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Megaton nuclear underground tests and catastrophic events on Novaya Zemlya

A satellite study

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[Abstract] During the first NUPI study of the Novaya Zemlya underground nuclear test site in 1991–92, much information was generated. This relates both to facilities and testing activities. One of the most important discoveries made was the enormous catastrophic rockslide caused by an underground test.

In recent years, new information has become available also from Russian sources. Declassified US satellite imagery made it possible for NUPI to study in more detail the effects of the powerful underground nuclear tests on Novaya Zemlya. This report contains the most pivotal discoveries and findings during the three years of studying this arctic test site.

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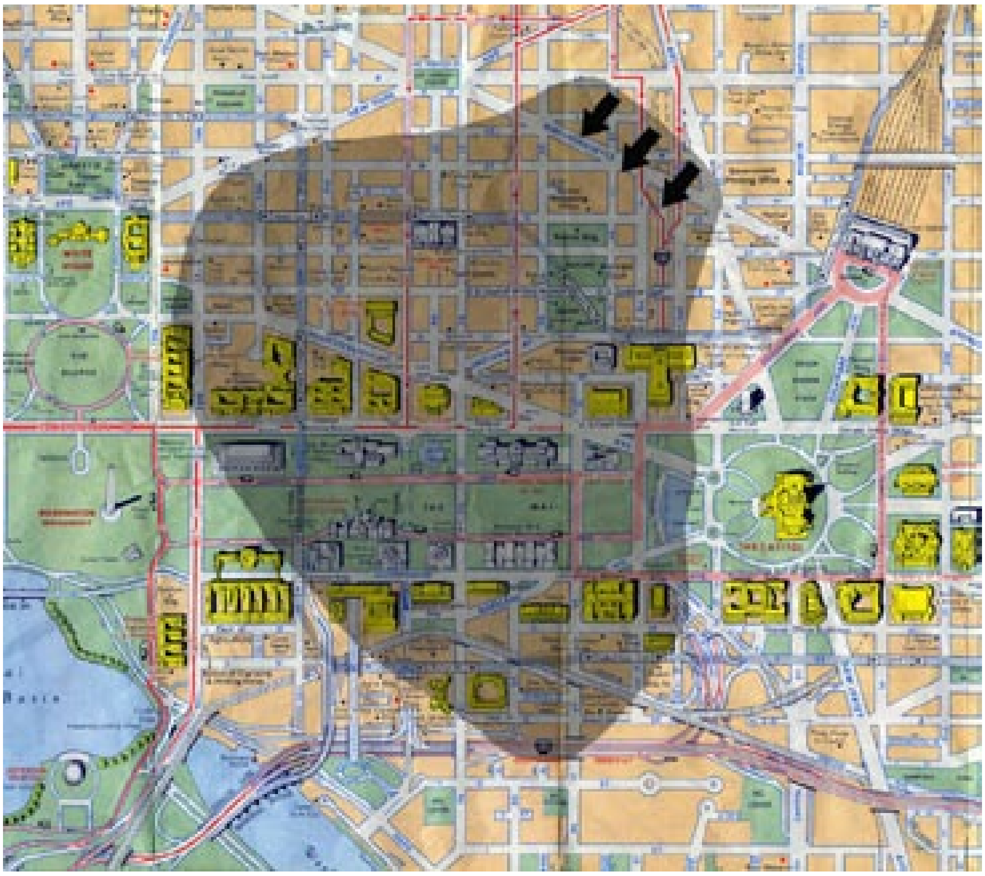

Fig. 1. The rockslide projected on to Washington D.C.
This massive rockslide of September 1973 is here projected onto a map of Washington DC to illustrate the proportions.
Over a stretch of roughly 600 m, the rockslide was released from the top part of the steep valley side. On the projection this is just NE of Massachusetts Avenue between Mt. Vernon Square and Union Station. Its eastern edge runs only 350 m from The Capitol. The southernmost part of the rockslide reaches the Southwestern Freeway just covering the Department of Transportation. Its western edge passes about 400 m from the Washington Monument and 370 m from the White House.
The rockslide covers about 2.5 mill.m² of the valley floor; total volume of rock in the slide is estimated to be 80 mill. m³. The base is buried under about 50m of rocks.

Figure: Johnny Skorve, NUPI. Graphical design: Edgar Kiøsterud

Preface

Jonny Skorve
Researcher, NUPI,
Oslo, December
2006

The study

This study focuses on a set of extremely powerful underground nuclear tests conducted at Novaya Zemlya test site in the former Soviet Union, between 1970 and 1975. These tests culminated in September 1973, with the most powerful underground test ever detonated, with a yield of 4.2 megatons or about 350 times the strength of the Hiroshima bomb. Four simultaneous explosions set off a catastrophic rockslide that filled an entire valley, blocking a river and thus forming a lake of trapped water behind the masses. The slide was massive, with a total rock volume of 80 million cubic meters.

Also other powerful tests conducted during this period had dramatic effects on the Arctic landscape, as noted in this report.

The study is based on interpretation and analysis of satellite images combined with recent Russian information on the underground nuclear testing on Novaya Zemlya. The satellite images used cover a long time-span, from declassified US reconnaissance satellite photographs of the 1960s to IKONOS and Quick Bird commercial high-resolution digital images taken only a few years ago. The study reveals further details on how the testing was conducted and what safety measures were employed.

The most recent underground test at the Novaya Zemlya site took place in 1990.

Novaya Zemlya updated

Novaya Zemlya is today Russia's only nuclear test site. For the past few years the only ongoing activities there have been sub-critical tests. However, indications have emerged that Russia is preparing to resume nuclear testing. On 19 July 2006 the Russian Defense Minister Sergey Ivanov inspected the northern Novaya Zemlya nuclear test site; then on 10 August the Russian Embassy in Oslo issued a press release stating:

> Defense Minister Sergey Ivanov noted that: Russia has ratified the CTBT (Comprehensive Test Ban Treaty) and kept strictly to its obligations. Concerning a Russian resumption of nuclear testing, the Defense Minister reminded that some important nations with nuclear weapons have not ratified the CTBT. Taking this reality into account, Novaya Zemlya is on constant alert to resume nuclear testing if a change in the political situation demands it.

According to a Russian statement issued in 2005, some 4,000 personnel are working at Novaya Zemlya in connection with the sub-critical experiments at this northern test site. (See Schneider 2006:31) There have also been some indications of ill-defined activities here since the mid-1990s. As Russia is a nuclear superpower, an upgrading of its northern test site to meet national security requirements could be expected.

Introduction

The nuclear test site area in focus here is located at the high Arctic latitude of 73º N, nearer the pole than the northernmost point in Alaska. The Novaya Zemlya test site has a challenging environment. For some eight months each year it is completely snow-covered. Then in June and July the top part of the permafrost terrain thaws, making the poor roads worse, indeed even impossible to use.

The main base of Severny on the southern side of the Matochkin Shar Strait has been the center of underground nuclear testing activities at this test site. As a rule, for each test considerably smaller bases have been built, for drilling adits into the mountains and preparing nuclear detonations.

The main settlement on Novaya Zemlya is the town of Belushya, the administrative center of the two large islands. It is situated 225 km SSW of the Severny base. Most of the population of Novaya Zemlya live here, many directly or indirectly engaged in nuclear testing activities. Some are full-time participants in the command and administration of testing. A second large group consists of personnel who spend the summer season working at the northern test site.

Located 10 km. north of Belushya is Rogachevo, the only sizeable airport / airbase, with a 2,470 m long runway. Goods and people are transported between Belushya and Severny partly by ship. There is also an important helicopter link between Rogachevo and the landing strip, just one kilometer SSE of Severny.

The present report is new and more comprehensive than the report on underground nuclear testing on Novaya Zemlya issued by the Norwegian Institute of International Affairs (NUPI) in 1992. It concentrates on the underground nuclear tests carried out in the innermost part of the Arctic northern island test site during the period 1970–75. Several of these tests were megaton explosions.

The enormous rockslide in the Zhuravlevka Valley on Novaya Zemlya came into focus when it became increasingly evident that the slide had been released by underground nuclear explosions. In 1992, information on this rockslide was far from complete. By the end of the first study, the rockslide had been described and measured by the use of the few available maps, and through the interpretation of SPOT imagery enlargements in particular. It was also suggested that the slide had been caused by one of three alternative underground megaton explosions.

Recent studies made by NUPI researcher Johnny Skorve have uncovered a large amount of new material. Through combining the various types of data and subsequent analyses, NUPI researchers have been able to reveal dramatic consequences of the rockslide and similar underground nuclear explosions.

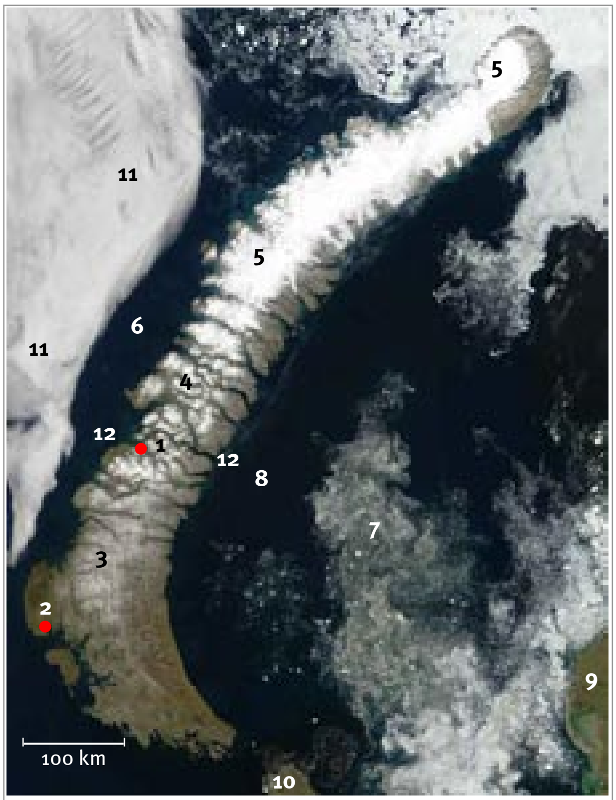

Fig 2. Satellite summer image of Novaya Zemlya area

1. Novaya Zemlya northern nuclear test site
2. Belushya
3. Southern Island
4. Northern Island
5. Glaciers covering most of Northern Island
6. Barents Sea
7. Melting sea ice
8. Kara Sea
9. Yamal Peninsula
10. Vaygach Island
11. Clouds over Barents Sea
12. Matoshkin Shar Strait

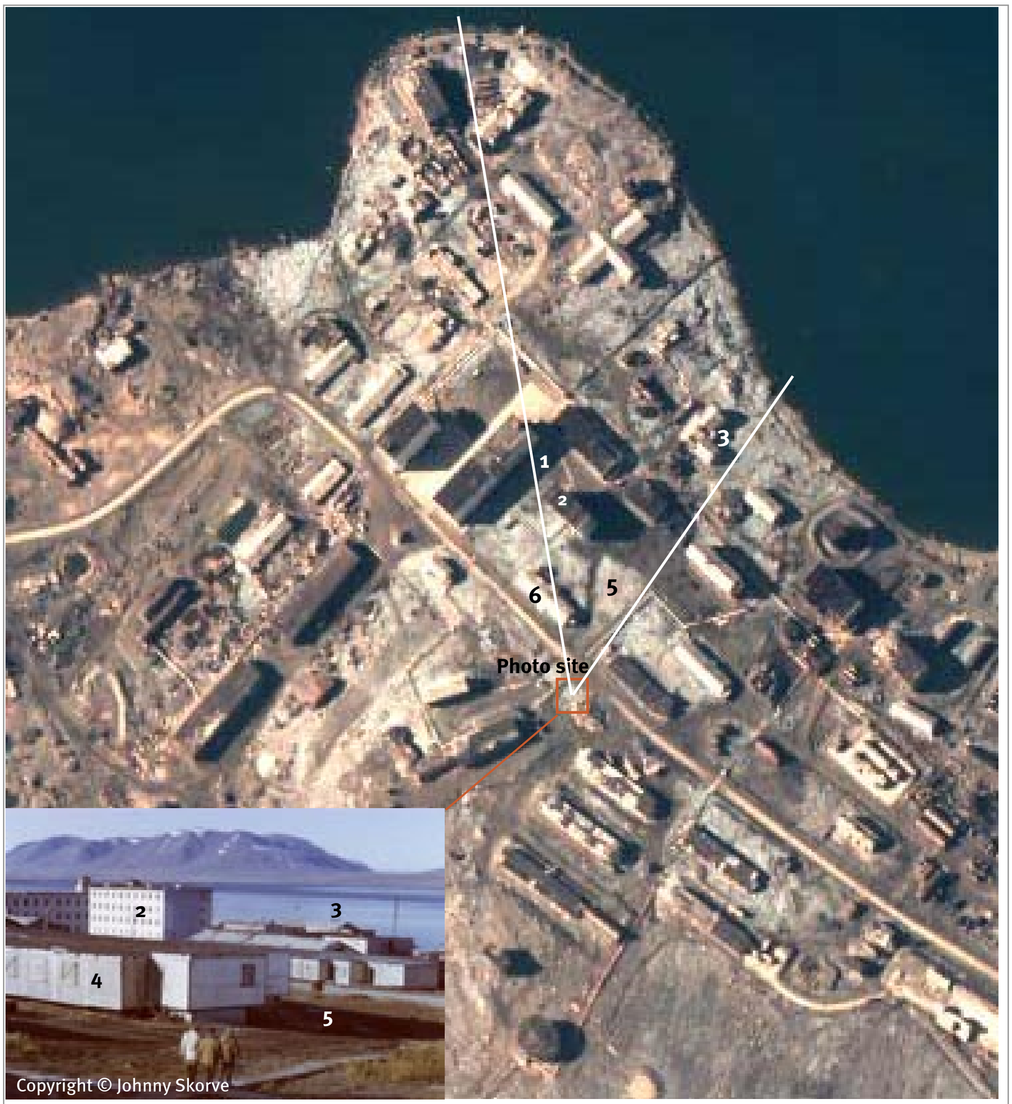

Fig. 3. Severny base
Severny, the main base for northern nuclear testing activities on Novaya Zemlya, facing west. The mountain in the background is similar to those in the Shumilikha Valley area. The tall buildings (left) are also seen on the Quick Bird image. As the extensive barracks complex in the foreground was not there when Quick Bird imaged the area in 2002 (Fig.4), this must have been demolished and replaced by a new, smaller, brightly colored building.

