International Journal of GEOMATE, July, 2018 Vol.15, Issue 47, pp.158-163
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2018.47.20218
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

INTEGRATED INSTRUMENTAL MONITORING OF HAZARDOUS GEOLOGICAL PROCESSES UNDER THE KAZBEK VOLCANIC CENTER

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ABSTRACT: Kazbek volcanic center is characterized by the complex interrelationship of various hazardous geological processes. The proximity of populated areas and infrastructure objects (the main one is the Georgian Military Road connecting Russia with South Caucasus) determines high social and economic risks of the region. Disasters of 2002 and 2014 caused by ice-rock fall govern importance of investigation of the area. It must be based on instrumental data collection and seismic monitoring is the first continuous technique covering both exogenous and endogenous processes, especially of possible volcanic activity and various postvolcanic phenomena. That’s why complex observational network “Karmadon Parametric Range” was established in September 2003. The network recorded a collapse of the mass of ice and rocks in the region of the Devdorak glacier on May 17, 2014 and the movement of the formed stone-ice avalanche. Research group for the first time faced with the movement of massive extended objects seismic records processing and analysis. New techniques as energy release and wavelet-based spectral-temporal graphs were developed. Flow velocities are estimated on the basis of slope variation along the trace. As the result, determined accordance of the events of 2002 Kolka glaciers fall and the 2014 Devdorak region rockfall is probably an evidence of general formation nature of both processes. And the main aim is to determine early evidences of the future events on the basis of a new instrumental monitoring of Kazbek volcanic center system. It must reveal characteristics of the Kazbek volcano and significantly improve natural hazards safety of the region.

Keywords: Glacier, Rock-Ice avalanche, Monitoring, Seismic records, Wavelet analysis

1. INTRODUCTION

The territory of North Ossetia is exposed to a number of hazardous natural and technogenic processes, the most destructive of which is possible consequences of earthquakes. The greatest hazard due to its proximity to Vladikavkaz territory as a source of seismic impact is the Vladikavkaz fault, the seismic potential of which is estimated at M = 6.5-7.1, and the maximum magnitude can reach values M = 7.1 [1], [2].

Another hazardous and catastrophic endogenous geological processes is a possible eruption of the volcano, accompanied by a breakthrough to the earth's surface of a material of juvenile (deep) origin, different in phase composition and aggregate state, and also the removal and rejection of the previously frozen (resurgent) material and rocks of the volcanic “frame”, not having volcanic composition and origin.

There are different views on the possible activity resumption of the Kazbek Volcanic Center [3], nevertheless, the importance of monitoring is obvious.

In the most probable places of possible localization are naturally concentrated the most significant according to intensity signs, preceded (and, respectively, foreshadowing) volcanic eruptions – their forerunners, the detection of which is extremely important to forecast eruptions and minimizing their negative consequences.

The forecast of an eruption may not be realized even in the countries that are the most favorable for a reliable volcanic forecast and which are best instrumentally equipped. For example, the time of the eruption of one of the largest in the XX century supergiant directional eruption (explosion) of St. Helens volcano on May 18, 1980, in the northwest of the USA (State of Washington) was practically not predicted. One of the main reasons for this is a short seismic quiescence before the eruption [4].

In this regard, the use of a possibly wide range of observations and the continuity of observations within each of the methods of this complex is the most important condition for the successful volcanic forecast [5].

It is also necessary to distinguish the precursors of eruptions from the fluctuations typical for the regions of modern and newest volcanism in the dynamics of post-volcanic phenomena, including those significant in scale, observed, in particular, at the beginning of the current century in the Kazbek-Dzhimara district of the Kazbek neovolcanic region. According to individual authors, one of the manifestations and results of the post-volcanic processes precisely was, in particular, the Kolka (Karmadon, Genadon) glacial catastrophe on September 20, 2002 [6].

2. DEVELOPMENT OF SEISMIC OBSERVATION NETWORKS

In this connection, and also taking into account the activation of other hazardous natural processes in the Caucasus at the end of 2003, the existing North Ossetian Seismic Observing Network of the Geophysical Institute was transformed into a network of complex observations “Karmadon Parametric Range”. The task of the modern system of seismological, geodynamic and gravimetric observations organization was stated [7]. The purpose of the network is the development of a concept for the population safety in mountain regions and the creation of reference scenarios for hazardous geological processes (landslides, glacier movements, earthquakes, etc.).

The local network of seismic digital stations of the first generation on the territory of the Republic of North Ossetia-Alania was organized and started operating in 1998–1999 with the support of the Ministry of Emergency Situations of the Russian Federation [7]. The catastrophic fall of the Kolka glacier in 2002 was recorded by the network. Later on the territory of the Republic 7-8, seismic observation points were functioning simultaneously. On September 8, 2003 very important seismic station at Karmadon (KAR) was connected to the network after almost two years of inactivity. Alfa-Geon recording equipment was installed at all observation points.

