THE INFLUENCE OF SEISMIC EFFECT ON AVALANCHE RELEASE

Evgueni Mokrov[1], Pavel Chernouss[1], Yuri Fedorenko[2,3], Eystein Husebye[3]

[1)]Center of Avalanche Safety of "Apatit" JSC, 33a, 50 years of October St., Kirovsk, Murmansk Region, 184250 Russia
[2)]Institute of Ecology, Kola Science Centre of Russian Academy of Science, Fersmana St., 14, Apatity, Murmansk Region, 184200 Russia
[3)]Institute Solid Earth Physics, University of Bergen, Allegaten 41, N-5007 Bergen, Norway

ABSTRACT: The mines in the Khibiny Mountains produce many chemical explosions, which occasionally are tied to explosive charges exceeding 100 tons. Such explosions have the potential of a sudden avalanche releases in avalanche prone valleys in the Khibiny. It is known that a ground shaking earthquakes have triggered avalanches although this phenomenon has been neither quantified nor well documented yet. In 1999 a joint project to study the influence of seismic loading on avalanche release was initiated by the Center of Avalanche Safety of "Apatit" JSC, Kola Science Center, Russian Academy of Science and the University of Bergen. Studies of archive data on avalanche releases for twenty years show that the distribution of avalanche occurrences over day of weeks are sharply non-uniform as confirmed by chi-square statistical test. The shape of these distributions is very similar to those of explosions. The attempts to study the explosions influence on avalanche release by statistical methods are described. In order to monitor the seismic events a seismic station (Nansen Kola Seismic Station) was installed at the snow and avalanche field station on the top of the mountain plateau in a distance of a few kilometers from main places of explosions. It is planned to use some portable stations for the measurements on avalanche dangerous slopes. The program of the future studies is presented.

KEYWORDS: Avalanche release, seismic effect, chemical explosions, seismic station.

1. INTRODUCTION

The Khibiny Mountains in Kola is highly snow avalanche prone during winter months and as such represent severe hazards for skiers and miners in this area. In the pioneering days of mining operations in the Khibiny, which commenced in 1929, the avalanche hazards were largely ignored until a tragic accident on December 5, 1935 when 88 miners perished near Kirovsk (Figure 1). Avalanche safety operations had already been initiated in 1933, and even at this early stage artificial avalanche release experiments were conducted. The 1935 tragedy triggered more comprehensive avalanche safety measures with associated research programs to assess the physical snow conditions, precipitation, prevailing winds and other meteorological parameters. The ultimate goals of these efforts, dating back to 1935, are enhanced safety measures and improved avalanche forecasting (Zuzin, 1996). The latter goal has proved rather elusive because the avalanche releases are a nonlinear process. Nevertheless, it remains highly relevant today, as mining activities remain strong and skiers continue to "invade" the Khibiny in ever increasing numbers.

Surprisingly, an almost unstudied problem in understanding avalanche formation is the role of earthquakes as a trigger mechanism. Any quantitative assessments of this factor of seismic loading are absent albeit avalanches are artificially triggered routinely using dynamite or firing mortar rounds into the snow on the potentially hazardous slopes. These techniques are well proven measures for mitigating such hazards. Avalanches may also be released by seismic loading, which in

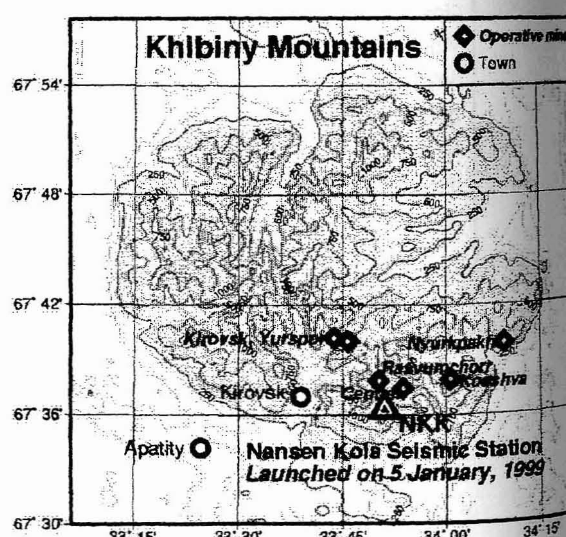

Figure 1: Khibiny Mountains map and location of apatite mines.

the case of the Khibiny, are caused by open pit and underground mine explosions. Over the period 1959-1999, approximately 225 avalanches were recognized as triggered in this manner, excluding those released intentionally by *in situ* shootings (Figure 2). For example, a large

Figure 2: Intentionally released avalanche by *in situ* shooting.

explosion approximately of 100 tons of dynamite triggered an avalanche of 40,000 cubic meters directly into the open pit of the Centralnyi mine on January 20, 1998. As a result, a stretch of a road 600 meters long was buried under thick layers of snow. Ad hoc evaluations show that even moderate mine explosions with charges of a few hundred kilograms of dynamite can trigger avalanches at ranges of 2-3 km away while the larger (tens and hundreds tons) explosions can trigger avalanches at distances up to 10-15 km. Nevertheless, nobody has really seen the avalanche releases exactly at the moment of explosion. The decisions that the explosion is a main agent of the specific avalanche release or trigger mechanism are subjective and just the most probable. Such influence must be proved by statistics.