Fig. 4. Severny base from 450 km altitude
This zoomed-in Quick Bird enlargement of the Severny Base also covers the area of the ground-based photo. The probable photo site has been identified, but the two do not fit in all details, since the two pictures may differ in time by as much as 20 to 30 years.

Numbered features in Figs. 3 and 4
1. The left building on the ground-based photo
2. Tallest building
3. Small building closest to the Matoshkin Shar Strait
4. Barracks on the ground-based photo
5. Location of the barracks (4) projected on to the satellite photo
6. The (presumably newer) brightly colored building

Photo: Digital Globe

Table 1. New information and material, in approximate chronological order

1993–94	Scientific evaluation and response by the Russian Ministry of Energy to the 1992 NUPI Novaya Zemlya report (The Matushchenko Commission report)
1995-96	Declassification of US reconnaissance CORONA satellite photographs of Novaya Zemlya taken during the period 1960–1972
2000	New details on underground nuclear testing on Novaya Zemlya provided by Russian officials
1999–02	New high-resolution satellite images taken by the US commercial satellites IKONOS and Quick Bird, covering the nuclear test sites on Novaya Zemlya
2000–01	New information on Novaya Zemlya nuclear test sites published in recent Russian literature
2002–03	Declassification of more US reconnaissance photographs taken in the period 1963–1967 by the first very high-resolution photo satellites of the KH-7 type, and by quality mapping cameras on KH-9 satellites 1973–1980

Fig. 5. Simple Zhuralevka river crossing
Zhuravleka River downstream, close to where it emerges from under the massive rockslide of 12 September 1973. Note the tiny suspension bridge. For some 4 km the Zhuravlevka River runs basically parallel to the Shumilikha River before their confluence. In the background, mostly obscured, the Shumilikha River flows to the right towards the Matoshkin Shar Strait. The mountain to the left is 7–8 km. distant, while the rounded top to the right is about 15 km. away, situated on the western side of the Matoshkin Shar Strait.

Nature and types of new information and their sources: brief description

The Matushchenko commission report

After the publication of the NUPI Novaya Zemlya report, the Norwegian Ministry of Foreign Affairs provided copies of the report to the delegations at the Conference on Disarmament in Geneva in 1993. However, when the Russian delegation read the report, they mistakenly understood it to be a study made by NUPI at the request of the Norwegian Ministry of Foreign Affairs. Minister of Energy, V.N. Mikhailov appointed a 13-member expert commission to review and comment on the NUPI study, headed by A. M. Matushchenko, scientific adviser to the Minister of Energy.

Several years later, NUPI received a Norwegian translation of the Matushchenko Report from the Norwegian Ministry of Foreign Affairs. The Commission confirmed most of the important findings in the NUPI study and found it to be correct overall. Commission members further responded to questions raised in the NUPI report concerning radioactive material released at the explosion sites, in particular regarding environmental safety and protection against possible radioactive releases to rivers and coastal water along the western shores of the Barents Sea.

Their comments contained much new and interesting information on nuclear testing on Novaya Zemlya. However, and rather surprisingly, the Matushchenko Report made no mention whatsoever of the enormous rockslide .

The declassification of US reconnaissance satellite photographs in 1995

In 1960, the USA started using military photo satellites to observe and map sites and areas of military and strategic interest in the Soviet Union and other East-bloc states. During the first years, these CORONA photographs revealed surface details around 5–8 meters. During the period 1965–72, the best photographs had a resolution of 2 meters.

Declassified CORONA photographs – new windows on Novaya Zemlya

In 1995 the USA announced that photographs taken by the CORONA reconnaissance satellites during the period 1960–72 were in the process of being declassified and would be made available to the scientific community worldwide. Those at NUPI who had been studying military bases on the Kola Peninsula and Novaya Zemlya during the period 1986–92, using civilian satellite imagery, immediately recognized the importance of the CORONA photographs.

NUPI researcher Johnny Skorve prepared for the study of these photographs, and was able to spend one week at the National Archives (NARA) outside Washington DC immediately after the CORONA photographs became available there. Using the excellent NARA facilities, he searched for photographs covering top-priority areas like the nuclear test sites on Novaya Zemlya and a few others areas in the former Soviet Union.

Prior to this, NUPI had not been able to access satellite images better than those taken by the first SPOT satellites, with a resolution of 10 meters. The best Corona photos were 25 times more detailed than these SPOT images. Accompanying the CORONA photographs at NARA there were maps, notes and comments made by CIA staff members who had made interpretation and analyses of the photographs taken in the 1960s. For a researcher who had been engaged in the same kind of satellite-imagery related work at NUPI during the period 1985–1992 on a small and modest scale, it was rewarding to discover that the approaches and interpretations of the CIA and NUPI were in many respects similar.

After this valuable experience with CORONA photos, a list was made of the most interesting and relevant photographs. These selected CORONA photos were then purchased by NUPI from USGS, EROS Data Center (EDC).

The CORONA photos are important in several respects. In addition to offering far better resolution than those of the SPOT and Landsat TM images, they show how the test site was used at the time of imaging, and collectively, how activities expanded geographically over time.

It should be borne in mind that most of the SPOT and Landsat TM images used in the first NUPI study of Novaya Zemlya were taken in the late 1980s. By that time, nearly all underground testing on this island had been completed. (And, as noted, no underground nuclear tests have been conducted there since 1990.) Therefore all major changes in the terrain caused by nuclear testing activities had taken place by the time Landsat and SPOT took their images – the ones used in the first NUPI study of nuclear underground testing on Novaya Zemlya. These changes include surface disturbances and landscape modifications, whether caused directly by underground nuclear explosions or resulting from general human activities of various sorts within the test site.

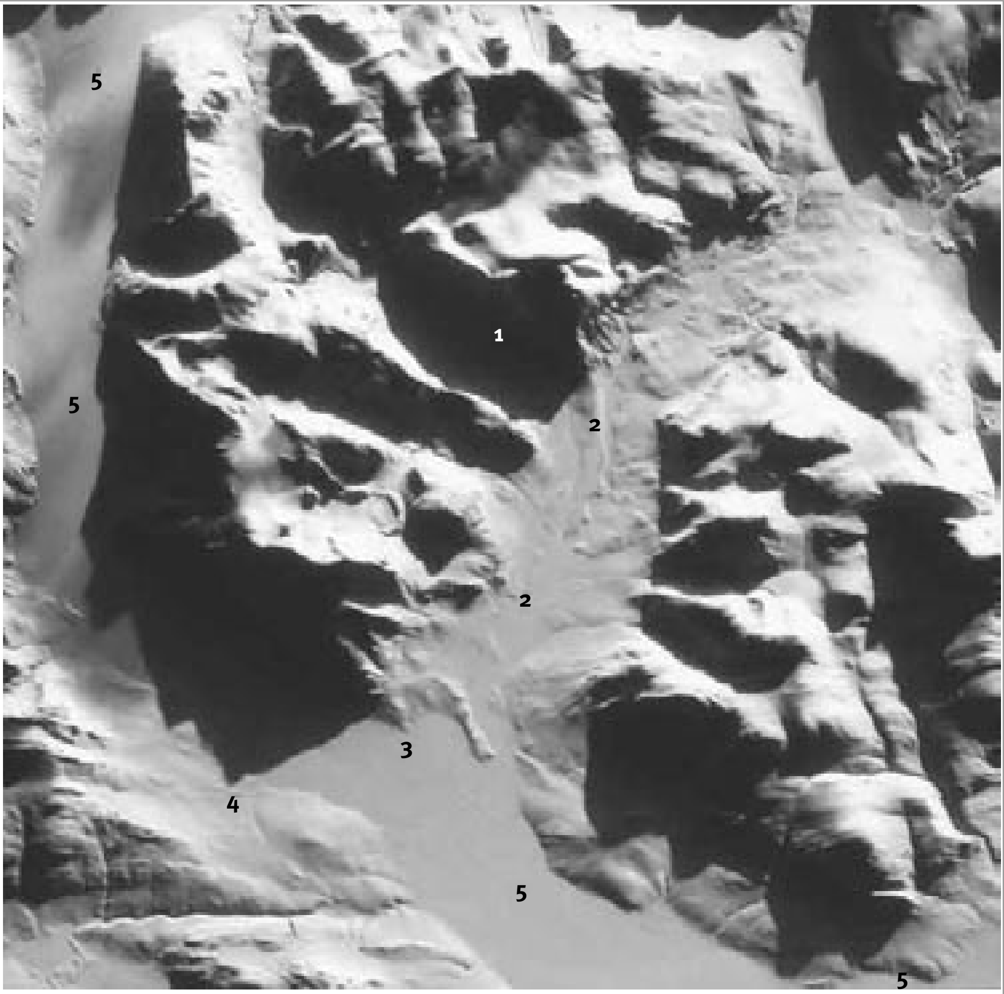

Fig. 6. Snow-covered Novaya Zemlya nuclear testing area
Late one morning in March 1966 a CORONA reconnaissance satellite took this photograph of the northern Novaya Zemlya nuclear test site. It covers about 15 x 15 km, and shows the area in an easterly direction with the landscape shadows falling in the direction of the reader.

1. The Zhuralevka Valley is hidden by the shadow of the Chernaya Mountain. The powerful 1973 test released a massive rockslide that blocked the entire valley.
2. The Shumilikha Valley
3. Severny, main base of the nuclear test site.
4. The tip of the 3700 m shadow from the 650 m peak of the mountain range north of Severny. The shadow crossed and reached the northern shore of the 2 km wide Matochkin Shar Strait.
5. Matochkin Shar Strait.

Photo: CIA - USGS

Table 2 Major changes visible on satellite images

1	Craters formed by underground nuclear explosions
2	Rockslides released by underground nuclear explosions
3	Diverted rivers caused by earth/rockslides or new rock-faults and fractures caused by underground nuclear explosions
4	Expanded and new bases
5	Harbors and transport facilities
6	Storage sites for equipment, oil and fuel
7	Roads, tracks and bridges
8	Water reservoirs
9	Bases for adit / shaft drilling
10	Large tailing piles of rock dumped outside adit entrances
11	Numerous accumulations/storage sites, from small to very large, for all kinds of waste – empty barrels, container parts, damaged equipment, vehicles, etc.
12	Extensive vegetation damage due to heavy vehicles driving in the melted, vulnerable part of the Arctic permafrost active layer during summer season

The northern Novaya Zemlya nuclear test site was quite frequently photographed by the CORONA satellites. However, only a limited number of cloud-free photographs were taken – and, unfortunately, none at all during the summer season, because of the very poor weather and bad luck in the random timing of the photography. This made it was difficult to follow in close detail the progress and expansion of the nuclear testing facilities.

New details about testing on Novaya Zemlya, available from official sources

Information made available recently includes adjustments/corrections with improved accuracy of geographical coordinates of epicenters of the explosions. Also of great importance is the new information that most tests consisted of several individual, simultaneous explosions. There were in all 133 nuclear explosions at the 39 underground tests. (Kalturin et al. 2005:20)

US commercial high-resolution satellite images

During the mid-1990s there was strong pressure from the high-tech industry on the US Congress, the Pentagon and the CIA to allow commercial production and use of civilian very-high-resolution imaging satellites. More than two years of negotiations resulted in success for the industry, and a few US firms were granted licenses to build satellites to take, produce and sell these types of images commercially.

Since the imaging camera systems and the related satellite technology are classified as high-tech systems, most technical details on the satellites themselves are not available, but the images they produce are open-market products. The first of these satellites to be launched into orbit around the Earth was Space Imaging's IKONOS, which started operation late in 1999. From an altitude of 600 km it can take crisp digital pictures with a spatial resolution of one meter.

The Quick Bird satellite was launched in 2002. However, this was only a few weeks before the beginning of the war in Afghanistan. The Pentagon soon took control of the satellite and employed it for military reconnaissance. Most of its imaging was used for making damage assessments after US strikes against various types of targets. After the USA and its allies had gained reasonable military control in Afghanistan, Quick Bird was released from military service and began operating as a commercial, high-resolution imaging satellite.

Both IKONOS and Quick Bird have taken images of the Novaya Zemlya northern test site, providing information of impressive quality.

New information on nuclear testing on Novaya Zemlya in recent Russian literature

One recent book is devoted exclusively to activities on Novaya Zemlya. A rich variety of topics is described and discussed, including security with respect to the testing as well as environmental effects. Also technical details on each individual test are provided.[1]

Additional declassified US military satellite photographs

In 1961, soon after the US intelligence community began using the CORONA satellite photographs, CIA experts had difficulty in finding high-priority military and strategic targets on the 70-mm wide format of the CORONA films. We now know that the development of larger and more advanced satellites capable of taking more detailed photographs was initiated immediately. The first of these 'KH-7' satellites was launched in 1963. Satellites of this type launched prior to 1966 took photographs showing details down to 1.2 m, while those that followed could provide an impressive resolution of 0.60 m. This is comparable to the resolution available from the best commercial imaging satellites of today.

Fig. 7. Excavation in tunnel
Drilling activities in an adit at the Novaya Zemlya northern test site. In the lower portion of the picture, rocks from the adit excavation; in the center the rail transporting rocks from the mining site to tailing piles outside the adit opening. To the right, a miner with helmet headlamp. Cables are loosely fastened to the adit wall, far right.

From 1974 to 1980, separate mapping cameras were carried on board the very-high-resolution KH-9 ('Big Bird') photo reconnaissance satellites. During their two first years of operation, these cameras took large-scale photographs for defense map-making purposes, with a resolution of 10 meters; later the resolution was improved to 7 meters.

Late in 2002 these two types of military satellite photographs were declassified. However, very little information was released concerning the satellites themselves – in stark contrast to the earlier US tradition of generous openness.

