges of end moraines (Groswald, 1983) it is possible to try to explain by such alternate lake damming. Probably glacial karst destroys any part of glacial sheet then its development weakened. Further glacial karst renewed only at occurrence of again necessary conditions of ice damming by end moraine. In that case stage moraine ridges can mark periods of intensive glacial karst development at glacial sheet edge retreating.

It is possible to explain many forms of glacial relief, which has developed on a place of previous glacial sheet existing by wide glacial karst development. These are all kinds of eskers, kames and also probably all sites of hummocky relief. (Fig. 6).

As the indirect demonstration of wide glacial karst development in edge part of glacial sheet may serve traces of outbreaks of large subglacial reservoirs. However till now researchers disscus how far this assumption is proved. This idea has supporters and opponents. For example in work (Shaw et al, 1996) it is considered that subglacial water outbreaks from Laurentide glacial sheet were an often phenomenons, and many forms of relief of Canada and USA are results of such floods. In spite of the fact that most likely edges of glacial sheet were frozen to bed in a strip up to 2 km in width, some authors consider that runoff of melt water can occur from subglacial reservoirs which by size of drainage up to 10^6 m^3/s can have huge sizes (Shaw, 1994). Other authors come to conclusion that there is no proof of existence of subglacial lakes under edges of glacial sheets (Brown, 1994).

Destruction rates of glaciers by glacial karst are almost not known as process of its formation and evolution studied still not enough. Separate most investigated examples from Tien-Shan, Himalayas and New Zealand (Mavlyudov, 1995; Yamada, 1998; Kikbridge, 1993) allow to say that this rates are high enough. According to our estimations for a glacier Northern Inyltchek (Mavlyudov, 1995), intensity of glacier destruction by glacial karst ("eating" of glacier from inside) is comparable to rates of glacier edges retreat by calving.

Fig. 6. Forms of hummocky relief, which probably are traces of intensive glacial karst development, Ireland (Charlesworth, 1957)

distributed in depth of glacial sheet, destruction intensity of edge of a glacial sheet by glacial karst can be much higher. We think that in this conditions areas affected of mature stage of glacial karst can have width of many tens kilometers. In our opinion intensive glacial karst development at edges of glacial sheets alongside with calving in glacial lakes is one of mechanisms of glacial sheets destruction and can explain high deglaciation rates in the north of Europe and Northern America during last glaciation.

Confirmation of active glacial karst development at edges of glacial sheets in the past can be finds of glacial karst at edges of modern glacial sheets. The largest processes of glacier degradation are marked on periphery of the Greenland glacial sheet. As the Greenland glacial sheet does not distribute to plain as it was done by Scandinavian glacial sheet, it means that forms of glacial karst here can develop others. On outlet glaciers and in peripheries of sheet moulins are met rather frequently (Moreau, 2002, Romeo, 2002). Along the western periphery of glacial sheet the extensive zone of glacial lakes is distributed. Here it is possible to see large number of not very small lakes which are situated directly on ice (Fig. 5).

For concrete Northern Inyltchek Glacier this rate consist about 100 m/year. It means that glacial karst development may increase rate of destruction of glacial sheet edge approximately twice in comparison with those conditions when this edge would have been destroyed only by calving. It is possible to assume that in conditions when small ice thickness at edge of inactive or motionless ice was far

Existence of big number of lakes lead to more active surface ablation in case of lake absence. Thus it is possible to say that glacial karst not only a usual phenomenon at edges of glacial sheets but its development can accelerate glacial sheets destruction both in present and in past.

Conclusions

The Scandinavian glacial sheet within the limits of Russia covered extensive flat areas. Discussion of the degradation reasons at edges of glacial sheet such as the accelerated ice melting from above, from below and from inside, calving in fresh-water lakes, movement of ice sheet, surges, etc. has shown that the reason of its accelerated retreating is connected with calving, intensive development of glacial karst and superficial ice melting. Glacial karst at edge of sheet can develop both in lake and dry stages. On the basis of studying the processes occurring in modern areas of glacial karst development it was concluded that intensity of destruction of glacial sheet edge by glacial karst can be comparable to rate of destruction of edge of sheet by calving.

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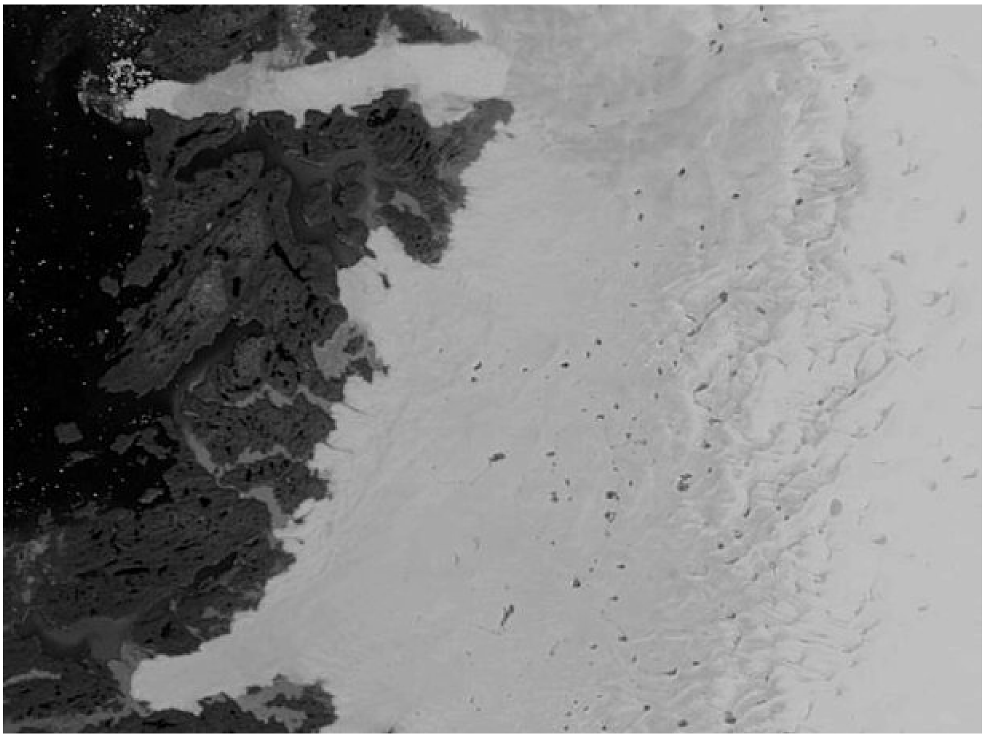

Fig. 7. Glacial lakes on ice surface at western edge of Greenland glacial sheet, 69°N.
In upper part situated the Yakobshavns Glacier. Image from space

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