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Research of hazardous Alpine lakes in Kyrgyzstan

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ABSTRACT

Nearly 20 % of about 2000 of Kyrgyz Alpine lakes covering more than 0.1 hectares are supposed to be potentially dangerous because of instability of moraine or landslide dams, overflowing of water, and rapid development of lake basins and melting of buried ice inside the moraine. According to the last inventory (Yerokhin 2009), in total 328 lakes have been considered as potentially dangerous. Since 1952, more than 70 disastrous cases of lake outburst have been registered. The danger of GLOF is increasing significantly due to the influence of recent climate changes and rapid glacier retreat. Evidence for this fact was the outburst of the Zyndan Lake in 2008. The largest potentially hazardous glacial lake is the Petrov Lake. According to the present day knowledge, the lake has an area of 4.03 km^2, water volume of 64 mil m^3 and the maximum depth of 69 m. Annual retreat of frontal part of the glacier tongue is 40–65 m during the last decade. The lake lies inside the area of the Kumtor gold mine just two kilometres upstream from a pond containing poisonous tailings after ore processing. The tailings can be washed down during an extremely powerful outburst. Glacial lakes and landslide-dammed lakes on the northern slope of the Kyrgyz range are monitored on a long-term basis. The lakes threaten the densely populated Chu valley including the Kyrgyz capital Bishkek as well as popular tourist areas nearby. The climatological and glaciological programmes have been implemented in addition to lake monitoring of the Adygine pilot locality.

Keywords: Tin-Shan, glacier melting, glacial lakes, natural hazards, GLOF

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INTRODUCTION

An intensive melting and retreat of glaciers is observed in the majority of high mountains all over the world. High dynamics of development of glacial complexes causes the changes of hydrological regime and rapid filling of lake basins in some cases. The dams of many lakes are very unstable and they often burst open. This process is evident in most of world's high mountain including Kyrgyzstan. Mountain lakes outburst floods (GLOF) are common in high-mountain areas around the world. They have been reported from the Alps (Haeberli 1983, Haeberli et al. 2001, Huggel et al. 2002, Huss et al. 2007), Karakoram (Hewitt 1982), Himalayas (Ding and Liu1992, Mool 1995, Pant and Reynolds 2000, Richardson and Reynolds 2000, Kattelmann 2003, Bayracharya and Mool 2009), Tien-Shan (Meiners 1997, Jansky et al. 2009, Mayer et al. 2008), Coast Mountains (McKillop and Clague 2003, 2007), Rocky Mountains (Blown and Church 1985, Mayo 1989, Walder and Driedger 1995, Clague and Evans 2000) and Andes (Reynolds 1992, Clague and Evans 1994, Reynolds 2006, Carey 2008). Whereas the inventories in most of these regions contain hundreds of moraine-dammed, landslides and debris-flows-dammed lakes and a lot of systematic information for hazard assessment, only few data exist for the Tien-Shan Mountains in the territory of Kyrgyzstan.

The joint group of Czech and Kyrgyz researchers has been working in Kyrgyz Tien-Shan within the period from 2004 to 2010. Almost 60 lakes have been investigated and their hazardousness has been assessed. The relations between the development of lakes, glacier melting and current climate changes has been studied. The article brings the background information on types of hazardous lakes in Kyrgyzstan as well as the case studies on several lakes studied in detail.

TYPOLOGY OF HAZARDOUS ALPINE LAKES IN KYRGYZSTAN

The Alpine lakes in the territory of Kyrgyzstan can be subdivided into several types and subtypes. The criteria for such a classification include lake genesis and related morphological features. The degree of dangerousness of individual types and their proneness to failure and sudden breakout of water depend on the stage of lake´s evolution, position and character of discharge.

The criteria of the mountain lake outbursts danger for the first stage of monitoring have been developed by the experts of Geology and Mineral Resources of the Kyrgyz Republic State Agency (Yerokhin 2002). The main criterion of the mountain lake typification concerning danger of outburst is the origin of their dams. According to the origin, which determines the dams structure and composition, dangerous lakes are divided into the following types (Jansky et al. 2006): glacial, moraine-glacial, thermokarst, moraine, those dammed by a rock barrier and dammed by a landslide or a rock-fall (Fig. 1).