The cartographic photographs produced by the KH-9 satellites are of very good quality, but they are not high-resolution products. Each photo covers tens of thousands of square kilometers and is thus suitable for large-area overviews. Since mapping was the main objective, only a few stereo pairs of each area were needed. Accordingly, in most cases only one or two cloud-free photographs were taken of each area.

1 Logachev 2000. In the NUPI study, selected sections of Chapter 8 translated into Norwegian were used

Complexity in preparing underground nuclear tests

Preparing for underground nuclear testing is both complicated and comprehensive. The area around the site of the planned detonations is subject to thorough 3-D geological and geophysical mapping and prospecting. The main Soviet criterion for a test location was that, within a radius of 500 m of ground zero, the geology of rock types must be acceptable with respect to homogeneity and content of gases, and the amount of ice and water in the surroundings[2] An additional criterion was that there must be no significant faults or fractures within that rock volume.

During drilling in the bedrock, continuous geophysical and geological monitoring took place. If weak and difficult rocks were found, drilling stopped and was later redirected to another, safer, explosion site.

With underground nuclear tests, detonation usually takes place in a small volume of open space. Because of the enormous explosive force, it is vital to prevent the radioactive gases and material from being blown through the shafts and adits into the open air.

To obtain containment, the shafts were filled from bottom to top with a special type of cement, in such a way that the solidified cement had exactly the same volume as the slurry injected into the shaft. This is one crucial safeguard against leakage from the detonation chambers.

On Novaya Zemlya, large volumes of cement were needed to close the adits before they were secured and ready for the tests. All the cement used was produced at the main base of Severny at the Matochkin Shar Strait, whereas the most distant adits were more than 10 km away. It was difficult to transport large volumes of ready-made cement because the infrastructure was poor and the weather frequently very rough. However, during the 1980s roads and bridges were improved considerably.

In adits, the sealing is complex. Closest to the explosion chamber there are sets of concrete elements with chipped fillings in-between. This prevents the enormous detonation pressure from breaking through into the adit.

Further out in the adits there were several concrete walls: these serve as additional pressure dampers and also prevent any released radioactive gases from escaping further into the open air.

What makes preparation of underground nuclear testing so time-consuming and technically complex are the various procedural steps that have to be followed. After the nuclear charges have been placed in their cavities in the rock, the adits and shafts are secured against explosion effects as described above.

The aim and top priority of nuclear testing is to register and store measurements and information from numerous sensors emplaced in and close to the detonation cavities, as well as at several strategic locations in the shafts and adits. These data are vital for developing methods to improve the production of more effective and diverse nuclear weapons.

Most of the data are transmitted from the sensors via bundles of special cables that have been pulled through the adits and shafts to the center for information collection and data storage. As a rule, these are located in special

Fig. 8. Nuclear detonation cave
An underground nuclear explosion cave at the end of an adit inside the mountain, Novaya Zemlya northern test site. The cave has been readied to receive the nuclear device, monitoring and control equipment.

2 Mikhailov & Baarli (eds), 1992: 15

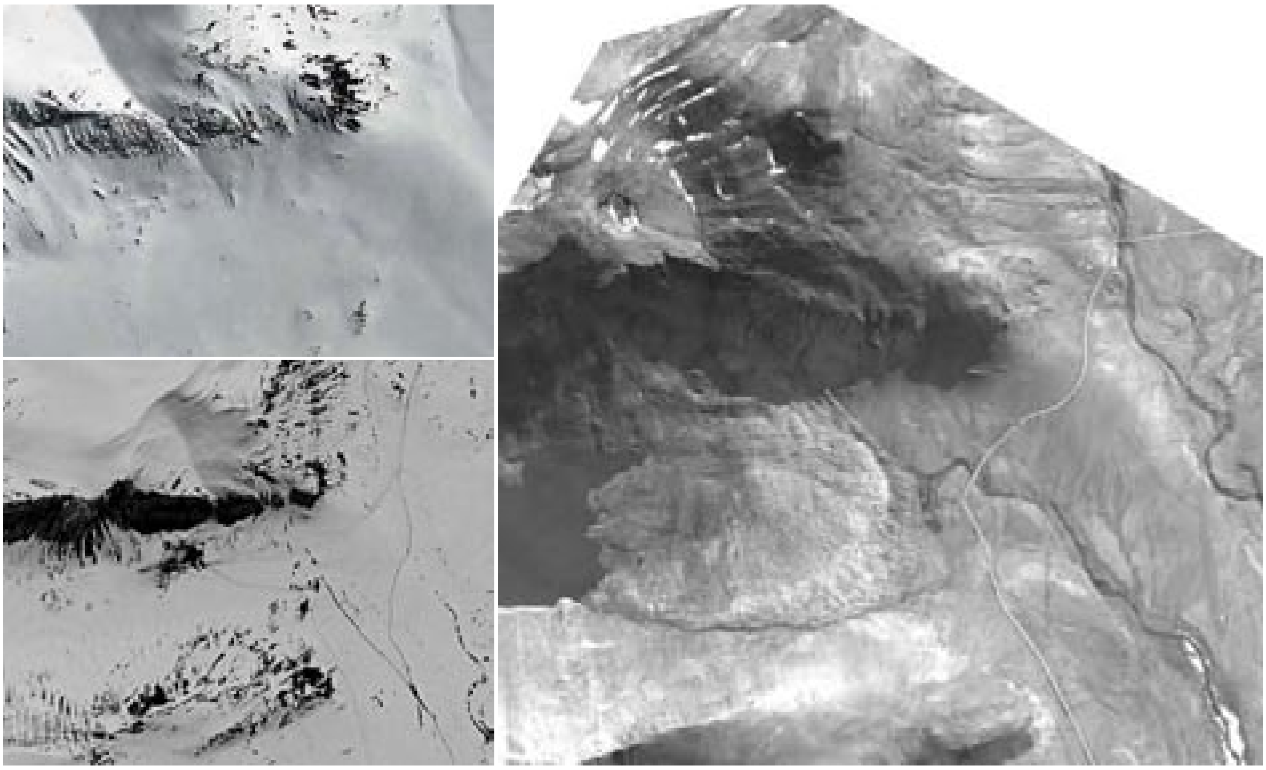

Fig. 9, 10 and 11. The 1973 testing site before and after the explosions
Development of the Zhuralevka Valley nuclear testing area over time, shown on three images.

1. Oblique KH-7 photograph, spring 1967, 25A
2. Oblique CORONA photograph, spring 1970, 25B
3. Vertical Quick Bird image, summer 2002, 25C

The 1967 photograph shows the area before any human influence.
The 1970 photograph reveals construction of a base camp for the September 1973 underground nuclear test.
The Quick Bird image shows how the area has looked since 1973, when the massive rockslide and newly-formed Lake Nalivnoye covered most of the Zhuralevka Valley.

Pictures: CIA-USGS and Digital Globe

trailers outside the mountain and close to the base. After the nuclear charge has been emplaced at the bottom of the shaft, all the sensors in this cavity area are connected and assembled in the cables, before the start of filling the shaft completely with cement. A small open channel in the center of the shaft makes room for the cables all the way to the top of the shaft.

However, these cable channels are highly vulnerable to explosion effects, for adits as well as shafts. To counter this risk, the cables are enclosed in strong metal sheaths, grouted by cement mortar. There is also gas-blocking equipment to prevent the release of dangerous gas through the cable channels.

At Novaya Zemlya, a State Commission was established to be in charge of planning and organization of the testing. One of its main tasks was to prevent any emission of radioactive gases from underground explosions from spreading into the surroundings. The best way to do this was to exploit a certain weather condition that caused a prevailing easterly wind to blow over the test area. This would quickly sweep away any released gases in the direction of the Kara Sea.

At the test site, such desirable weather conditions are unfortunately very rare during the autumn. Sometimes the testing staff had to wait more than a month before they got the go-ahead. Such long delays were very stressful and demanding for the many hundred staff members involved in the final preparation of the tests.

Heavy constructions, equipment and fuel had to be transported to the many drilling bases at the testing site. Declassified US reconnaissance satellite photographs reveal that when construction materials were brought to Novaya Zemlya by cargo ships, the harbor facilities at the main base of Severny were not always used.

In the later half of the 1960s, several underground tests were carried out near the Matochkin Shar Strait. The NUPI study shows that satellite photographs from that period showed that, during the winter season, some ships had sailed past the Severny harbor and stopped at a point further north, where they had unloaded their cargo onto the thick ice covering the Matochkin Shar Strait. From here large trucks transported the material inland to the drilling base, which was situated only a short distance from to the coastal mountain slope with its adit entrances. (Skorve, 2000).

The most powerful set of nuclear underground explosions on Novaya Zemlya: 1970–75

Underground nuclear testing on Novaya Zemlya started in 1964. Initial activities were carried out on the northern part of the test site, close to the Matochkin Shar Strait.

However, the most powerful set of underground tests took place in the southeastern part of the test site during the period 1970–75. As mentioned, the high-resolution photographs taken by the KH-7 satellites were unexpectedly declassified in 2002. In these new archives NUPI researcher Johnny Skorve found a few nearly cloud-free photographs covering the northern nuclear test site on Novaya Zemlya. One of the best, taken in June 1967, shows that the eastern Shumilikha Valley area was still virtually untouched by human activity at that time.

Satellitee photos taken by CORONA in 1970 reveal that during the three years between 1967 and 1970, the military had made a large-scale expansion further into the Shumilikha Valley, preparing for more nuclear testing. Located in this area is the Zhuravlevka Valley, which was later blocked by a catastrophic rockslide, as described in the 1992 NUPI report (Skorve & Skogan 1992).

Here the nearly 900 m high Chernaya Mountain consists of three main rock strata. The upper and lower parts are both of the coaly-clay shale type, with some difference in composition. Between them are dolomitic limestones folded as a monocline flexure, dipping southerly about 30º with respect to the horizontal plane. (Kalturin et al., 2005: 23; Logachev, 2000: 339)

When the slide started in the upper part of the valley slope, it moved downwards in quite thick layers that spread almost horizontally across the valley bottom (Logachev, 2000: 339). As a result, the Zhuralevka River running down the valley became blocked. Gradually a lake was formed, now known as Lake Nalivnoye.

Accidents and safty measures

During the underground test of 14 October 1969, northeast of the main base Severny, a radioactive gas plume burst from an adit, exposing many of the personnel to radiation. According to the report: “Several hundred test personnel in the vicinity of the radioactive plume were subjected to radiation injury. They were not evacuated until 40

Fig. 12. Radioactive gass eruption
Violent eruption of a radioactive gas stream that broke through the ground shortly after an underground nuclear explosion at the northern Novaya Zemlya test site. In the foreground, one of many helicopters that quickly evacuated personnel from the area.

Photo: from V. N. Mikhailov

to 60 minutes later… " *(Johnston's Archive* 1969; Kalturin et al. 2005: 27) Fortunately, this was one of very few incidents where radioactive gas emerged from the ground close to nuclear testing personnel.

The second dramatic accident occurred in August 1987, when a powerful burst of hot gas escaped along a geological fault close to the adit. After melting the permafrost layer close to the surface, it erupted into the open air. People in the vicinity were evacuated quickly *(Fig.12)*.

As a safety procedure on Novaya Zemlya, all personnel on the test site would be evacuated prior to an underground nuclear test. The Soviet Navy chartered passenger ships that took the evacuees on board from Severny harbor on the southern shore of the Matochkin Shar Strait. The ships would sail out to a safe distance before the nuclear charges were detonated. After a successful test, the passengers were returned to the test site.

Fig. 13. Tunnel iron shelter
Inside an iron hull of the type built in front of adit entrances to detonation caves for underground nuclear tests on Novaya Zemlya. Such hulls enabled mining and preparatory activities to continue during the long and harsh winter season.
Above all, these protective iron hulls were used for recording the data and measurements from nuclear explosions. This was done from inside monitoring trailers that were moved into these strong shelters before the tests. Cables from the detonation caves and adits were connected to the instruments in the trailers.
This type of iron construction can be seen in Fig. 28, no. 3; Fig. 29, nos. 5 and 6, and Fig. 30, no. 6.

During the two accidents mentioned above, however, the safety rules and procedures for underground nuclear testing had clearly not been followed.

To safeguard personnel from exposure to radioactive gases, a network of small dosimeter stations was installed in the area around the epicenters for each nuclear underground test. These dosimeters measured radioactivity levels and thus could alert of radiation danger as the propagation and level of radioactivity were monitored. In several case, this network proved very helpful, as those in charge of the testing could know the locations of dangerous sites and evacuate personnel before radioactive gases reached them. Helicopters were used to install the dosimeter stations in difficult, inaccessible terrain, making the radiation monitoring service very reliable.

During the first few years, the testing experts experienced some accidents that most probably served as a highly valuable learning experience with respect to the later planning of the major test, which was held in the Zhuralevka Valley in September 1973.

Such nuclear tests were controlled from heavily instrumented large trailers that were physically connected to the nuclear device in the explosion cave by bundles of cables. These cables were also used for diagnostic surveillance and monitoring of the total environment within the testing mountain. The trailers also received and stored all the vital data from the nuclear explosions.

Prior to an underground nuclear test, the trailers were moved into a solid, protective iron hull that was usually built about 100m in front of adit entrances. These iron structures can be seen on several satellite images and ground-base photographs reproduced in this report *(Figs. 4, 5, 20, and 21).*

In the late 1960s, with the detonation of a nuclear charge near the Matochkin Shar inside a steep coastal mountain some 500–600 m high, a major rockslide occurred. Debris from this rockslide hit and completely buried the iron hull containing the trailers that had stored the vital data and measurements collected during nuclear explosions.

Experts were sent to the site to evaluate the possibility of excavating the trailers. In-between the large boulders covering the iron hull they could see a bluish glow from a transparent gas venting out from the crevasse below. This was the so-called Cherenckov effect, caused by radioactive particles from the nuclear explosion inside the mountain. The group immediately retreated from the site. Because of the danger it was not recommended to excavate and retrieve the data and information stored in the trailers. However, some data had been transmitted to the control post located at a safe distance.