In September 2003, according to the agreement between the North Caucasian Institute of Mining and Metallurgy (State Technological University) (Vladikavkaz), the GEON Center of the Ministry of Natural Resources of Russia (Moscow) and the Geophysical Institute of the VSC RAS, the “Carmadon Parametric Range” was established. The existing local network of observations was the basis of the seismological network of the range. As it was mentioned above, the organization of the “Karmadon” observation point in September 2003 was the beginning of the actual functioning of the range. The main purpose of the newly created local network “Karmadon Parametric Range” was study and the forecast of hazardous geological processes in the form of endogenous (volcanic activity, earthquakes, etc.) and exogenous processes (avalanches, glaciers, landslides, etc.). Moreover, the network should allow studying natural and technogenic events in their organic interconnection.

It is obvious that one of the main tasks was the development of instrumental observations directly in the upper reaches of the Genaldon River in order to study the reasons of the 2002 Karmadon disaster, i.e. for the solution of the problem of seismic monitoring of glaciers [8]. The project of the organization of instrumental observation station directly in the area of the Kolka glacier bed was developed in 2011. With the support of the Ministry of Emergency Situations of the Russian Federation for RNO-A, the equipment was delivered to the area of the Kolka Glacier Lodge by helicopter on April 27, 2012, and later the group of climbers led by O.N. Ryzhanov at an altitude of 2,970 meters above sea level has installed and activated a seismic station, which became operational on May 19, 2012 (Figure 1, station code of KLK) [7].

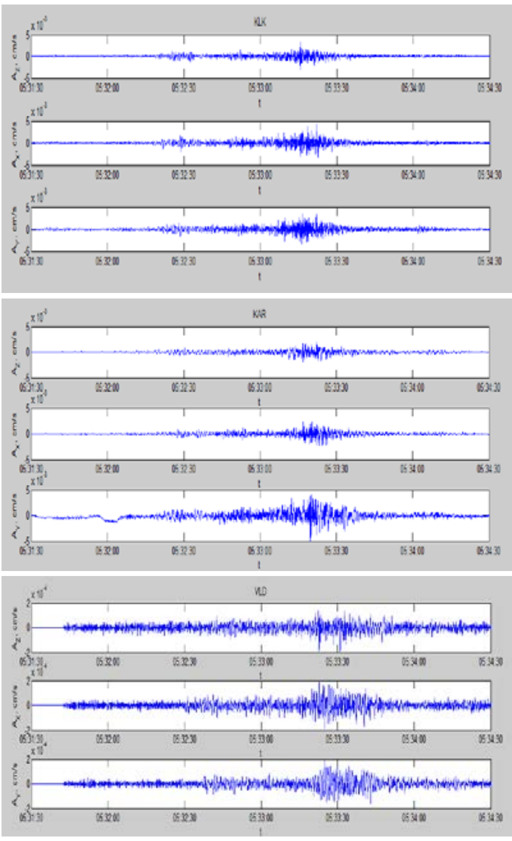
Fig.1 Location of Russian seismic stations: KLK - Kolka, FIG - Fiagdon, KAR - Karmadon, VLD - Vladikavkaz, and Georgian: GER - Gergeti, GUD-Gudauri

3. COLLAPSE IN THE AREA OF THE DEVDORAK GLACIER

The Kolka Station operates in a continuous mode and it has completely detected the process of the avalanche flow on May 17, 2014. The separation zone is located on the eastern slope of Kazbek, in the feeding area of the right branch of the Devdorak glacier, at an altitude of 4400-4500 m. The collapse was spread to the right of the main Devdorak icefall and fell on the tongue of the glacier. Then there was a transformation of the collapse into an “avalanche-like flow” or “rock-ice avalanche” [9]-[10]. People died.

The resulting obstruction blocked the mouth of the Terek River, which led to the formation of a ponded lake. The hazard of a failure which threatened Vladikavkaz remained until the moment when the River Terek filled the diversion tunnel and the water level began to decline.

The entire process of the movement of the avalanche flow is recorded by seismic stations of the Karmadon Parametric Range located in close vicinity to the transit zone (Fig. 2).