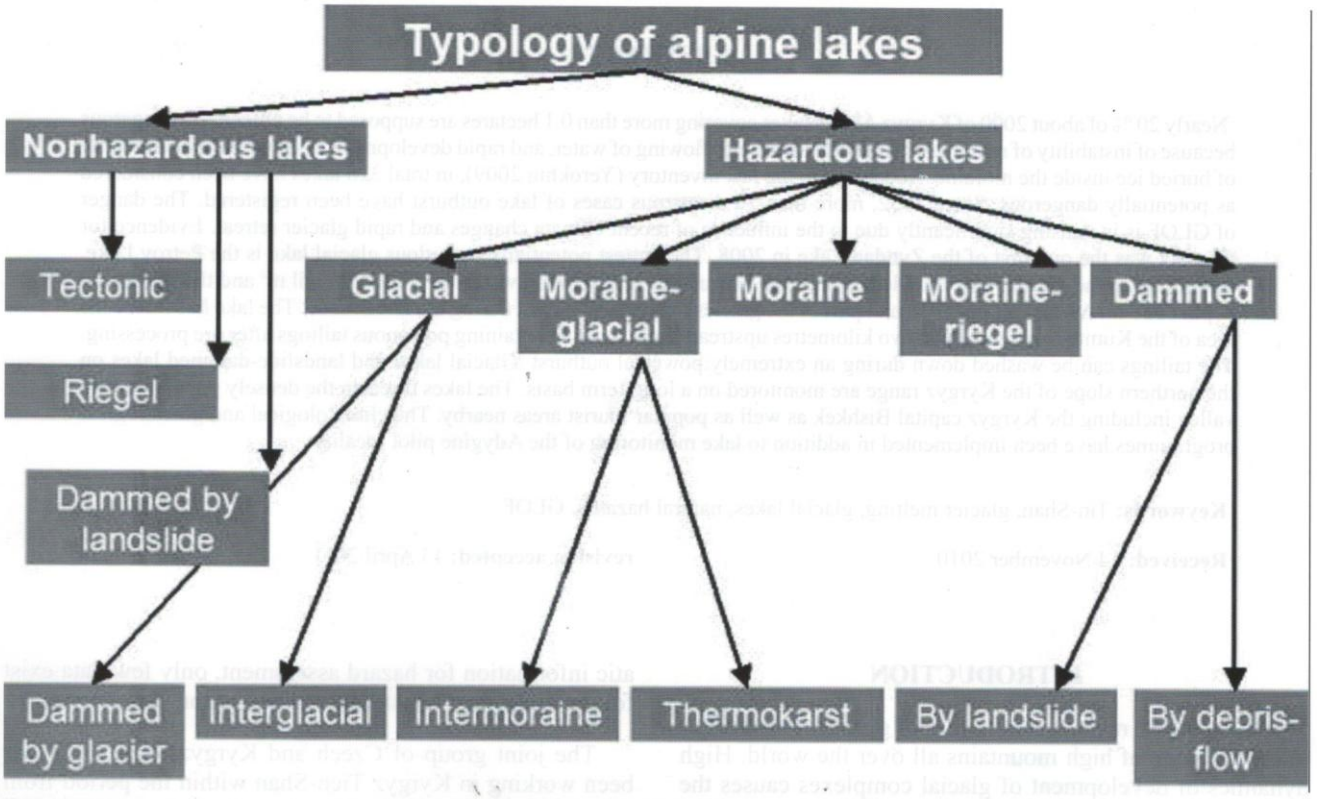

Fig. 1: Typology of hazardous and non-hazardous alpine lakes (Yerokhin 2009).

The lakes of each type and subtype have different characteristics. It is important to know them in order to assess the danger of their outbursts correctly. According to the following criteria it is possible to assess the possibility of mountain lake outburst: nature of its drainage; condition of drainage channels; rate of the lake basin expansion; possibility of lake overflow; stability of the lake dam regarding thermokarst and erosion process and others.