Construction and preparation for underground nuclear testing was very complicated and time-consuming. To improve the safety of personnel working inside the mountain in case an unexpected critical situation should arise, emergency adits were drilled, enabling rapid evacuation to the immediate vicinity of the base camp.

The catastrophic rockslide of September 1973

The 1973 rockslide was truly enormous, covering more than 3 million m^2 of the valley floor. Its volume was calculated in the NUPI 1992 Novaya Zemlya Report (Skorve & Skogan, 1992) to be around 60 million m^3, but more recent Russian estimates indicate a volume of approximately 80 million m^3 (Logachev 2000: 339).

The rockslide is actually larger than what we can see on the satellite image, since a significant part of it was flooded by the rising water level in the newly formed Lake Nalivnoye. The southwestern part of the lake floor is now covered by rocks from the slide masses. The lake grew in extent and volume as the water gradually flooded more of the upper part of the valley.

The masses that came down from the upper valley slope consisted of rocks of highly differing sizes and thus contained some void. At the bottom of the rockslide the voids made it possible for lake water to penetrate and move along the valley, seeping down into and through the old Zhuravlevka riverbed. The water reappears at the edge of the rockslide, more than two and a half kilometers further downstream from the lower end of the lake. Some time after the formation of Lake Nalivnoye, its water level stopped rising, as water-flow equilibrium through the rockslide had been reached.

Comparison of images from IKONOS and Quick Bird from two summer seasons reveals only minor differences in water level. A SPOT winter image from the mid-1980s shows the lake as considerably smaller than seen on various SPOT summer images. However, it is reasonable to expect lower water levels during the winter season as a result of low runoff, compared with the spring and summer season, which are characterized by the high runoff from melting snow and ice. Generally, fluctuations in river runoff reflect seasonal as well as random changes in meteorological conditions.

Fig. 14. Novaya Zemlya landscape
Shumilika Valley nuclear test site, late summer. Water level is low and the flat floodplain is covered by rows of sand ripples formed by relatively non-uniform turbulent flow, probably during the late spring/early summer high water runoff.

On the 1965 KH-7 and 1970 CORONA photos it is even possible to trace the location of the ice/snow-covered Zhuravlevka riverbed.

In 1992 we knew only that this rockslide had most probably been released by one of the three dated nuclear tests performed in this area between the years 1970 and 1975. New information available in more recent Russian documentation dates the rockslide precisely: on September 12, 1973, the most powerful underground nuclear test on Novaya Zemlya took place. As usual, seismologists used global registrations to locate these explosions geographically and measure their joint yield. In 1990s, seismic experts concluded that the test had been slightly in excess of two megatons.

A shocking revelation

A stereo set of two CORONA photographs of the test site, taken during late spring 1970, revealed the existence of this base and clearly showed that nuclear testing activities were in the process of being moved to the southernmost part of the Shumilikha Valley. The landscape was then still fully snow-covered, and the numerous streaks visible in the snow revealed a pattern of vehicle transport for at least the last month prior to the CORONA satellite imaging.

The tracks led to several interesting sites, but most interesting by far was a new relatively large base then being built in the bottom in the southwestern half of the Zhuravlevka Valley.

When Johnny Skorve compared these CORONA photographs with SPOT images from the late 1980s, he realized that this base must have been crushed and buried under some 50 m of rock on the bottom of the 80 mill. m³ mass avalanche that had come from the northeastern part of the upper Zhuravlevka Valley slope.

This discovery was made at NUPI in 1997. After a critical review of the findings and the material used in the interpretation and analysis, there could be no doubt that a major event had indeed taken place, and that it had been triggered by a powerful underground nuclear test. However, at that time it was not clear which of the three possible tests had caused it.

The discovery revealed an obvious grand-scale catastrophe. Accordingly the Norwegian Ministry of Foreign Affairs was contacted. At a meeting with the section dealing with Russian relations, the NUPI representative presented the disclosure of the consequences of the enormous rockslide after the interpretation and analysis of satellite pictures. It was explained that this discovery had been made possible due to the good knowledge about that area obtained during the 1991–92 NUPI study using civilian satellite images; by combining this with the new information extracted from two declassified CORONA photographs from 1970, the catastrophe became evident. However, the Norwegian Foreign Ministry had difficulty in believing the NUPI findings, maintaining that a major event of this size could not have escaped their attention.

Years later the Russians themselves revealed that the catastrophic slide had been set off by the four underground nuclear explosions that constituted the September 1973 test. Since a large base had been constructed in this valley only three years earlier, it seems unlikely that any major rockslide was expected here during the planned nuclear testing, or at least not during preparations for the test. One the other hand, after a successful test on such an immense scale, the loss of a base camp might well be deemed a bearable sacrifice.

In fact, this base was the one used to prepare and execute this most powerful and complex underground nuclear test on Novaya Zemlya. Thus it is ironic that the very people working at the base obliterated their own camp by setting off the explosions that triggered the enormous rockslide.

Given the extremely powerful shock-waves of the September 1973 test and the steepness of the valley-side from where the rockslide was released, it is most probable that the slide masses started to move only a few seconds after the detonations. Had any staff been at the base or in the Zhuralevka Valley at that time, they would not have had any chance of survival. Within a few minutes the entire area was covered by tens of meters of rockslide debris.

As mentioned, preparations for the 1973 test in the Zhuralevka Valley had been previously detected on CORONA satellite photographs taken in May 1970. They show that the new testing base was built about 200 m from the southern valley slope, which was as expected with respect to the location of the adit opening. No other available satellite image was taken of this test area before it was completely covered by the enormous rockslide three years later.

The Russians have later admitted that the procedures for this comprehensive test clearly deviated from the norm. For one thing, the monitoring trailers mentioned above were not emplaced close to the adit entrance. They had been moved across the valley floor to where the small Zhuravlevka River was flowing toward the larger and more open Shumilikha Valley. Here the trailers were placed about 1,500 m from the adit opening. Technicians then had to pull the cables all the way from the mountain opening and to the trailers, enabling them able to record all the measurements to be made during the nuclear explosions.

The State Commission for nuclear testing recognized the risk of having a steep valley-side, more than 700 m high, above the adit entrance. The test accident mentioned earlier, when the monitoring trailers had been buried under a large rockslide, obviously served as a clear warning that was taken into account in preparations for the September 1973 test.

The command and observation post was situated on a small hill, close to the Matochkin Shar Strait, about 10 km north of the testing base. From this vantage point, the upper part of the Chernaya mountain could be seen. When the four nuclear devices detonated simultaneously, the ground shook. Then part of the mountain began to creep down the Zhuralevka Valley slope – the catastrophic rockslide had started!

Traveling at high speed and over a wide front, the rock masses spread across the

Fig. 15. Monitoring trailers' ride on the top of the rockslide
Looking southward, the catastrophic rockslide (center) and Lake Nalivnoye (lower left). Approximate locations are indicated by circles:

1. Base camp and the adit opening entrance into the mountain
2. Pre-explosion sites of the trailers that measured the effects of the four explosions (Here 1 and 2 both buried under the rock masses)
3. Where the trailers were found after having been hit and moved by the rockslide
4. Where the group of Russian testing experts stood at the edge of the rockslide when the photo was taken: Fig.16 in this report

C1 The 270 m explosion crater
C2 The 150 m explosion crater

A Eastern testing base on the northern shore of Lake Nalivnoye (see Fig. 4 for detailed photo)
B Middle testing base
C Western testing base.

Photo: Digital Globe

valley floor. They slammed into the trailers and their equipment, throwing them up onto the rockslide, where they were transported several hundred meters towards the other side of the valley. The whole mass finally came to a standstill shortly after riding a short way up slope more than two kilometers from where it had started.

Before the detonations, an observation helicopter lifted off and was ready to film and take photographs of the Chernaya mountain from a high-altitude vantage position at the moment of the explosions. Detailed observations of the surprising catastrophic rockslide were an unexpected and very valuable bonus. The helicopter was also able to track the movement of the trailers as they rode atop the rockslide until it stopped. From the helicopter it was possible to tell where on the rockslide surface the trailers were located. Thus it took only two hours before experts arrived at the exact site. Externally the trailers were damaged but the experts managed to enter them, and there they found that all the data registered from the test were intact.

Fig. 16. Testing experts at the edge of the rockslide
Russian experts inspecting masses of dark rock fragments in front of the southwestern edge soon after the catastrophic rockslide of 1973.
The location of this spot is seen as the blue circle no. 4 on Fig. 15.

Photo: from V. A. Logachev

Immediately after the detonation, personnel at the control post saw three white geyser-like plumes shooting up from the top of the Chernaya mountain. These were high-speed radioactive steam plumes, which reached an estimated altitude of several thousand meters. The ejection sites for these steam plumes on the mountain top coincide well with the three epicenters for this test that were found and identified in the course of the present NUPI study. The steam geysers confirmed clearly that in this test the radioactivity had not been contained.

This observation also is also backed up by a report by US and Russian scientists who recently studied data and documentation on earlier Novaya Zemlya nuclear testing (Kalturin et al., 2005). Concerning the September 1973 underground test, this group of scientists states that the nuclear devices appear to have been buried too shallow to contain the ensuing releases of radioactivity (ibid.: 25).

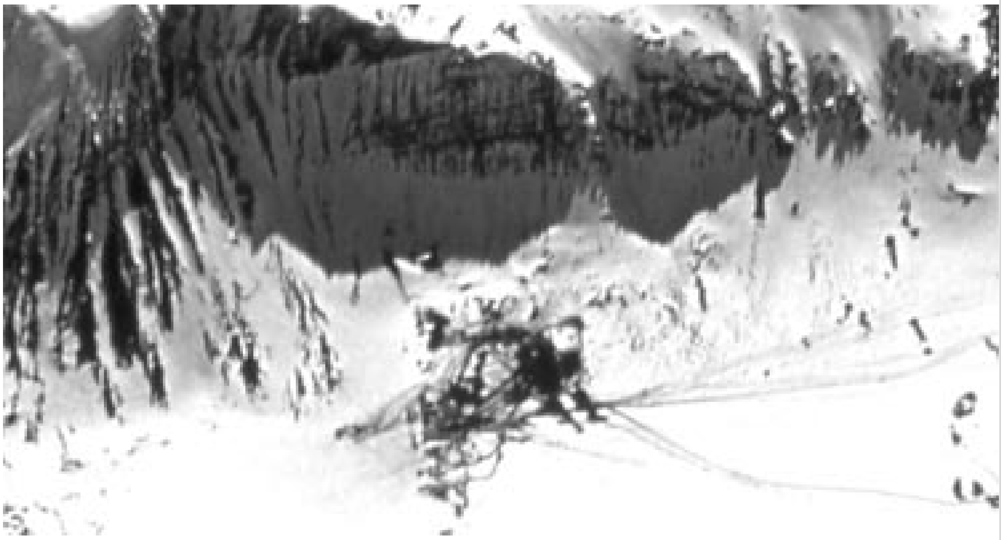

Fig. 17. The large testing base 1970
CORONA photograph from May 1970, of lower Zhuralevka Valley, still snow-covered. In the center is the base being built for the most important and largest underground nuclear test on Novaya Zemlya. The elongated, dark and irregular feature along the upper part of the picture is the shadow of the Chernaya mountain.
The source of the massive rockslide is the steep part of the mountain slope behind.
This enlargement comprises only about 1/10,000 part of the whole CORONA photo.
Photo: CIA - USGS

The rockslide base

The CORONA satellites took small-scale photographs. For the finest details to be clear, they had to be magnified from 20 to 50 times. The base covers less than 2 mm. x 2 mm. on the film. The real dimension of the base was about 650 x 800 meters, with its long axis parallel to the valley side.

Despite the complications due to the strong contrast between the snow cover and the darker parts of the base, interpretation provided information on how the base had been organized. Some of the buildings were aligned across the valley floor, others were oriented along the direction of the valley. The buildings were of varying lengths but generally the same semi-cylindrical shape. In an Arctic climate this is a favorable shape, since snow will be less likely accumulate – it slides easily off, or is blown away by the wind. Buildings of this type are well known from ground-based and satellite photos of bases on Novaya Zemlya *(Figs 20 and 21).*

Digging and construction work was taking place at the base location, and at its southern part it looks as if tall fences were being set up. Its position strongly indicates that this base was intended for preparing new nuclear explosions. It was from here that digging activities were directed and coordinated. These include drilling adits and shafts into the rocks for emplacement of nuclear charges and instruments to be brought into the detonation caves deep into the Chernaya mountain.

Both in the former Soviet Union and in the USA, the advanced control of nuclear underground tests and the vital collection of technical and scientific data from these explosions were carried out from a center within or close to the base. Often was this done in special robust trailers, as noted above.

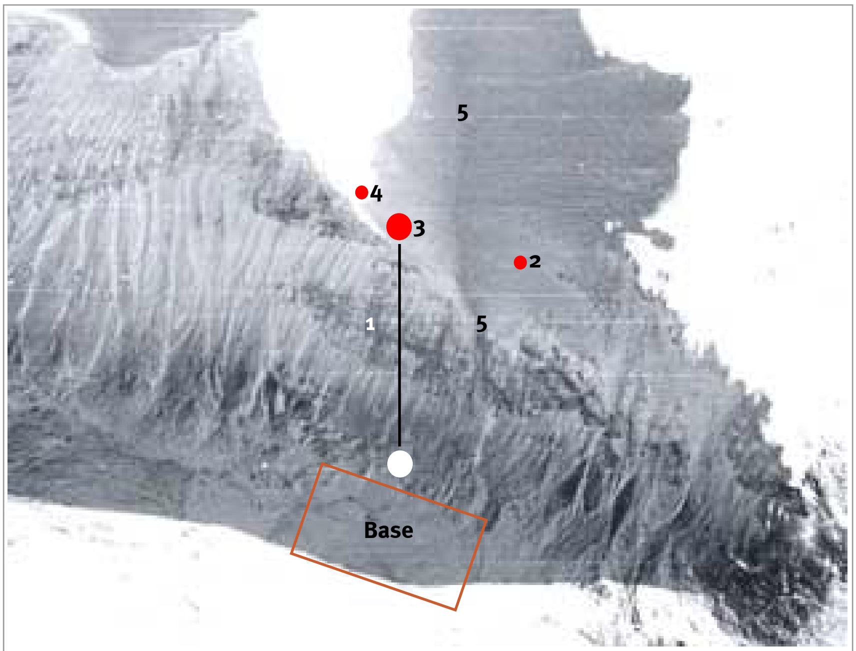

Fig.18. The 12. September 1973 test site
Location of the 12 September 1973 explosion epicenters, projected onto an oblique high resolution KH-7 photo from October 1965. The Zhuravlevka Valley area is snow-cowered, and the southern valley slope and parts of the Chernaya Mountain are in the shadow. This dark portion of the photo has been copied so as to bring out relevant details; thus the sunlit parts are overexposed.