2. DATA ANALYZED

The data on mining explosions and avalanche releases for the time intervals 1970 – 80 and 1989 – 2000 were extracted from data files at the Center of Avalanche Safety of "Apatit" JSC (CAS). For example, information on explosions (time, place and explosive charge) is sent to CAS routinely as a prewarning of scheduled forthcoming mine shootings. Amount of explosives, ranging from 30 kg to 659 tons, number of bore holes with explosive charges and firing delay were not taken into account at this stage of our analysis. However, Kozyrev et al. (1999) have demonstrated that these factors are important for stability of the constructions that is extent of ground shaking caused by explosion size and spatial configuration.

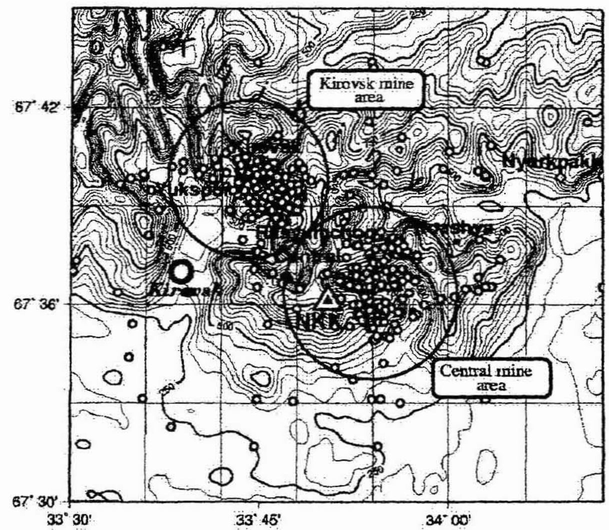

Figure 3: Mining explosion locations by the Kola Seismic Center RAS (http://www.krsc.ru). Epicenter clusters locate around mines but location precision is seldom better than 5 km. The neighboring Nansen (NKK) station in general provides more accurate explosion location.

Data quality, the errors in time of avalanche releases were usually within one day otherwise the event in question was excluded from analysis. Occasionally, some days with avalanche releases were missed due to bad weather conditions that made the field observations impossible. In other cases, announced explosions were not fired as verified by comparison with seismological recordings. Since explosions are concentrated around several centers, where underground mines and open pits are located (Figure 3), the data on avalanche releases were analyzed separately for the Kirovsk mine area and Central mine area, respectively. All days for any area were divided into two groups – the days with avalanche releases, when at least one avalanche release took place, and the days without avalanche releases.

3. INTERDEPENDENCE BETWEEN SEISMIC EVENTS AND AVALANCHE RELEASES

Firstly, both explosions and the avalanche releases day-of-week occurrences were taken into account. Such distributions were constructed for each area and are shown in Figure 4. Uniform

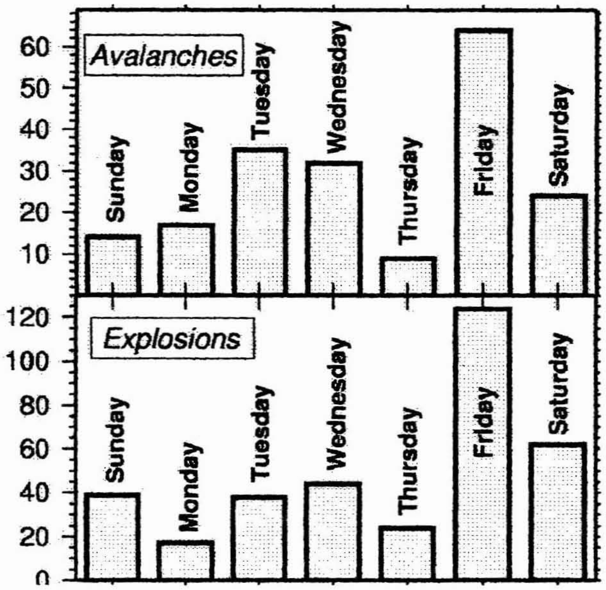

Figure 4a: Number of known avalanches and mining explosions in the Central mine area. Notice the relative large number of Friday avalanches, which from Fig. 4b is clearly correlated with the large number of explosions on Fridays that is explosions trigger avalanche releases.

distribution of avalanche releases as a function of day of week was chosen as a null hypothesis. Justification tests with the chi-square criterion gave that these hypotheses should be rejected at the 90% confidence level for the Kirovsk mine area and at the 99% confidence level for the Central mine area. In addition, it is easy to see a shape similarity in the distributions of avalanche releases and distributions of explosions.