Systematic study of mountain lakes has been carried out in Kyrgyzstan since 1966, when the catastrophic outburst of the landslide-dammed Yashilkul Lake occurred in the Isfairamsai River valley on 18 June 1966 (Karpov and Tsytsenko 1966). At present, the specialists of the Kyrgyz complex hydro geological expedition of the Ministry of Natural Resources (formerly the Geology and Mineral Resources of Kyrgyz Republic State Agency) are conducting the lake investigation. Since 2004, monitoring and systematic research of hazardous alpine lakes is carried out by the Czech-Kyrgyz project funded (sponsored) by the Czech Development Agency.

During the work on the common project Alpine lakes of Kyrgyzstan have been catalogued and a database of hazardous lakes has been prepared. At present, the database contains information of about 330 lakes, investigated to various degrees during the period from 1966 until 2010. Depending on the level of danger, the lakes are classified into three categories:

1. The lakes at highest risk: The lake is at a stage of immediate danger of failure that may result in far-reaching serious consequences and impacts on the property and population.
2. Dangerous lakes: These lakes at a specific stage of development are close to those that tend to fail.
3. Lakes that failed sometime in the past but the danger of failure is negligible at the present time.

As to the lake type, the moraine-glacial type lakes pose the greatest threat because of the highest dynamics of the development. In the catalogue, 47% of dangerous lakes them become to this type; lakes dammed partly by rock barrier make up 26%, moraine lakes – 14%, landslide dammed lakes – 12 %, and the glacial ones - 1%.

The distribution of hazardous lakes on the territory of Kyrgyzstan is irregular (Fig. 2). They are linked to particular mountain ranges of Tien-Shan and Pamiro-Alay. The highest number of the lakes appears at altitudes of about 3300-4000 m where the melting of glaciers and oscillation of the snow limit are most intensive. Above that level the dynamics of development of the glacier terminus is not so influential and appearance of hazardous lakes is scarcer.

DEVELOPMENT OF ALPINE LAKES AND CLIMATE CHANGES

The danger of outburst is increasing significantly due to the influence of recent climate changes. Global climate warming causes an intensive melting and retreat of glaciers in the majority of high mountains all over the world. This process is evident also in the mountain regions of central Tien - Shan. The hydrological regime of water streams is influenced by water from melting glaciers. The changes of outflow channels can cause the overfilling of the Alpine lake basins.

The lifetime of majority of the lakes is mostly a few decades and the level of water in them oscillates widely during particular years. When the underground channels draining these lakes are blocked by glacial sediments, the water level rises rapidly, often leading to the catastrophic failure of poorly stabilized moraine dams followed by catastrophic floods. The development of glacial lakes and their dynamics have accelerated during the last two decades. The risks of flooding are amplified by greater ranges in temperature and atmospheric precipitation during single years and by increases in the annual totals.

The analyses of meteorological data from selected weather stations confirmed the changes of course of climate characteristics during the last decades. Nevertheless, the characteristics of particular stations are quite different. Some of them show rather regular precipitation and temperature cycles with clear mutual correlation, whilst the others are irregular. In general, the trend of curves indicates increase of temperatures and precipitations during the last two decades.

Increasing temperature and changing distribution of precipitations influence the development of glaciers in the zone of higher weather variation. The ascending line of liquid precipitations at the cost of snow-dominated ones contributes to faster glacier melting. It is evident that the situation will be the same in the next decades. It means that the number of hazardous lakes will increase in most of mountain ridges on the Kyrgyz territory. The appearance of such types of lakes in new areas considered as non-hazardous to date is expected.