1. Portion of valley slope where the rockslide was released
2. Epicenter of explosion KB-2, and the location of the 150 m crater
3. Epicenter of explosions KB-1 and KB-4, and center of the 270 m crater
4. Epicenter of explosion KB-3, and center of the spalled rock area
5. Small mountain valley where the two large craters were formed during the 12 September 1973 test.

The black line is the projection of the 1223 m long adit drilled from the base camp to the KB-1 detonation cave inside the mountain.

Photo: CIA-USGS

Multi-explosion tests

It has been known for some time that practically all underground tests on Novaya Zemlya consisted of several nearly simultaneous explosions in each test. The 39 underground tests conducted on Novaya Zemlya comprised a total of 133 explosions. According to international agreements, for each test, explosions have to occur within 0.1 second in time and the epicenters must be within a circle of radius less than one km. Otherwise, each explosion will be counted as a separate test.

Russia has not released information regarding the exact strength of each explosion, only the range, and this within broad limits. For example, when an explosion is described as being within the range of 20–150, this means that the yield could be anywhere between 20 and 150 kilotons.

For the test carried out on September 12, 1973, we known that it comprised four separate explosions with the following kiloton ranges:

A: 1500–10000
B: 150–1500
C: 150–1500
D: 150–1500

Hybrid emplacement of nuclear charges

Three of the nuclear charges were emplaced in adits and the detonations took place under a 700–800 m high mountain. The most powerful charge exploded at the bottom of a 500 m shaft that had been drilled vertically down from the end of a 1223 m long adit *(No. 2 in Fig 14)* running from the base in the Zhuralevka Valley and into the mountain. (Kalturin et al., 2005: 25) Thus there was about 1200–1300 m of rock separating this nuclear charge from its epicenter on the upper part of the mountain. Explosion KB-4 at this location had a yield of between 1.5 and 10 megatons.

In addition to the catastrophic rockslide, this test resulted in the formation of two big craters in the mountainous terrain, where the explosion epicenters had been located *(Nos. 3 and 2 in Fig. 15, and Nos. 1 and 2 in Fig. 16),* just south of the Zhuralevka Valley. The larger of these is situated on the northern slope of an elevated valley; the other one is found on the opposite slope of the same valley.

The larger crater *(No. 3 in Fig. 8 and No. 7 in Fig. 14)* was formed by the combined effects of two simultaneous explosions. The adit had been drilled southeastward from the side-valley of Zhuravlevka and into the Chernaya mountain. An explosion cavity at the end of the 1223 m adit was the location of the nuclear charge, KB-1 *(No. 3 in Fig. 14),* which had a yield in the range of 150–1500 kilotons.

It was from this same cavity that miners had drilled the 500 m deep vertical shaft, 3 m in diameter *(No. 4 in Fig. 14),* where another explosion cavity was pre-

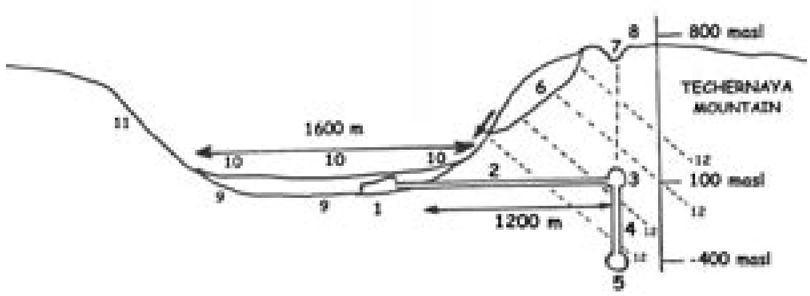

Fig.19. Zhuralevka Valley profile

Cross-section cutting through the adit from the base to the KB-1 detonation cave; further, the shaft down to KB-4 detonation cave. Upwards it crosses the center of the largest crater. To the left, the source of the rock release, the valley bottom and cross-section of the rockslide.

1. Nuclear testing base
2. 1223 m. long adit to KB-1 explosion site
3. KB-1 explosion cave
4. Shaft down to KB-4 explosion site
5. KB-4 explosion cave
6. Portion of the mountain that slid down into the Zhuralevka Valley
7. The 270 m crater
8. Glacier squeezed by the explosions
9. Zhuralevka Valley, bottom
10. Rockslide surface
11. Zhuralevka Valley, northern slope
12. Chernaya Mountain, direction of geological layers

Drawing: Johnny Skorve, NUPI

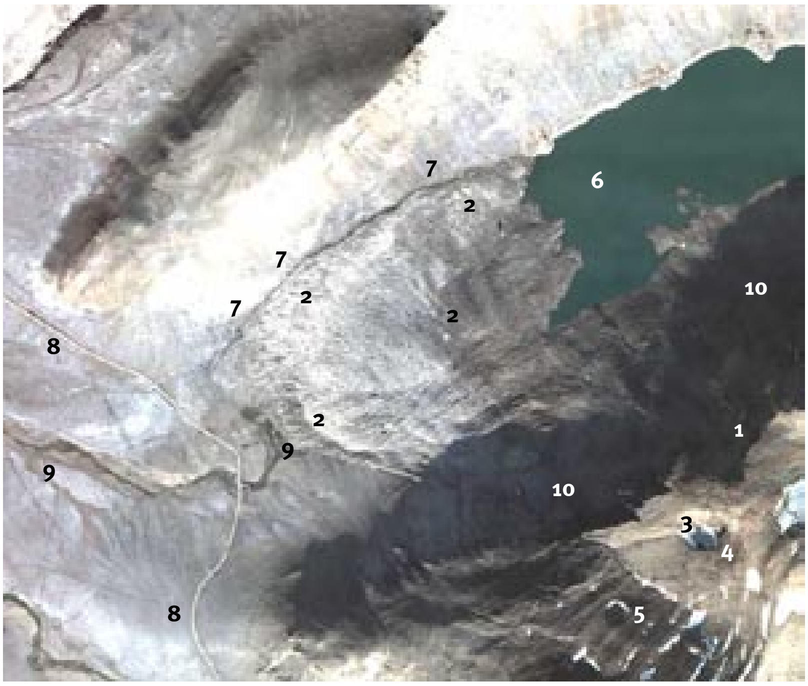

Fig. 20. Rockslide and Lake Nalivnoye
Quick Bird image of the catastrophic rockslide area

1 Rugged top of the rockslide scar from where the rock masses were released
2 Rockslide blocking the entire lower part of the Zhuralevka Valley
3 Crater (270 m diameter, 70 m deep) formed by the most powerful of the four simultaneous underground nuclear explosions in 1973
4 Ridge (170 x 260 m) pushed up during the formation of the crater (3)
5 Crater (150 m) formed by one of the other powerful explosions
6 Western part of Lake Nalivnoye created by the pounding water following the blocking rockslide
7 Rockslide rim, northern side of Zhuralevka Valley. Close and parallel to it is the road later built to connect the main Severny base with the three nuclear testing bases on the northern shore of Lake Nalivnoye (A, B and C, Fig. 28)
8 Road from the coast facilities to the inner, southern parts of the Shumilikha Valley
9 Lake water emerging, having penetrated the rockslide masses along the old Zhuralevka riverbed
10 Zhuralevka Valley, southern side, darkened by the mountain shadow

pared. It was here that the most powerful nuclear charge (KB-4) was emplaced *(No. 5 in Fig. 14),* about 1200 m below the top of the mountain.

Surface disturbances, subsidence craters

The two big craters in this area were discovered on Landsat and SPOT images during the first NUPI study. Recent measurements on IKONOS and Quick Bird satellite images have showed that the larger of the two craters was 270 m in diameter and 70 m deep *(No. 1 in Fig. 23).*

Adjacent to its eastern rim is an elongated ridge of rocks *(No. 2 in Fig. 23)* that was also formed as the result of the explosions. It measures about 170 x 260 meters. Since this large crater and the upheaval of the ridge of rock are so close together, they must have been formed simultaneously by the two KB-1 and KB-4 nuclear explosions directly below them. This strongly indicates that the dramatic event completely destroyed a surface area that measures about 400x450 m centered around their common epicenter. Further to the east of the crater, there are several long open, concentric fissures, especially in the area to the south of the crater rim *(No. 4 in Fig. 23)* These were probably formed by the strong shockwaves from the powerful explosions. The longest fissures are about 200 m in length, but not more than 50 m as straight lines, because they are intersected by narrow perpendicular cracks. The fissures continue in a somewhat different direction, creating an irregular pattern. They must be quite deep, as dark shadows can be seen down in the upper part of the fissures, and most of them seem to be one meter or wider, with depth estimated by means of shadow length.

The crater on southern side of the mountain valley has a diameter of 150 m, but the surrounding terrain is not as disturbed as around the largest crater. This can be explained by the fact that the southern explosion (KB-3) was considerably weaker and thus its shock wave damage was restricted to a smaller area close to its epicenter. However, it

Fig 21. The 270 m wide crater
This Quick Bird image enlargement shows the enormous ground effects of the multi-megaton nuclear underground explosions on 12 September 1973.
1. The epicenter of the KH-1 and KH-4 explosions at the bottom of the 270 x 70 m crater created by these two simultaneous explosions.
2. The large upwelling of elongated of rock-masses measuring 170 x 260 m, that emerged simultaneously with the formation of the crater. Some of it seems to have slid down into the crater.
3. The round, spalled rock surface just north of the large crater; this fragmented rock surface was probably formed by the KH-2 explosion some 700 m below.
4. Further outwards from the epicenter, the explosions resulted in the formation of faults and cracks in the terrain, many visible in the right part of the picture. Parallel faults formed also close to the lower rim of the crater.
5. The sharp shadow of the lower rim onto the inner snowy crater slope clearly shows the rugged rim topography.

Photo: Digital Globe

is still one of the largest craters in the Novaya Zemlya northern test range.

Interpretation of the CORONA images of this new base area *(Fig. 10)* was difficult, even though the resolution was as good as 2 to 3 meters. Due to the snow-covered terrain, there were extreme contrasts between the bright snow and the dark soil and rock from the digging and construction activities in the base area, and this prevented full exploitation of the image resolution, compared with what could have been obtained if the photographs had been of snow-free summer terrain.

The base may not have been fully completed at the time of imaging, but could have been so at the end of the 1970 summer season. By late1970, the base resembled a small mining town, ready to start drilling adits and shafts into the mountain. This was probably the situation for a year or a year and a half, until all adits and shafts were ready for the nuclear testing equipment to be installed. In 1972–73 it became a more high-tech base that received the nuclear charges and advanced control and monitoring instruments for the test.

Explosion yield and containment

The September 1973 test that was prepared from and executed by the Zhuravlevka Valley base was unique, as this was the first-time use of a hybrid solution that combined adit and shaft emplacements of nuclear charges. The first part of the adit was drilled in permafrost rock, while the innermost parts, as well as the whole shaft, were below the permafrost boundary, in surroundings with temperatures above freezing.

The Line of Least Resistance to Free Surface (LLR) is an important relation between underground nuclear explosion and their environmental effects**.** It may be described as the direction of the line from the explosion site, through the weakest part of the protecting rock overburden, and to the surface above. It is the physical quality / strength of the rocks above a nuclear charge in an underground detonation that determines how powerful an explosive yield can be, in order for the burst to be kept contained.

If, for example, the rock quality is only moderate, the mountain overburden must be greater to ensure containment, compared with the case for high-quality rock overburden.

The depth of emplacement of a nuclear device is dependent on the expected/calculated yield of a given explosion and is defined as:

THE SCALED DEPTH OF BURIAL (SDOB). When determining the depth of burial of a nuclear device, the following general law of energy scaling is used, in accordance with which depth of the explosion is:

$$D = q^{1/3}$$

Where

D is the depth in meters,

q in kilotons (kt) (the yield)

The inverse cubic scaling law is applied.

The Zhuravlevka quadruple test

To understand why and how the catastrophic rockslide was triggered, it is logical examine the SDOB and LLR for the September 1973 test.

Three of the four nuclear charges were emplaced into the mountain via horizontal adits, and in drifts from it, so their LLRs were nearly the same. The local topography on the top part of the Chernaya mountain probably differs less than 100 m in elevation for the three epicenters, so these charges all had LLRs in the range of 600 to 700 meters. However, the strongest nuclear explosion took place at the bottom of a 500 m deep shaft down from the adit; thus its LLR was around 1200 m. The LLR is usually roughly vertically above where the nuclear device is located in the bedrock.

The combined effect of the simultaneous KB-1 and KB-4 underground explosions was most impressive, as they jointly created a large crater 270 m in diameter. Measuring the shadow of its rim on a Quick Bird satellite image, calculations show the crater is about 70 m deep.

Some 600 m to the west of the 270 m crater is another crater, 150 m in diameter. This was most probably formed by what the present report defines as the KB-2 explosion.

Inspection of the Quick Bird image of this area revealed an interesting feature only 220 m northwest of the common epicenter of the KB-1 and KB-4 explosions. This was a rounded area, about 100 m wide with a dense concentration of large boulders and rocks. This is probably the location of the epicenter of the KB-3 explosion *(No. 3 in Fig. 23)*. This boulder field must have been formed when the shockwaves fragmented the rock surface, right above the nuclear explosion that took place some 700 m below.