In another analysis, a contingency table was used to test correlation between days with avalanche releases and days with explosions. In this case, we considered "same winters" in a manner similar to "days of week analysis".

Areas where explosions and avalanche releases were registered were combined. The chi-square test showed that the hypothesis about independence of days with explosions and ones with avalanche releases should be rejected at the 99% confidence level. Evidently, there is a weak association between explosions and avalanche releases. The contingency coefficient, Pearson's R and Kendall's τ_b coefficients (Tyurin, Makarov, 1995) which represent the measure of the

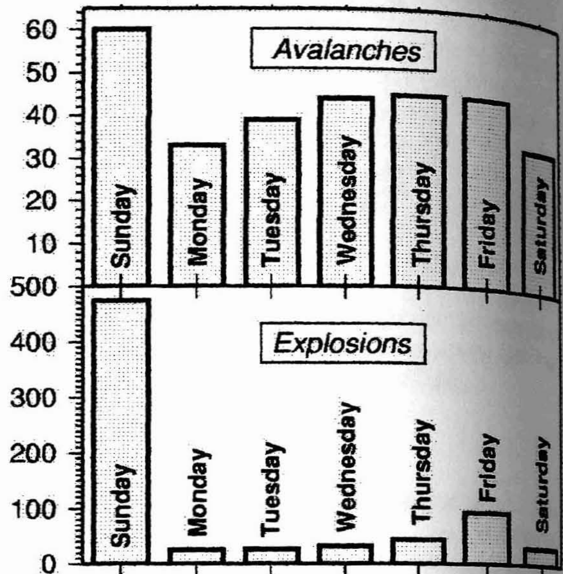

Figure 4b: Number of known avalanches and mining explosions in the Kirovsk mine area.

degree of association between rows and columns in the Table 1 is equal 0.0427. The P-values of Pearson's and Kendall's statistics indicate a

	Days with explosions	Days without explosions	Row total
Days *with* avalanche releases	266 5.61%	238 5.02%	504 10.62%
Days *without* avalanche releases	1913 40.32%	2328 49.06%	4241 89.38%
Column total	2179 45.92%	2566 54.08%	4745 100.0%

Table 1: The contingency table for the days with explosions and the days with avalanche releases.

significant association between rows and columns at the 95% confidence level. Thus, the correlation between days of explosions and avalanche releases is clearly being recognized but on the other hand is too weak in order to use it for avalanche release prediction. As analyzed data show there is significant correlation between mass explosions (or seismic events) and avalanche releases which evidently has a cause and effect relation. To better understand the physics of such mechanism additional theoretical studies will be carried out.

4. THE NANSEN STATION – SEISMIC LOADING MONITORING

As previously mentioned, observations indicate that a causal relationship exists between seismic loading and avalanche releases. To model the phenomena, we require a more quantitative relationship, which, in turn, motivated our deployment of the Nansen (NKK) station near the Kirovsk mining town (Figure 1). The station became operational January 5, 1999 and since that time hundreds of mining explosions have been recorded. The SP seismometers record ground motion velocities which are easily converted to peak ground accelerations (PGAs) and similar measures well known from earthquake hazard analysis. The challenge is to simulate PGAs for an arbitrary explosion over larger Khibiny areas using 3D wave field synthetics, and properly accounting for topographic focusing/defocusing effects (Hestholm and Ruud, 1998). For a verification of the simulation, obtaining parameters of the model it is planned to use the Nansen 3-component station as a stationary one and a few removable stations to measure accelerations in the avalanche starting zones.

5. PERSPECTIVES

For simulating avalanche releases, it is planned to improve the 3D stochastic model (Chernouss and Fedorenko, 1998) where the snow cover is considered as a thin elastic shell on a rigid underlying surface of arbitrary configuration. The results of calculations of PGAs at avalanche starting zones will be used for simulating the exceedance (seismic loading) of critical friction force limits in order to initiate an avalanche release.

Statistical and physically based analysis of the influence of an explosion air shock waves on snow cover stability will also be carried out.

Avalanche safety operations are well handled by the Center of Avalanche Safety of "Apatit" JSC, Kirovsk, but their areas of operations are limited to mining towns and their surroundings. However, our project aims at avalanche forecasting for larger areas, in particular those popular with weekend skiers. The most difficult part of the project would be to merge wind modeling and snow accumulations with changing snow conditions and avalanche triggering levels into an Avalanche Hazard Model. Our approach would, in some respects, be similar to those used in earthquake risk analysis and prediction.

6. ACNOWLEDGMENTS

We express our sincere thanks to "Apatit" JSC for the logistical and technical support. The Nansen Foundation, Norwegian Academy of Sciences, Oslo sponsored the Nansen station, while financial support for part of research work reported here came from The Nordic Council, Copenhagen.

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