The retreat of glaciers in all the studied sites has been recognized. Reconstruction of the development of frontal parts of glaciers and adjacent lakes was performed within the framework of the project. Majority of the studied areas are situated on the northern slopes of Kyrgyz ridge, which belongs to the western part of Tien-Shan. The altitude of most of the mountains ranges from 4000 to 5000 m. There are mostly small size glaciers on the mountain saddles and terminal parts of the valleys. The glacier terminuses lie generally at an altitude of 3300–3700 m. Aerial photographs taken in the years 1957 to 1988 were used as the basis for the research of development of glacial complexes and sub-

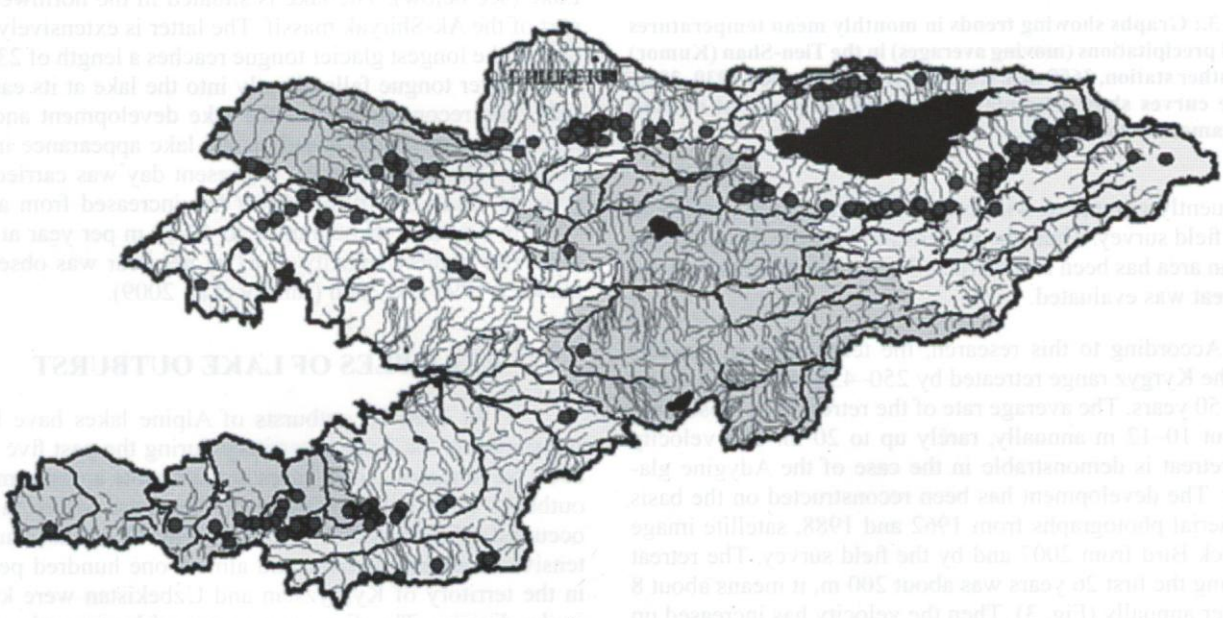

Fig. 2: The distribution of hazardous lakes on the territory of Kyrgyzstan is irregular. The highest concentration is found in the northern part of the Kyrgyz territory, on the northern slopes of Talas, Kyrgyz, Terskey and Kungey ridges. Original map scale 1 : 2 000 000