In addition to the crater formations and fragmentation of the rock surface, this same test also released the catastrophic rockslide that blocked the whole Zhuralevka Valley.

Viewed collectively, the 4 LLRs seem to have been pointing in the direction of the southern side of the Zhuralevka Valley. This is where the rockslide started when the simultaneous explosions generated expanding ground motions with peak velocities in the direction of the LLR exit line. These motions dislodged a thick layer of rock here. This destabilization and a reduction of the rock sheer stress initiated a motion of the dislodged rock layer, resulting in the enormous rockslide that spread into and across the Zhuralevka Valley.

As noted, the yield of the four nuclear detonations can be known only within wide margins. However, Russian sources have provided the total annual megatons detonated every year at the Novaya Zemlya Northern test site. By taking into account the yield of the two other underground tests in 1973, we can arrive at an improved estimate of the overall strength of the Zhuravlevka Valley test on September 12, 1973 – namely, 4.2 megatons. (Kalturin et al., 2005: 25)

Additional information from Russia indicates that the nuclear charge at the bottom of the shaft was by far the most powerful explosion of the four.

As mentioned earlier, one of the three other charges detonated at the intersection between the end of the adit and the top of the shaft. Russian sources have not yet provided more precise information about the location of the two other detonation caves. For the September 1973 test, Russian sources have reported that LLR = 95 $m/kt^{1/3}$

US and Russian scientists have recently examined several probable spatial distributions for the yields. Their conclusion: the yield distribution of the four explosions, LLR = 95$m/kt^{1/3}$ as per Russian reports, is inconsistent with a total yield of 4.2 megatons. The safety rule LLR ≥100$m/kt^{1/3}$, required to keep the explosions contained, appears not to have been followed. (Kalturin et al., 2005: 25)

Thus the depth of burial (LLR= 1200 m) chosen for the most powerful nuclear device proved to be too shallow for the 4.2 mt nuclear test.

Combining this new information with the use of image interpretation and analysis of the high-resolution satellite images taken by IKONOS and Quick Bird has made it possible to trace the probable location of the epicenters of the two other explosions (KB-2) and (KB-3), by studying the surface disturbances caused by shockwaves from their explosions. Some 600 m west of the 270 m large crater is a crater 150 m in diameter, obviously created by KB-2. In the middle of this crater we find the epicenter of this explosion.

Once the previously unknown locations of the two underground explosions had been identified, at NUPI a three-dimensional set of x-y-z coordinates was produced for all the four nuclear explosions of the September 1973 test.

When Russia first announced that this test had consisted of four detonations, it was immediately understood at NUPI that the southernmost 150 m large crater had been formed by one of the other four detonations of that test.

The rockslide can thus be set in the correct geometrical relation to the four locations of these nearly simultaneous explosions. Also, analysis of the satellite images with respect to the different surface effects made it evident that the yield of the southernmost KB-2 explosion must have been stronger than that of KB-3. Obviously, a considerably stronger yield would have been needed to form a 150 m crater than an explosion that created an 100 m area of spalled mountain surface, since both detonations took place at approximately the same depth. When seismologists and geologists later study this in greater detail, they may well be able to calculate more accurately the ratio/difference between the yields of these two explosions.

Using craters and spalled rock surfaces to locate the epicenters of underground nuclear explosions, we have been able to provide the following epicenter coordinates for the underground nuclear test of September 12, 1973:

KB-1 270 m crater, 73.329º N, 54.976º E
KB-4 270 m crater 73.329° N, 54.976° E
KB-2 150 m crater, 73.315º N, 55.062º E
KB-3 100 m spalled rocks 73.330º N, 54.979º E

Plotting these coordinates on a map reveals that they all are located nearly on a straight line with a directional azimuth of 43º / 223º. This is almost parallel with the crest of the mountain in which the test took place. Measurements of the coordinates were done using a geo-corrected Quick Bird image. The distances between the centers of the two craters and that of the spalled area are as follows:

- between KB-2 and KB-1/KB-4, 620 m.
- between KB-1/KB-4 and KB-3, 220 m.

The explosion depths of KB-1, KB-2 and KB-3 were, as mentioned, all around 700m, while the depth of KB-4 was 1200 m.

As all four explosions were simultaneous, their shockwaves formed an *interference pattern.* Thereby the enormous rockslide was released, two large craters were formed, and the mountain surface near the epicenters was spalled, with faults and cracks even further out.

A very important point is the interference of shock waves, as this creates a combined power stronger than the seismic effects associated with those from each of the four explosions taken separately. (Kalturin et al., 2005: 27)

Being able to identify the locations of all the ground zero points for the four explosions of September 12, 1973, will make it possible to calculate more precisely the magnitude and how the shockwaves set off the catastrophic rockslide in the Zhuravlevka Valley. And knowing that there was a major difference between the yields of the KB-2 and the KB-3 explosions may make it easier to arrive at a more correct yield distribution among the four explosions.

An alternative location for the KB-3 explosion?

Later in this study underlying this report, the top area of the Chernaya mountain, east of the slide scar, was scrutinized in greater detail. Additional terrain disturbances were found, apparently were caused by the nearby nuclear explosions of September 12, 1973.

But could these disturbances be explained by the locations of the four detonations, as indicated earlier? An alternative explanation might be that the KB-3 explosion took place somewhat further east.

The findings obtained from this new survey are presented below .

An elliptical feature was found about 550 m from the 270 m crater. The dimension of the central ellipse is 60 x 90 m, while its outer concentric ring measures 110 x 150 m. It looks as if the elongated formation is dipping up in the northern direction where its rim is prominent. However, the southern rim is mostly "buried" in the landscape *(No. 4 in Fig. 16).* With its shape, appearance and location, the feature immediately stands out as being a possible subsidence crater created by an underground nuclear explosion. Its location lies well within the required limit of one kilometer radius from the other epicenters of this test. An alternative explanation could be that the feature is a karstic doline caused by dissolution of the dolomitic limestone.

However, in contrast to the two neighboring subsidence craters and the spalled area, this feature looks very smooth and undisturbed. On the slope below it, there are no traces of the rocks and debris that one would expect to find with an instant crater formation following an underground nuclear explosion.

The geographical coordinates of the center of this elliptical feature are

73.378º N, 54.993º E. The elliptical feature seems rather to be in the center of a bend in a geological folding. One would expect to find more folds in the neighborhood, but such are not found. The explanation could be that close by, there is a fault that may have broken the next one. Also this particular area is located very close to the edge of the available Quick Bird image; thus we unfortunately cannot see enough of the neighboring landscape to enable a proper geological assessment.

In addition, the glacier zone in the immediate neighborhood *(the central-right part of Fig. 16),* has an abnormal appearance, being very jagged. This dramatic change in appearance might have been caused by shockwaves from an underground explosion. Strong forces obviously squeezed or pushed large rock masses on to it from both north and south, nearly dividing the glacier in two *(No. 6 in Fig. 16).*

This glacier is small compared with the one a few kil-

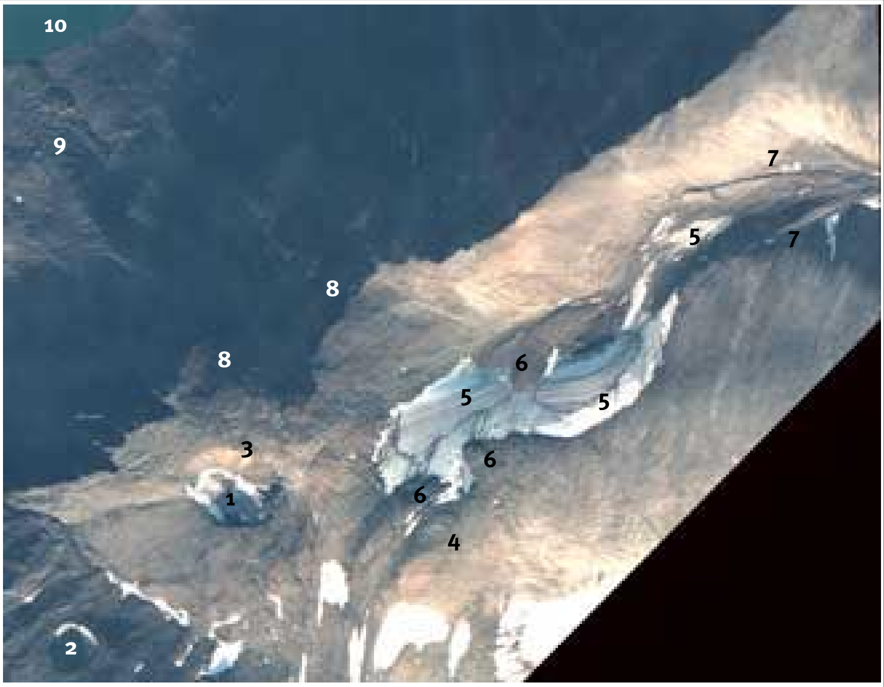

Fig. 22. Glacier damaged by underground nuclear explosions
Quick Bird picture from 2002 of the catastrophic rock slide area
1. Largest crater (270 m in diameter, 70 m deep), directly atop the site of two powerful underground nuclear detonations (KB-1 and KB-4)
2. 150 m crater above the KB-3 detonation
3. Spalled rock area, 100 m in diameter, probable epicenter above the less powerful KB-2 detonation
4. Newly discovered elliptical formation apparently in the center of a bend in a geological folding – or could it mark the epicenter of the KB-2 detonation?
5. Glacier nearly cut in two by the explosions
6. Large masses of rock apparently pushed onto the glacier
7. Lateral moraines showing previous position of glacier
8. Crest of the mountain/root of the rockfall
9. Sunlit rockfall masses, bottom of the Zhuralevka Valley
10. Edge of new lake, Nalivnoye, formed behind the rockslide masses

Photo: Digital Globe

ometers further east that flows down into a north-facing valley and is blocked by a big terminal moraine at the valley bottom. Over the past 150 years much of the lower part of the valley glacier has gradually retreated, as the ice is wasted due to climatic warming. Much of the water caught by the Zhuravlevka River, feeding the dammed lake behind the rockslide, has its drainage basin in this glacier area.

The small glacier close to the subsidence craters can be seen on Landsat TM and SPOT images from the late 1980s. As it seems very much like what we see on IKONOS and Quick Bird images from 2000 and 2002, this would indicate that it cannot have been very active.

The CORONA photo from late spring 1970 shows the glacier area in cloud-free conditions. Everything is snow-covered, and the glacier shape that emerges through the snow looks regular and even. This strongly indicates that the glacier got its odd-looking, twisted shape from the shockwaves that were generated by the September 1973 underground test.

The undisturbed, smooth surrounding of the elliptical feature, without any sign of violent, damaging effects on the terrain that are typical of an underground nuclear explosion, make it far less probable as the epicenter feature for KB-3 event. It may be well that the combined strength of all the explosions was what caused the observed damages and changes to the glacier located 350–850 m east of their joint epicenter. The upheaval of rock masses near the middle part of the glacier has clear similarities with that of the large mounds adjacent to the 270 m crater. The Quick Bird image shows that the system of faults and cracks surrounding the 270 m crater extends to the area where the elliptical feature and the glacier are located. Also the pattern and shape of the fault and crack system seem centered around the KH-1 and KH-4 epicenter. This makes it even less probable that the elliptical feature was the location of the KH-2 explosion epicenter.

Understanding the rockslide

The Zhuralevka Valley is visible on both CORONA and KH-7 photographs. The KH-7 photography from late spring 1967 is, as noted, from a time when the area was still untouched by human activities. The photography is very crisp and shows terrain formations as small as 60 centimeters in size *(Fig. 25A).* The valley is very favorably illuminated by the sun, making it easy to see all details of the pre-rockslide slope area, including several traces of earlier and smaller rockfalls. Along the upper part of the valley-side there are many close and parallel slide-scars, typical of the steepest parts of the cliffs. It is in this area that the catastrophic rockslide of 1973 was released. Below on the valley floor, where the nuclear testing base was built, there are big boulders and pieces of rock that have fallen from the steep mountainside irregularly over a long time. Several of the largest ones can also be seen on the CORONA photographs from 1970 *(Fig. 25B)* in addition to the main attraction – the new base under construction. Further north, the slide-scars run closer together but are considerably longer as they stretch further downhill, towards the valley bottom, where there also are large boulders scattered about.

The steep profile of the valley-side indicates that rockfalls might be expected here. The rather flat top part of the Chernaya mountain lies at between 800 and 900 m above sea level, while the upper part of the valley-side has a slope angle of between 30° and 40°. In the steep cliffs below, the slope angle is 60°–70°, but decreases abruptly closer to the valley floor.

Recent research has made possible new understanding with respect to rockslide and

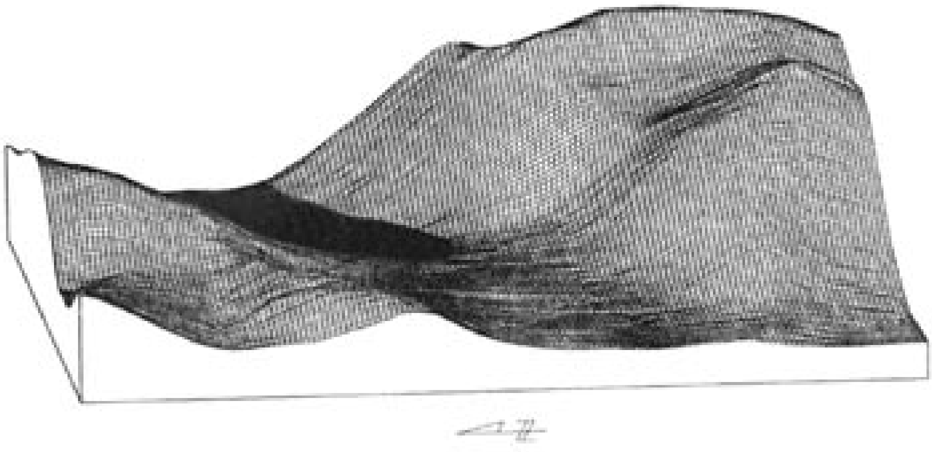

Fig. 23. Terrain model of rockslide valley
A digital terrain model 3D-map of the Zhuralevka Valley as observed from the central part of the Novaya Zemlya nuclear test site. The right half of the map is dominated by the Chernaya Mountain (840 m). To the left, this northern mountain ridge reaches to 400 m but is considerably higher further east.
The catastrophic rockslide started from the steep slope of Mt. Chernya near the center of the map. The black inner part of the valley is Lake Nalivnoye, formed by river water behind the blocking barrier of the 1973 rockslide.