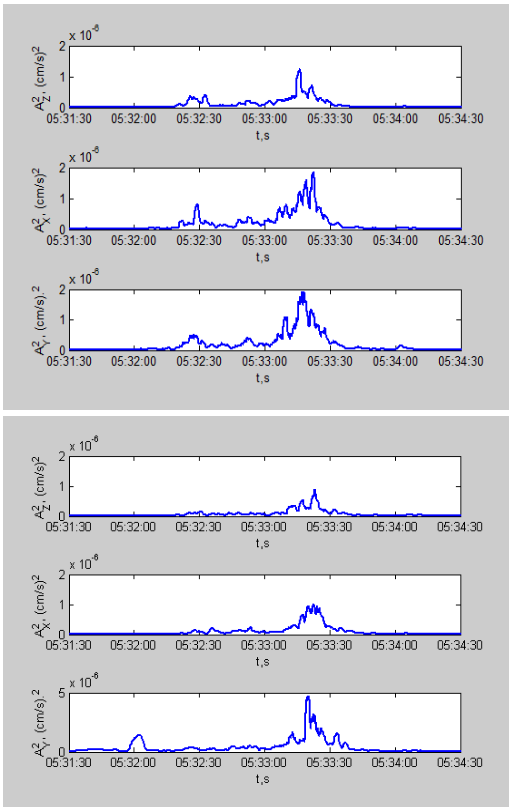
a) b) c)

Fig. 2. Seismic records of the motion process of an avalanche-like flow on May 17, 2014: a) Kolka (station code KLK); b) Carmadon (station code of KAR); c) Vladikavkaz (station code VLD).

Energy release diagrams [6] were constructed and a spectral-temporal analysis of the records was performed for the nearest stations Kolka and Karmadon (Figures 3-4) equipped with identical modern domestic seismometers SPV-3K [10]. At that time the nearest station from the Georgian side was the Gudauri station, which was situated almost 50 km away from the fall region. In this connection, the records of Kolka and Karmadon stations were very important.

Data analysis of these events shows that spectral-temporal analysis is a good and reliable tool for classification of signals [5] and development of their models [11].

At the initial stage of the collapse formation, the movement takes place in the north towards the seismic station "Karmadon" (station code KAR) and, in fact, perpendicular to the direction to the Kolka station (station code KLK) (Fig. 4). Further, the flow affected the left side in the region of the tongue of the Devdorak glacier - on the left side (the Bart-Kort ridge) there was a significant overlap [9], [12]. Further, there is a rotation of the flow, in which the eastern direction predominates, and in this case, the flow changes its direction several times during the motion.



a) b)

Fig. 3. Energy release graphs: a) Kolka (station code KLK); b) Karmadon (station code KAR)

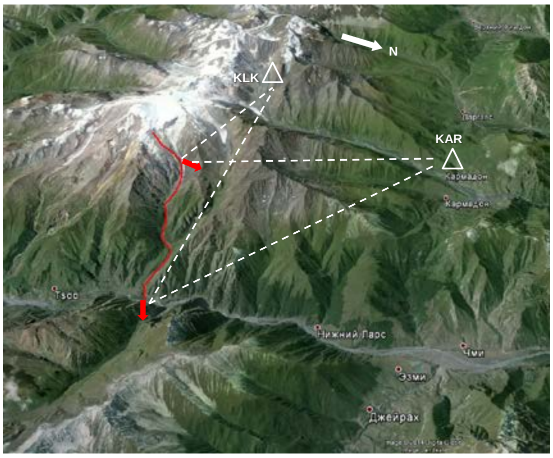


Fig. 4. The location map of the seismic stations Kolka (KLK), Karmadon (KAR) and the avalanche-flow transit zone on May 17, 2014, the arrows show the directions of impact on the slopes

S.S. Chernomorets [12] cites the following data: “According to witnesses - Georgian border guards who stood at the post below the confluence of the Amilishka and Chach rivers, the event occurred around 9:30 am local time (the time is the same as in Moscow).There was no heavy rumble. The flow was rapid. The border guard did not manage to reach the cliff above the Kabahi River (100 m), and during this time the mass passed several hundred meters”. Records of our station (Kolka) confirmed the time of the beginning of the collapse with an accuracy of fractions of seconds. Taking into account the length of the flow, it can be considered as an extended seismic source. Then the flow reached the bed of the River Terek near the Georgian Military Highway which is the most important road between Russia and Georgia. The splash on the right side of the Terek can visually be estimated at 20-25 m above the current channel. This moment is characterized by the maximum level of impact, which is noted on the Y component (“west-east” direction) of the station “Karmadon”, where a high-frequency pulse is recorded on all seismograms (Fig. 5).

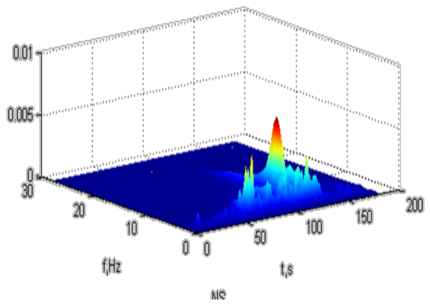


Fig. 5. Spectral-temporal analysis of the Kolka station (KLK) record, Z-component

In this connection, it is interesting to note that broadband (without a clearly pronounced predominant frequency) pulses were also observed in the spectral-temporal analysis of the recording of the Kolka glacier in 2002 on the records of the Fiagdon station (Fig. 6), which is probably due to the general formation nature of the both processes.