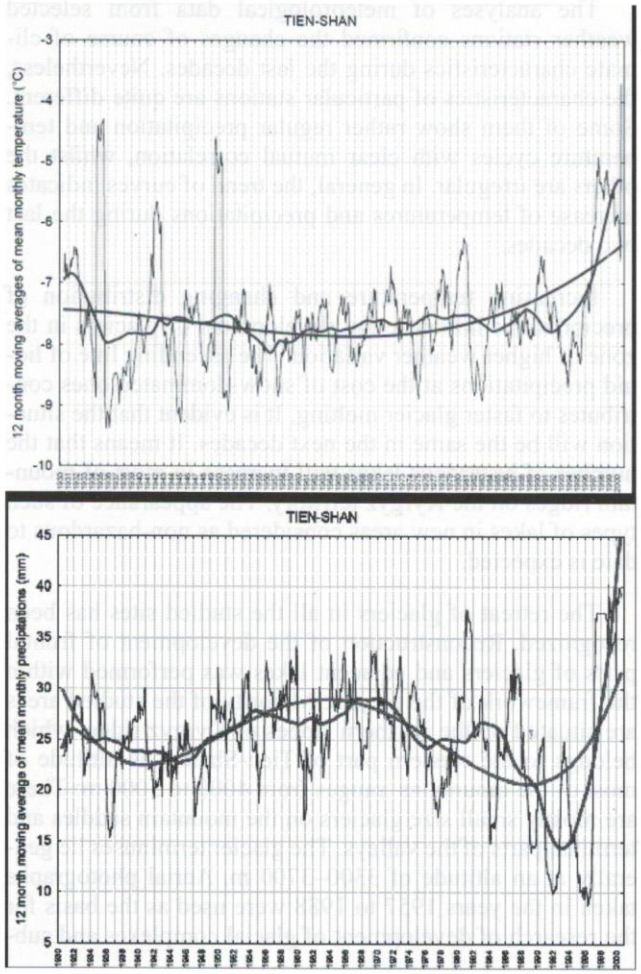

Fig 3.: Graphs showing trends in monthly mean temperatures and precipitations (moving averages) in the Tien-Shan (Kumor) weather station, 3659 m a. s. l. Data from the period 1930–2008. The curves show irregular cycles and steep ascent of both parameters since 1990.

sequently compared with recent satellite images and with the field survey. Thus, the picture showing the development of an area has been reconstructed and velocity of the glacier retreat was evaluated.

According to this research, the terminuses of glaciers in the Kyrgyz range retreated by 250–450 m during the last 40–50 years. The average rate of the retreat is in most cases about 10–12 m annually, rarely up to 20 m. The velocity of retreat is demonstrable in the case of the Adygine glacier. The development has been reconstructed on the basis of aerial photographs from 1962 and 1988, satellite image Quick Bird from 2007 and by the field survey. The retreat during the first 26 years was about 200 m, it means about 8 meter annually (Fig. 3). Then the velocity has increased up to current 13 m (250 m during 19 years since 1988).

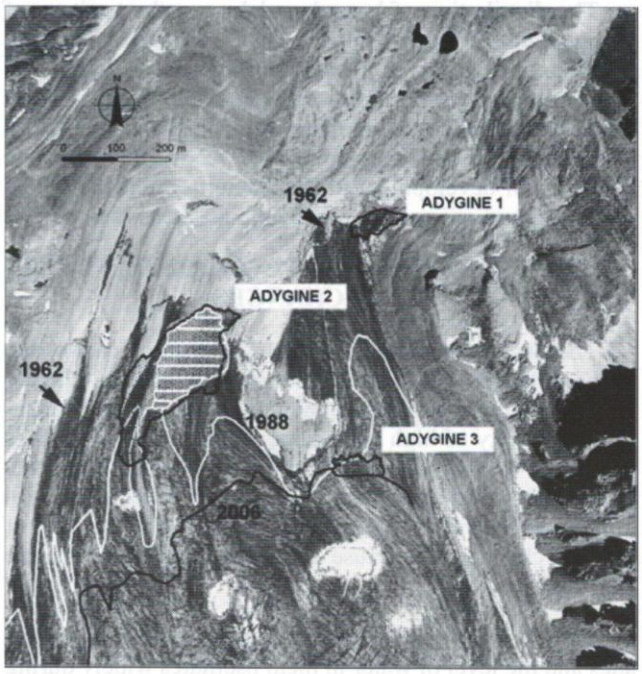

Fig. 4: Development of glacial complex Adygine since 1962. Year 1962: Lower lake doesn´t exists, upper lake forms narrov belt behind a rock barrier, glacier reaches to the rock barrier. Year 1988: Lower lake begins developing, upper lake is growing, glacier retreaded by 200 m Year 2007: Lower lake is fully developed, upper lake is behind its maximum development and is step by step filled by glacial sediments, glacier have retreated by 250 m upwards.

The fastest retreat was recorded in the case of the Petrov Lake (see below). The lake is situated in the northwestern part of the Ak-Shiryak massif. The latter is extensively glaciated, the longest glacier tongue reaches a length of 23 km. The glacier tongue falls directly into the lake at its eastern side. The reconstruction of the lake development and the rate of glacier retreat based on the lake appearance in the middle of the 19th century to present day was carried out (Fig. 4). The velocity of retreat has increased from about 15 m in a year at its beginning to 40-50 m per year at present. The highest velocity of 61 m per year was observed between 1999 and 2006 (Jansky et al. 2009).