Map production: North West Regional Research Laboratory
University of Lancaster, UK

geology. It is now recognized that climatic change has an impact on the probability of slides occurring in a rock formation. Cyclical periods of ice ages interspersed with much warmer interglacial times represent large climatic fluctuations.

About 10,000 years ago the last ice age ended on Novaya Zemlya, as it did in the rest of the Northern Hemisphere. The ice cover, several thousand meters thick, melted and the landscape again became exposed after more than 100,000 years under the ice.

This was certainly also the case for the Zhuravlevka Valley. For as long as the ice age lasted, this valley was filled completely with ice. After the ice disappeared rather quickly here, the mountainsides were no longer "protected" by the ice. This unloading after the wasting of the valley glacier created new conditions. This led to dilation jointing, since the wall of rock has reduced shear strength, parallel to the slope. When rock sheets fail, it is due mainly to loading by meltwater from the snow, increasing the stresses.

We may conclude that the Zhuravlevka Valley today is more vulnerable to rockslides because of its recent glacial history than would be the case with an otherwise similar valley and geology with no history of glaciation.

Precisely how coherent the dolomitic limestone of the test site was remains a matter of speculation, If karstified, it would have contained solution features, perhaps even small caves. Certainly joints and fissures would have been enlarged. It may seem strange to think of karstification in an Arctic environment, but there are two important factors to bear in mind. First, CO_2 is actually more soluble in cold water than in warm, so water seeping into the limestone would be acidic and react with the rock. Second, although the landscape has been recently glaciated, we must also recall that for many millions of years during the Tertiary and early Quaternary periods the region had no ice cover, providing ample time for karst processes to operate. Thus, although the rocks may appear superficially coherent, they may contain hidden pockets of dissolved limestone that would act to reduce the shear strength of the rock by lessening its cohesion.

It is noteworthy that the 1973 rockslide moved all across the valley bottom to the far end of the valley slope. It even looks as if the rockfall began riding up the far slope – a point confirmed by V.N. Mikhailov. However, as far as we know, no photogrammetric measurements have been made, so the level of rockslide climbing cannot yet be calculated using stereo pairs of images taken by aircraft or satellites.

Recent studies show that some extreme rockfalls ride on a cushion of air. In this way, with the reduced underlying friction, rockslide masses can ride tens of meters up the far part of a valley slope. This is the most probable explanation of how the Zhuravlevka rockslide first moved about two kilometers across the valley floor, and then up the far side of the slope of the valley.

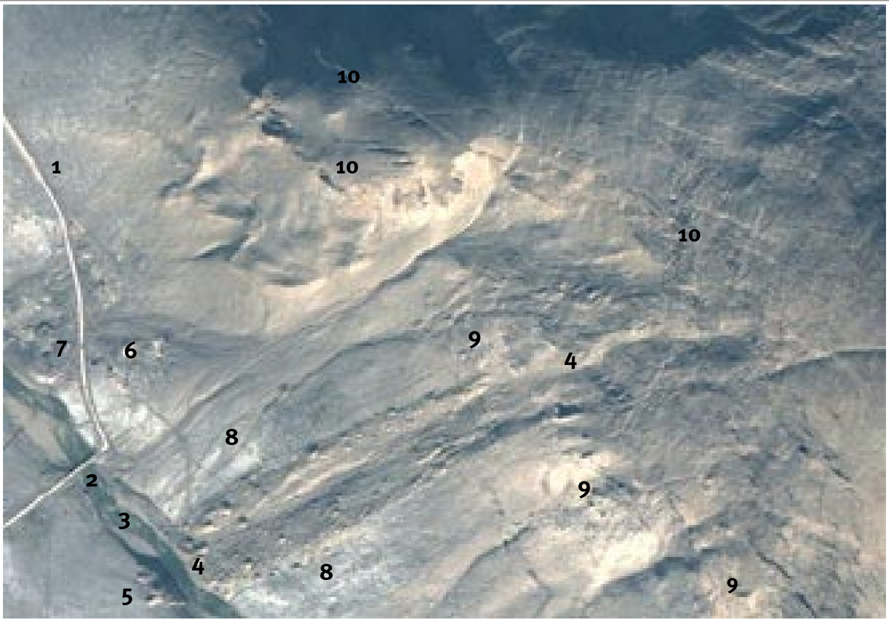

Fig. 24. Rockslide blocking the Shumilikha river
Quick Bird image from 2002, showing underground nuclear area east of the Shumilikha and south of the Zhuravlevka rivers. These explosions took place on October 21, 1975.

1. Road from the main base of Severny
2. Bridge across the Shumilikha River. (Its shadow on the ground can be seen just to the left of the bridge)
3. Banks of the Shumilikha River
4. Long rockslide released by the October 21, 1975 underground explosions. Note the many large boulders.
5. Rockslide crossed the river: rocks and large boulders can be seen on the left side of the riverbed.
6. Ruins of buildings at the base of the October 21, 1975 test and nearby tailing piles of rocks from adit excavation.
7. Tailing piles leveled after the test; the rock masses now extend to the area west of the road.
8. More than 200 m of previous road buried under the rockslide
9. Spalled rock areas indicate location of epicenters of three of the five October 21, 1975 underground explosions.
10. Cracks and fissures in the bedrock, probably caused by the powerful underground explosions.

Photo: Digital Globe

Another large rockslide

The study of high-resolution commercial images covering this area led to the discovery of further terrain damages and disturbances in a mountainous area somewhat further away from the two craters described above and in the Shumilikha Valley.

On the eastern mountain slope of the inner Shumilikha Valley, satellite images shows a long rockslide oriented down the mountain slope in a southwesterly direction. It is between 175 and 200 m wide and 900 m long *(no. 4 in Fig. 18)*. These masses of boulders and gravel reached the bottom of the valley. Actually the rockslide crossed the Shumilikha River and stopped less than 100 meters beyond it, on the opposite, southwestern bank of the river *(no. 5 in Fig. 18)*. For a period the river must have been blocked, as the water accumulated behind the rockslide. The impounded water level rose, but later the water broke through the masses and regained its river bed.

However, the sudden release of the trapped water may have caused flooding downstream in the Shumilikha Valley, closer to the main base at Severny. High-resolution satellite images show that the slide contains numerous big boulders, some as large as 20 m, and of a rather uniform and somewhat rounded shape. This indicates that some large boulders must have moved quite far off the main track of the rockfall.

Down in the Shumilikha Valley, and close by on the eastern side of the river, another interesting observation was made. A road running parallel with the river clearly disappears under the rockslide, and then reappears about 200 m further north, emerging out of the rockslide. Obviously, then, this road predates the rockslide.

Fig. 25. Mountain road
The exact location of the area shown here is not known, but it is probably part of the mountainous landscape of the inner Shumilikha area of the northern Novaya Zemlya nuclear testing site. Near the left edge is a rockslide blocking the road. In the middle and to the right is a glacier surrounding a mountain with a cloud-covered summit.

Up on the steep mountain slope not far from where the long rockfall started, Quick Bird and IKONOS images show three areas with spalled rocks. Their centers are roughly aligned and oriented perpendicularly to the direction of the rockslide. All three seem situated at about the same elevation, approximately 700 m. above sea level. The largest one, in the middle, has a heavily shattered surface about 140 m wide and 270 m long *(Fig. 18)*. Here there are many large boulders, some more than 10 meters, producing a chaotic terrain. The center of this boulder field has the following coordinates: 73.316º N, 54.932º E

These spalled areas clearly indicate that they are at the locations of epicenters of the three simultaneous underground nuclear explosions referred to elsewhere. Unfortunately, this disturbed area is incompletely covered by Quick Bird and IKONOS imagery used in this study, so some of the epicenters of this test are not on the high-resolution satellite images available to us.

The adit drilling base for the underground explosions that caused the spalled areas described above cannot have been built when the area were photographed by KH-7 in 1967 and CORONA in 1970. On SPOT satellites from the 1980s, it can be faintly discerned when one knows its location, but may else be easily be overlooked.

On recent commercial high-resolution images, however, the base is easy to observe, even though in most cases only the foundations of the buildings seem to remain, except for one metallic semi-cylindrical building that appears intact. Buildings of this type are well known from ground-based photos of bases on Novaya Zemlya. Comparison of photos of Novaya Zemlya bases taken from ground level with commercial satellite images of the same areas makes it much easier to interpret imagery taken from space, as seen in Figures 20 and 21.

The geographical coordinates of the base are: 73.319º N, 54.904º E.

On a photograph taken during the summer 1976 with one of the KH-9 mapping cameras, the buildings in the base are clearly visible, probably because they were new and also their colors were still bright (Fig 17). Also, the then-recent rockslide is easily spotted. In general, new buildings, infrastructure and recent changes in the landscape are easy to detect on satellite images because their fresh appearance compared with

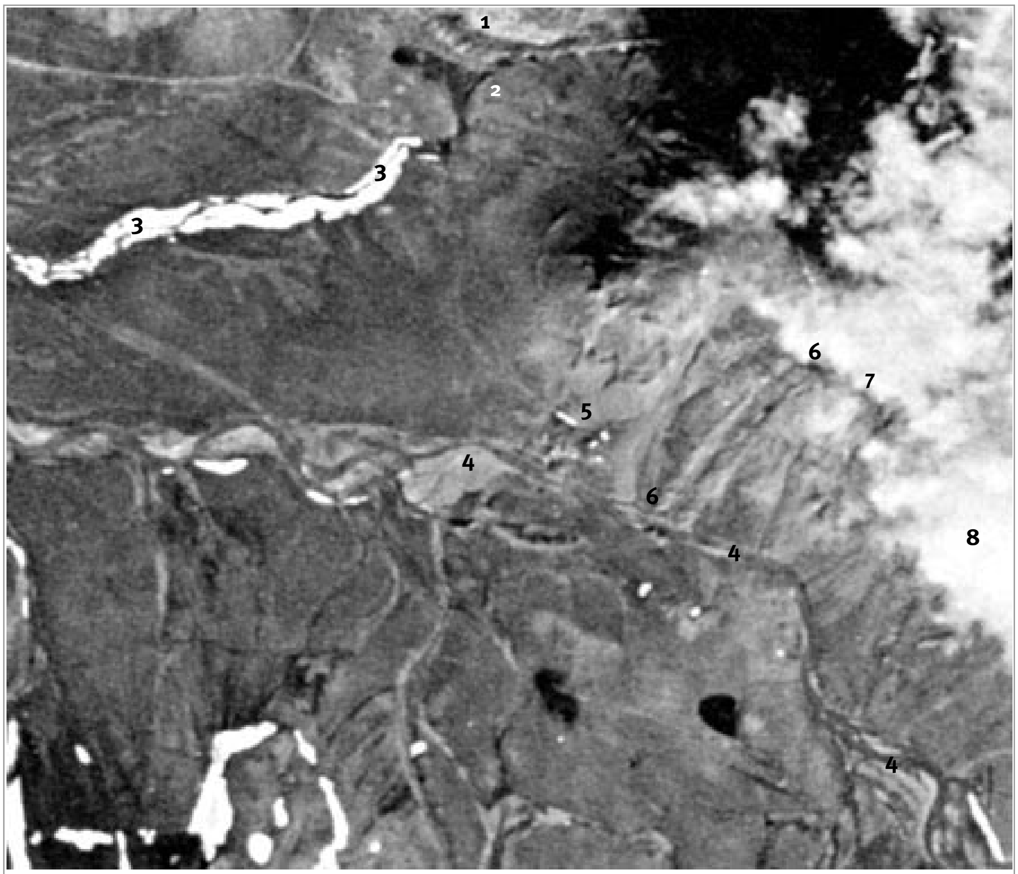

Fig. 26. 1975 nuclear test site
Area of activities and effects of the 21 October 1975 underground nuclear test. This is a medium-resolution satellite photograph taken by the mapping camera on a KH-9 reconnaissance satellite in July 1976.

1. Edge of 1973 rockslide
2. Zhuravlevka River emerging from under the rockslide
3. Ice-covered Zhuravlevka river bed
4. Shumilikha River
5. Base used for the October 21, 1975 test
6. Long rockslide released by this test
7. Approximate location of the 21 October 1975 test epicenters
8. Clouds

Photo: CIA/USGS

older features.

Nearby this base, Quick Bird and IKONOS images show that the rock-tailing piles seen on the 1976 KH-9 photo have since been leveled down. This is a clear indication that the base had been used for drilling adits eastward into the mountain, in preparation for underground nuclear test of 21 October 1975. Unfortunately, the 14 October 1970 testing area is not covered by the selected parts of the Quick Bird and IKONOS images available for this study.

On the CORONA images of the inner part of the Shumilikha River taken in late May 1970, several tracks in the snow-covered terrain lead to a location of what appears to be a small cluster of tiny buildings on the western side of the Shumilikha Valley, just south of a small rounded hilltop in the moderately elevated landscape. These CORONA photographs were taken five months before the October 14, 1970 underground nuclear test. The transportation activities revealed on the photographs make it more probable that this small base was used for preparing this test. However, due to the lack of high-resolution satellite imagery covering this base, it has not been possible to study the surface effects caused by this test, or their locations.

The geographical coordinates of this base are: 73.309º N, 55.917º E. Measurements were made on a geo-corrected CORONA photo.

The seismic epicenters

In the 1992 NUPI study of Novaya Zemlya it was not possible to make connections between the seismic location of epicenters and the two craters easily seen on Landsat and SPOT images.