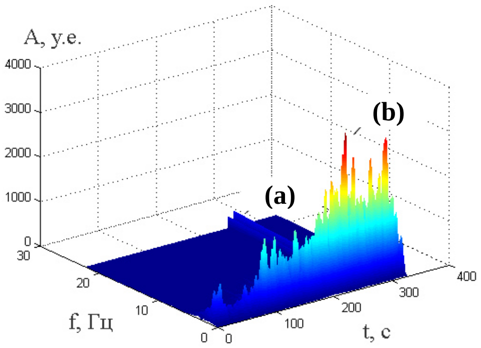


Fig. 6. Spectral-temporal analysis of records of Z-component of the Kolka glacier fall on September 20, 2002, station Fiagdon: a) high-frequency impulses; b) the base record

4. ESTIMATING THE VELOCITY OF AVALANCHE FLOW

To calculate the motion under the influence of gravity it is necessary to take into account the steepness of the slopes in different sections of the movement. In this connection, the flow profile was constructed according to the scheme in Fig. 4.

Let’s assume that the motion on each small section is described by the following equation (for the center of the system mass):

$$\frac{d^2S}{dt^2} = g(\sin\alpha - \mu\cos\alpha) - \xi\left(\frac{\partial S}{\partial t}\right)^2 \qquad (1)$$

where: S is the traversed path; α is the angle of inclination; μ is the coefficient of friction; ξ is a parameter that takes into account resistance forces proportional to the square of the velocity $V = \partial S/\partial t$.

The value of μ, usually determined empirically for different pairs of materials, is not exactly known to us, for friction ice against ice is about $3 \cdot 10^{-2}$ (Center for Advanced Friction Studies: http://frictioncenter.siu.edu), but differs significantly in each case. The strength of air resistance does not affect the movement at the initial stage, when the speed is small but becomes significant with increasing speed. In studying the peculiarities of the movement of the avalanche-like flow of the Kolka glacier in the corresponding calculations were used the values μ = 0.11 and ξ = 350 m/s^2 respectively. The results of the calculations are shown in Fig. 7. Although the maximum instantaneous speed, according to calculations, reached 130 m/s, the average flow velocity in the final section in accordance with this model is about 100 m/s.

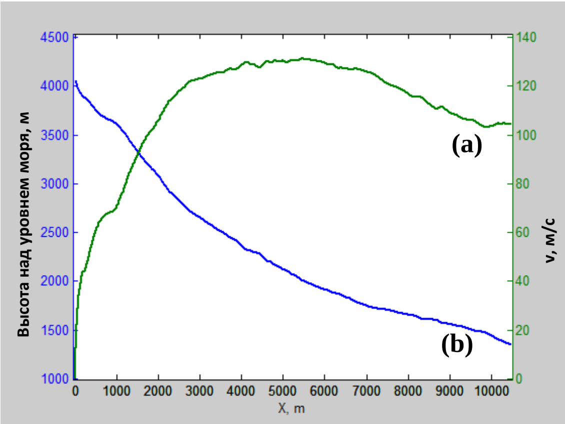


Fig. 7. Calculated changes in the velocity V, m/s of the avalanche-like flow (a) along the profile (b)

5. CONCLUSION

In connection with the activation of dangerous natural processes in the Caucasus and in particular the Kolka glacier fall on September 20, 2002, the core of the complex observational network "Karmadon Parametric Range" was formed in September 2003. In the strategic plan, the aim of the network creation was the development and subsequent implementation of the concept of population safety in mountain regions and the creation of reference scenarios for hazardous geological processes.

Therefore, a modern observational system that allows adequately solving the prognostic problems of hazardous natural and technogenic processes and mitigating the risks of various nature has been created on the territory of North Ossetia (Russia).

On May 17, 2014 the network of seismological observations "Karmadon Parametric Range" had recorded the process of the collapse of rock and ice mass in the area of the Devdorak glacier and the movement of the formed avalanche flow down the gorge.

A preliminary analysis of the obtained data was carried out, including an estimate of the velocity of the avalanche flow.

A system of instrumental monitoring of volcanic manifestations in the Kazbek volcanic center, including 4 seismic stations of the Karmadon Parametric Range (Russia) and 2 stations of the Georgian Seismological Service was created. An instrumental data exchange will reveal a whole number of important characteristics of the Kazbek volcano and will significantly increase the safety of life due to an adequate risk assessment and forecasting of hazardous processes.

6. ACKNOWLEDGEMENTS

The authors are grateful to Oleg Ryzhanov, Alexander Simakin, Nugzar Muzaev, Oleg Makeyev and all the persons involved in the Karmadon Parametric Range service.

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