EXAMPLES OF LAKE OUTBURST

At least 70 outbursts of Alpine lakes have been registered on the Kyrgyz territory during the past five decades. Nevertheless, most cases in the remote areas or minor outbursts have not been noticed. The most severe failure occurred at Shakhimardan Lake in 1998. This caused an extensive economic damage and almost one hundred people in the territory of Kyrgyzstan and Uzbekistan were killed in the disaster. The disaster was caused by an outburst of a rather small thermokarst lake of less than 40000 m3 of water volume.

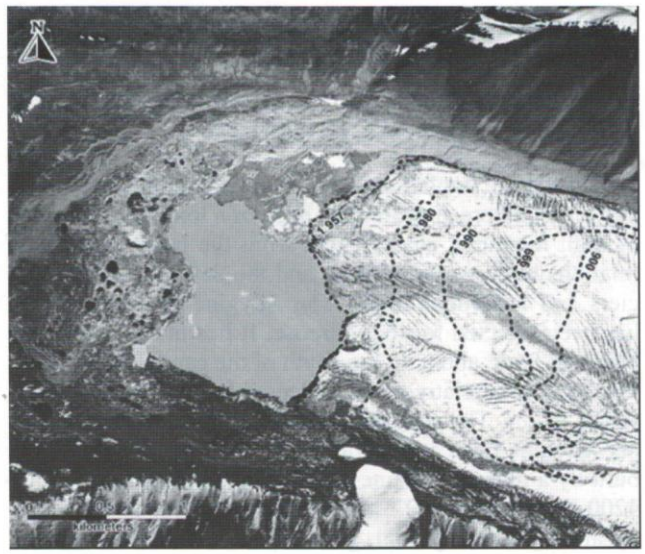

Fig. 5: Zyndan river two days after lake outburst. Three people died in a car fallen into the flow from a damaged road.

The most threatened regions are the valleys on the northern part of the Kyrgyz ridge and the adjacent densely populated Chu lowland including the capital Bishkek, northern slopes of the Terskey ridge close to the southern shore of the Issyk-Kul Lake and some parts of the Talas ridge in the west and Alay ridge in the south of the country. The situation can be explained by larger extend of glaciers due to colder and wetter climate conditions on northern slopes. The retreat of glaciers is very intensive in those parts of mountains and many new glacial lakes appear every year. Most of the valleys downstream are used for pasture farming ant tourism so the impact of outburst can be much higher than in case of less populated southern slopes.

The area of Ala-Archa National Park is under the monitoring of GLOF hazard in a long-term. There are at least three valleys with potentially dangerous lakes at the upper part of the Park. In the Ak-Say valley, the depression in frontal part of the glacier is periodically filled with water and then an outburst follows frequently. In total, nine outbursts were registered during the 1960s to 1980s. As a consequence of repeated outbursts and debris-flows, huge alluvial fan appeared in the mouth of the valley, three people died during an outburst in 1968. The situation of glacier snout and temporary lake basin is stable during the last two decades but it can change quickly when the intraglacial channels collapse or are clogged by glacial sediments. The basin will be filled by melting water and consequent outburst will be very probable. The site is very popular with tourists and inhabitants of Bishkek as a summer resort. Thousands of people come and relax there on summer weekends. Possible outburst and consequent debris-flow may cause a lot of casualties at present time. Other hazardous lakes are located in the Adygine and Terskey valleys. Several not very serious outbursts have occurred there during last ten years.

The evidence of increasing hazardousness of newly formed appeared lakes is the outburst of the Zydan Lake in 2008. The Ton catchment is known as the site of dynamic development of glacial complexes and several lakes in the upper parts of the valleys are considered to be potentially dangerous and are subject to long-term monitoring.