As described in detail, the location of the detonations of September 12, 1973, is now fairly well known. According to the best estimates, the uncertainty with respect to

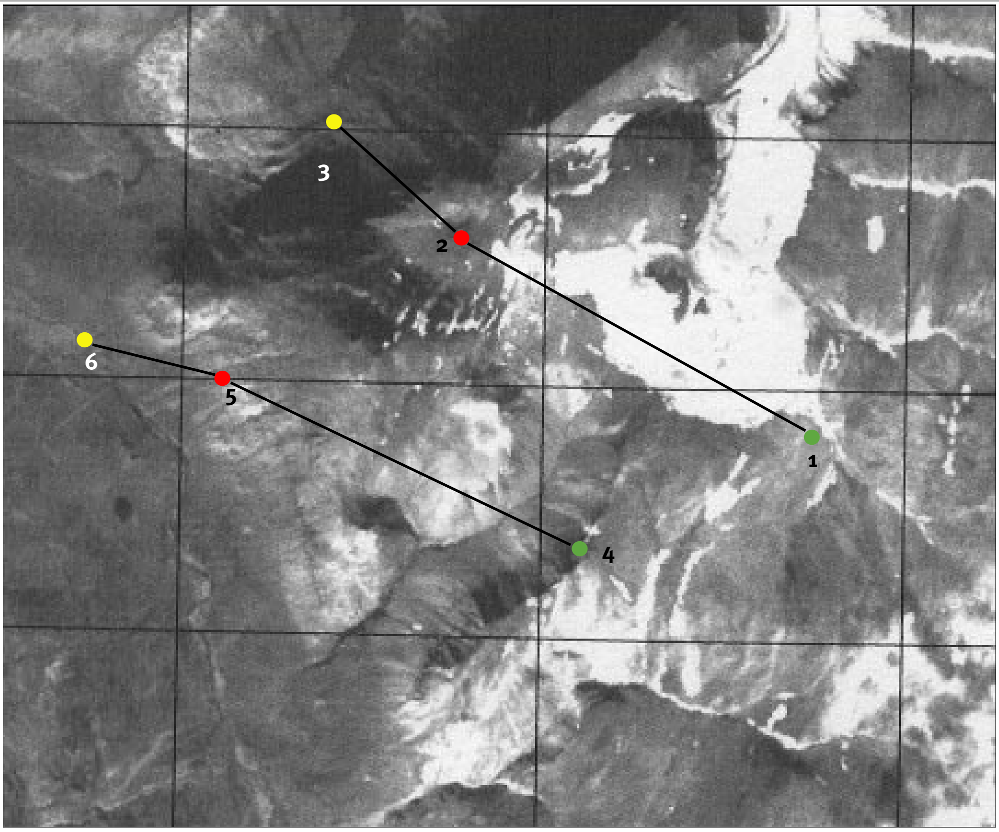

Fig. 27. Epicentre locations

Location of the seismic and the true epicenters of the 12 September 1973 and the 21 October 1975 tests, and adit entrances.

1. Seismic epicenter, 12 September 1973 test
2. True epicenter location, 12 September 1973 test
3. Adit entrance, 12 September 1973 test
4. Seismic epicenter, 21 October 1975 test
5. True location, 21 October 1975 test
6. Adit entrance, 21 October 1975 test

Figure: Johnny Skorve, NUPI

epicenter locations is described as the ellipse that can be placed around an epicenter. The size of the ellipse is a measure of the uncertainty: the larger it is, the greater is the uncertainty. The uncertainty is defined with respect to one reference, a well defined and centrally located nuclear underground explosion in the northern test site on Novaya Zemlya, the 29 (September,1976 test; restrained.

The area of the 12 September 1973 ellipse is 1.4 km², corresponding to a mean radius vector of 670 m. However, the distance from the seismic joint epicenter to the real one, very close to the center of the largest crater, is 3100 m. The azimuth of the seismic epicenter, observed from the true one, is 119º.

The same type of measurement has been carried out for the underground test of 21 October 1975. Here the azimuth angle of the seismic epicenter observed from the true one is 111º, and the intervening distance is 2900 m *(Fig. 19).*

It is interesting to note that for these two tests, the azimuths differ by only 8º, and the distances between true and seismic epicenter are nearly the identical.

The considerable distances between the true and seismic epicenters show why, in the NUPI 1992 study of Novaya Zemlya, it was deemed unreasonable to connect these seismic epicenters to the two large craters near the lower part of the Zhuravlevka Valley, given the small sizes of their uncertainty ellipses. This lack of relation was noted in the 1992 NUPI Novaya Zemlya Report (Skorve & Skogan, 1992: 33).

Some consequences of the catastrophic rockslide

SPOT and Landsat TM images from the late 1980s revealed that the nuclear test of September 12, 1973 was not the only one in the Zhuravlevka Valley. Three more underground tests had been planned for the northern slope of the valley, on the side opposite to where the rockslide took place. However, because the rockslide filled the entire southern part of the valley, these plans had to be altered. The road from the main Severny base at the Matochkin Shar Strait, running southeastward in the Shumilikha Valley, could not be continued as planned into the Zhuravlevka Valley. The new road had to make a turn northward and climb up onto the far edge of the rockslide (7 on Fig 8). From here the road continued nearly horizontally, at an elevation of about 70 m, above sea level according to topographical maps of the area, all the way along the rockslide rim to the northwestern end of Lake ***Nalivnoye***. The road then heads further eastward, above and parallel to shore of the lake, and ends after reaching two thirds of the length of the lake.

Here we find the southernmost of three bases for drilling adits into the 500 to 600m high mountain on the far side the Zhuravlevka Valley **(** A,B and C on Fig 30). The two other bases are also in close proximity to the road. The first of them is near to the northwestern end of the lake, while the other is halfway down the northern shoreline. The northeastern-most base (A) is seen in details on Figure 4. All three bases have adits that have been drilled nearly perpendicular into the mountain crest. The underground nuclear tests have resulted in several surface and terrain disturbances, of which only the largest one will be mentioned here. On the other side of the mountain crest, north of the Zhuralevka Valley, in the neighboring valley, detonations set off a wide and very long rockslide that was even larger than the one from October 1975 (described in ch. 23 above). The front of this rockslide stopped very close to a road coming from Severny, through the Shumilikha Valley and leading up to another base for underground nuclear testing. This high-altitude base can be seen in two pictures in this publication *(Figs. 20 and 21)*.

Fig. 28. Testing base by the shore of Lake Nalivnoye
Easternmost of the 3 nuclear testing bases on northern shore of Lake Nalivnoye in the Zhuralevka Valley, situated north of the large base constructed for the 12 September 1973 test. The 68 m long rusty structure in the right-middle part of the picture is an iron shelter protecting the adit opening. Through its lower end, rocks from mining the adit are transported out and deposited as tailing piles on the tongue of land to the lower right. The base has several semi-cylindrical buildings between 9 and 30 m long. Above the hill (upper part of photo) is a rather steep slope. The many small bright spots are rocks that have slid or rolled down. To the upper right, the dark lines and curves are stonewalls built to protect the base from rockfalls. To the left is a rectangular stone fence sheltering a building.

1. Stone fence and walls
2. Semi-cylindrical buildings
3. Iron shelter covering adit entrance
4. Rock deposits/tailing pile
5. Dry brooklet
6. Water outlet
7. Lake Nalivnoye

The location of this base is marked as A on Fig. 15

Image: Digital Globe

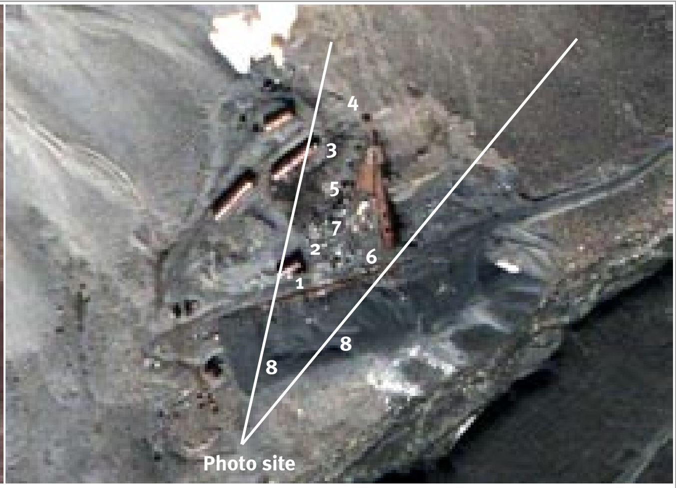

Fig. 29. Mountain testing base
This ground-based photograph and the Quick Bird satellite picture (Fig. 30) show the same area and are thus complementary, jointly providing more complete information about the base.

1. Small building
2. Portion of a semi-cylindrical building
3. Corner of a building
4. Rectangular structure
5. Iron shelter covering adit entrance into the mountain slope
6. Outer end of adit shelter
7. Storage site for mining waste and damaged equipment
8. Leveled mining rocks

Fig. 30. Mountain testing base from 450 km altitude
Quick Bird image of a typical Novaya Zemlya base for drilling adits to make underground nuclear tests. The base is located 3.5 km north of the base for the 12 September 1973 test and close to the northern shoreline of Lake Nalivnoye.

This high-altitude base has various semi-cylindrical buildings, the longest 30 m and the shortest 9m in length. The adit opening into the mountain is curved and protected by a large iron structure about 65m long and 7 m wide, and is connected to a tilting fan-shaped wing that measures 14x30 m. Rock masses transported out from the adit have been leveled in front of the base and measure 185x230 m.
During the study it became clear that a ground-based photograph had previously been taken of this base (Fig. 22). The numbers on these two pictures are the same as they mark identical objects and features seen on both pictures

Photo: Digital Globe

Summary

The aim of the research underlying this new NUPI publication was to gain better and more complete knowledge of the very powerful underground nuclear testing that took place in the Novaya Zemlya northern test site during the first half of the 1970s. Since the late 1990s, valuable information has been made available from various sources in Russia and elsewhere.

The key factor in this study was to blend the new information with the interpretation and analysis of satellite imagery of the nuclear test site.

Most of the satellite pictures used in the 1992 NUPI study report were taken by Landsat and SPOT satellites during the second half of the 1980s. These were medium-resolution images.

By 2004–2005 a wide range of satellite images had been made available, many of them with high resolution – generally, the ground resolution is between 0,6 and 2 m. Moreover, as the time of imaging covers a long period (from 1965 to 2002), many different phases of development and events have been captured.

Systematic comparison of multi-temporal images made it possible to reveal important events. The most dramatic one was the burial in September 1973 of the second largest

Fig. 31.Flood-damaged road
Main road between coastal base Severny 6 km. further to the left, and southern part of Novaya Zemlya test site. This Quick Bird satellite picture shows that more than 100 m of the road have been washed away by a flooding river coming from the right. Clearly downstream of the road, the flooded terrain is about 400 m wide. Before reaching this flat valley bottom, the mountain river flows down a narrow side valley that has been eroded into a deep canyon 2 km beyond to the right side of the picture.
This picture covers 800 x 1100 m.

Photo: Digital Globe

base on Novaya Zemlya Test Site under a truly massive rockslide (80 mill.m^3) that was released by the most powerful underground test ever conducted.

The satellite images contain also further information which we have not been able to exploit fully in this study. For example, the side of the Zhuralevka Valley from which the rockslide was released has not yet been properly measured and mapped. It will be possible to do so by photogrammetic means, combining the pre-rockslide stereo photos taken by a KH-7 satellite in 1967, with recent, post-rockslide stereo image sets that could be taken by Quick Bird or some other US commercial high-resolution satellites.

In recent years, considerable amounts of new information about former Soviet Union nuclear testing have been released, as documented by Khalturin et al. (2005). However, in the view of the present author, more in-depth information on the effects of the powerful underground nuclear explosions on Novaya Zemlya is still missing.

As Novaya Zemlya is today Russia's only underground nuclear test site, national security consideration set limits as to what may be deemed 'open information'. Even so, more information could be made available, without endangering security. After all, irrespective of what caused their release, truly large rockslides are of considerable interest for geotechnical science.

The catastrophic rockslide of September 12, 1973 is one of the largest in recent times. The documentation is unique, since it was filmed and photographed by helicopter from the very beginning. Additionally, it was closely observed from other vantage-points.

Another very interesting case is the long rockslide that was released by the 21 October 1975 underground nuclear test on Novaya Zemlya. This rockslide completely blocked the Shumilikha River, and large volumes of pounding water steadily rose behind the rock masses. Water runoff in the river is low at that time of the year, so it took longer for the build-up of the pounding water masses to break the barrier, compared to what would happened earlier in the summer season. This created a most interesting hydrological situation, raising several questions:

- Exactly how long did it take from the rockslide until the rock barrier was broken?
- What was the level of pounding water when it broke through the barrier?
- When the flood-wave moved downstream, to what degree were the banks of the river inundated, and what damage did this cause?

Most probably the documentation and observations of this test and the resulting rockslide were at least as good as they were for the incident that took place on September 12, 1973.

These are two examples of studies that could be undertaken as totally civilian research of phenomena caused by defense-related experiments.

Acknowledgements

The author wishes to thank NUPI for publishing this report and all those who provided information, recommendations and technical support during this study.

John Kristen Skogan, my colleague at NUPI and co-author of the first Novaya Zemlya 1992 report, has made valuable contributions through his critical evaluation and suggestions for improving this report.

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Drs. Frode Ringdal and Svein Mykkeltveit of NORSAR (Norwegian Seismic Array) provided the epicenter coordinates for the Novaya Zemlya nuclear underground tests. They also discussed with me topics related to seismology and underground testing.

Years of contact and co-working with Dr. Paul Richards of Columbia University, New York, have given me a better understanding of the seismology of Novaya Zemlya, based on his long-term study of this area. Recently he and US and Russian colleagues have jointly presented much new information on nuclear testing on Novaya Zemlya (see Khalturin et al.).

My thanks to Dr. John Baarli of the Department of Physics, University of Oslo, for giving me his approach to nuclear testing. Jointly with his Russian colleague V. N. Mikhailov, he has issued a report on the ecological security of underground nuclear tests (Mikhailov and Baarli 1992).

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Johnny Skorve

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