The lake in the Zyndan Valley of an estimated volume of 480 000 m^3 appeared during three or four months as a consequence of spring and early summer melting of a rather small glacier (Narama et al. 2009). The thermokarst depression in front of the glacier was by water from melting glacier within a very short time. The lake drained off through intraglacial channel on July 24, 2008. Three people died in a car fallen into the flow from a damaged road. In addition, there was damage to houses, gardens, irrigation system, water reservoirs, roads and other parts of the local infrastructure (Fig. 6). The case demonstrates that it is necessary to pay attention to the regions where development of new lakes is expected.

Fig. 6: Reconstruction of retreat of the frontal part of Petrov glacier since 1957. The speed of retreat is increasing continuously up to 60 m annually.

PETROV LAKE, THE LARGEST GLACIAL LAKE IN TIEN-SHAN

The largest glacial lake in the entire Tien-Shan is the Petrov Lake situated in the Ak-Shiyrak massif in the southwestern edge of the central Tien-Shan (Fig. 6). The lake has been studied and monitored in detail by a Czech-Kyrgyz team during the last six years. According to the recent knowledge, the lake has an area of 4.03 km^2, the water volume of more than 64 mil. m^3 and the maximum depth 69 m. During the last 50 years, the area of the lake has expanded 4 times and, during the recent period (from 1999 to 2009), the water surface has been increasing by more than 0.09 km^2, a year. The annual retreat of frontal part of the glacier tongue falling into the lake was 40–65 m during the last decade.

The first information on the Petrov Lake and glacier is given by Kaulbars (1875). According to a map from 1911, the surface of the lake was 0.2 or 0.3 km2. Since that time, the lake has increased its surface and volume considerably (Jansky et al. 2009).

The Petrov Lake is formed by two partial basins separated by a belt of shoals and islands which are a part of the central moraine formed on the contact of the two main tongues of the Petrov glacier. The southern basin has a smaller area and is markedly shallower with a maximal depth of 21 m in the middle part of the depression, whilst the northern one is morphologically much more complicated (Fig. 7). The maximum depth of the depression at the eastern part was 69.5 m (in 2006).

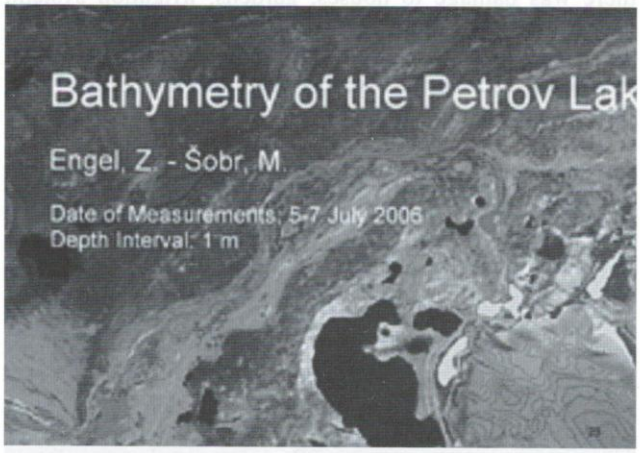

Fig. 7: Bathymetrical measurements of the Petrov lake were carried out in detail in 2006. The deepest part of nearly 70 m was confirmed by reference measurements following years.

The lake is considered to be the most dangerous in Kyrgyzstan. It is dammed by frontal moraine of three or four generations. According to the geophysical measurements performed by the Czech expedition an ice core is present inside the moraine. The ice body is divided by weak zones in separated segments. Repeated measurements have confirmed a decrease in volume of the ice and expansion of zones with lower content of ice. The decrease in ice volume is manifested by sinking of surface. Seepages appear on the outer side of the moraine, whereas denudation of the ice core is seen in some parts of the inner side.

The outburst of the lake in the future is highly probable. Because of high volume of lake water, a high wave and consequent forming of debris-flow can be expected after outburst. The situation is complicated by the fact that the lake lies in the area of the Kumtor gold mine. The ore is mined aside and above the lake but the tailings pond containing the mud from the cyanide gold processing is located just 3 km downstream. The side of the pond in front of the lakes is formed by Pleistocene moraine but its frontal dam is man-made thrown up. It is not possible to exclude the dams (the natural as well as the man-made) being washed away after an extremely powerful outburst and the poisonous mud being carried down the river.

SYSTEMATIC RESEARCH OF ADYGINE GLACIAL COMPLEX

During the implementation of the common Czech-Kyrgyz project there appeared the need of a long-term research of high mountain environment from the point of view of relations between the climate and the development of glaciers and hazardous lakes. The Adygine glacial complex has been selected for that purpose. It lies in the Ala-Archa National Park, about 40 km south of the capital of Bishkek. The locality is relatively well accessible from the main Ala-Archa valley. The station is situated at the shore of the upper Adygine Lake at an altitude of 3600 m. The locality is built by a glacier-moraine complex at an altitude of 3400–4200 m. Altogether 22 lakes currently occur at the locality among which glacial, glacial/moraine and thermokarst lakes and lakes partly dammed by a rock bar are most common. Three lakes are considered potentially dangerous. The lake Adygine Lower represents the thermokarst lake formed in deep depression. In case of break of its intramoraine outflow can be filed by water rapidly and then outburst through newly opened channel. The lake Adygine Upper is the biggest and partly dammed by moraine with ice core. The seepages appeared in the dam. The lake can outburst through this weak points. The third potentially dangerous lake arised in front of the glacier snout during last years.

Permanent research station was built at the shore of the upper lake in 2008. A small house was built for the crew and researchers as a base and two weather stations at different altitudes and other research tools were established at the site. The station is open for researchers from all over the world (Fig. 8).

Fig. 8: The permanent research station was built in 2008 in the northern slope of Kyrgyz ridge about 40 km from the capital Bishkek. The programme of the station includes the monitoring of hazardous lakes and hydrological, glaciological and climatological research.

DISCUSSION AND CONCLUSSION

Global climate warming causes an intensive melting and retreat of glaciers in mountain areas all over the world. This process is evident in mountain regions of Northern and Inner Tien-Shan in the territory of Kyrgyzstan as well. The changes of frontal part of glaciers and hydrological regime of upper part of rivers fed by melting water are very dynamic. The lakes are mostly dammed by unstable morains with decreasing ice core.

Long-term field research and evaluation of archive data confirmed increasing speed of glacier retreat in major part of Kyrgyz Tien-Shan. Changes of regularity of temperature and precipitation and distinctive increase of both paramters during last two decades has been confirmed too. High number of new lakes appear every year at the altitudes of 3500–4000 m due to described situation. Several outbursts happen annually, some of them with catastrophic consequences.

One of the most hazardous lakes in Kyrgyzstan is the Petrov Lake. The increase of the lake surface and volume of water along with weakening of the moraine dam represent permanent risk of moraine failure and lake outburst. Possible outburst of the lake would primarily threaten the infrastructure of the Kumtor Gold Mine. The tailings pond containing toxic remnants from gold processing, located about 3 km downstream can be destructed in case of extreme outburst. The municipalities and roads in a sparsely populated area, in the following section of river valley, will be threatened. A dam rupture could cause a water mass of up to 13 m in depth, representing 37 millions m^3 of water, i.e. roughly 62% of the lake's total volume, to flood the area.

Lakes in the Adygine region are situated in front of rapidly retreating valley glacier. This dynamically developing glacier complex includes retreating glacier and 22 lakes from which three lakes are considered potentially dangerous. The outburst of the lake Adygine Lower can be triggered by rapid filling of water in case of break of intramoraine channel. The other two lakes can be dangerous in certain conditions too. The danger is incerased by continual retreat of glacier snout and changing ice core content in the moraine. In case of a further retreat of the glacier, we can expect an increased inflow to the Upper Adygine Lake and after that to the Lower Adygine Lake. According to topographic conditions up to 300 000 m^3 of water can collect in the basin of Lower Adygine. A large volume of water will increase the risk of outburst floods. Outburst of such depression would cause a flood in the Ala-Archa valley and on the territory of Bishkek, the capital of Kyrgyzstan. The Adygine glacial complex has been studied systematically by Czech-Kyrgyz research team since 2004.

ACKNOWLEDGEMENTS

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