Volc. Seis., 1999, Vol. 20, pp. 525-537
Reprints available directly from the publisher
Photocopying permitted by license only

Published by license under
the Gordon and Breach Science
Publishers imprint
Printed in Malaysia

Local and Near Earthquakes in Greater Sochi Area, Russian Black-Sea Coast

V. Yu. BURMIN
United Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, 123810 Russia

(Received July 21, 1997)

This paper presents the results of seismological observations carried out in the greater Sochi area using a network of self-contained seismic stations to record low-magnitude seismicity during the period November 1995 to February 1996. The magnitude-frequency relations for two magnitude ranges, -1.0 to 1.0 and 2.5 to 5.5, are compared. The resulting plots for these two ranges turned out to be almost identical.

INTRODUCTION

The maximum seismicity in the Caucasus takes place in southern Georgia and Armenia where a belt of intensity-VIII earthquakes extends from Tbilisi across the Akhalkalak volcanic upland toward the southeast along all of southern Armenia, as well as in the Shemakha area, where shaking as strong as intensity IX was recorded in a restricted area.

The northwestern Caucasus was considered as a more quiet region. No damaging earthquakes are known to have occurred there with the exception of some rare shocks of intensity VII. The recent increase of seismicity in the northwestern Caucasus called for seismograph observations. The southern slope of the northwestern Caucasus had been repeatedly struck by past earthquakes. However, no seismographic observations had ever been conducted there; the knowledge of earthquake geography had been gathered from studies of microseisms.

A team of seismologists from the Institute of Seismology, United Institute of Physics of the Earth, Russian Academy of Sciences (UIPE RAS), conducted experiments to record local earthquakes in the Greater Sochi area during a period of October 1995 to February 1996. This work was supported financially by special funds allotted by the Russian Academy of Sciences for field operations.

The choice of study area was determined by several factors. First, the northern Caucasus is the only high-seismicity region that remains in European Russia after the breakup of the USSR. Secondly, the Black Sea coast is the least studied seismically compared with the other areas of the northern Caucasus. The entire coast can boast of two seismograph stations that are continually recording, one in Sochi and the other in Anapa. The Greater Sochi region was chosen because of its high population density, especially in summer vacations, this area being a well-known sea-side resort.

The work of the Team of Seismological Observations had two objectives in view. One was to determine local conditions for seismograph recording at various sites in the area, the other, to record near and local earthquakes. In both of these cases the instruments were self-contained analog seismic stations developed at UIPE RAS.

GEOLOGIC SETTING, TECTONICS AND SEISMICITY

There is extensive literature on the geology, structure, and seismicity of the region [1-8], [10-21], and [23-31]. According to V. A. Rastvorova [24], the geological complexity of region is specified by the fact that it is adjacent to a boundary between two sharply different tectonic zones. The northern zone belongs to the flysch zone of the southern slope of the Greater Caucasus; the southern zone is the western part of the Abkhazian facies zones of the Rioni Platform. The main difference between the two zones consists in their different mobilities during Mesozoic time. The flysch zone had much greater downward movements, the folding being intensive and complicated with numerous thrust faults. Downward movements at the margins of the Rioni Platform were less intensive, the fold forms are simple; the few available faults are normal ones. Neotectonic uplifting that produced the present-day relief began at the end of the Oligocene. The arch-type uplift of the Greater Caucasus started since that time. This process was accompanied by subsidence of the Black Sea Basin, which started during Mesozoic time.

The arching of the Greater Caucasus, which is been going on, was interrupted by two epochs of tectonic repose; during those periods the mountain relief produced by high tectonic activity previously underwent gradation. This resulted in a steplike structure of the Greater Caucasus. The southern slope zone, which is 45-50 km wide in the study area, has a stepwise topography. There is a high mountain step with heights of 2300 to 3200 m. Its southern edge is a sharp scarp 500-600 m high, which bounds the Achishkho and Aibgi uplands. Southward there is a medium-height mountain relief zone ranging between heights of 1000 and 1800 m. A well-expressed scarp passing along the southern slope of the Akhtsu-Dzykhra anticlinal mountain ranges separates this zone from a low-relief zone having heights of 100-600 m in the Adler-Sochi and Gudauty depressions.

There are several morphologic features suggesting that the sharp scarps that separate the steps are neotectonic or recent fault zones. Another such fault zone is probably the scarp passing along the continental slope of the Black Sea. It is 400–500 m high. The area around the scarp is devoid of recent deposits according to A. D. Arkhangelskii and N. M. Strakhov.

The area adjacent to Krasnaya Polyana seems to be a most active seismic zone; it lies at the boundary between the Greater Caucasus Range, higher in the north, and a depression on the southern slope, in the Krasnaya Polyana area.

The Mzymta River basin, higher of its tributary Achipse, occurs in a zone of longitudinal valleys on the southern slope. The Mzymta geologic sequence begins with Lower Jurassic deposits overlying various older rocks. The oldest rocks of the basin are Precambrian granite-gneiss, gneiss, and orthoschist. In the northwest, where the Archipse flows into the Mzymta, a Lower Jurassic schist suite marks a boundary between the northern and southern slopes of the Greater Caucasus Range.

Geologists estimate the sediment thickness in the Krasnaya Polyana area as 2–3 km. However, in the Adler area (a mere 35 km away along a straight line) the thickness is as great as 7–8 km.

Structurally, the Mzymta rocks are deformed to parallel folds with a set of parallel thrusts on the southern slope of the Greater Caucasus Range.

Apart from these fold structures, the Mzymta basin contains transverse troughs and uplifts and the related major transverse faults connected with longitudinal thrusts. This tectonic cluster occurs near the junction of the schist sequences of the northern and southern slopes of the Greater Caucasus Range west of the area where the Achipse flows to the Mzymta River. A transverse trough in the north seems to be bounded by the thrust of the southern slope in the north; in the south it extends as far as the Adler depression which is definitely of tectonic origin.

The intersection of the thrust and the transverse fault which bounds the uplifted zone is a seismic area (northeast of Krasnaya Polyana).

The northwestern part of the Caucasus, known as the Krasnodar Territory of Russia, is less active seismically compared with the other Caucasian areas. The known past earthquakes did not produce shaking above intensity VIII. The data compiled from historical sources for 120 years contain information on eight intensity VII earthquakes, 48 intensity VI–V, and 180 intensity IV–III events. One can get a fairly complete picture of the epicenter distribution in the Greater Sochi area by looking at Fig. 1 where about 140 events are plotted. Most of these were taken from the catalogs of the Regional Seismograph Network of the Georgian Soviet Republic, which ceased to be issued in 1991. Besides, the location uncertainty for epicenters is about 0.1 degrees, which is obviously not adequate for a detailed analysis of seismicity. This last circumstance can be seen in a map of the Greater Sochi (Fig. 1) showing epicenters aligned along latitude at intervals of about 10 km, which is obviously nonsense. It seems likely that the epicenters occur on tectonic faults, which certainly do not form a pattern as regular as that apparent in this map.

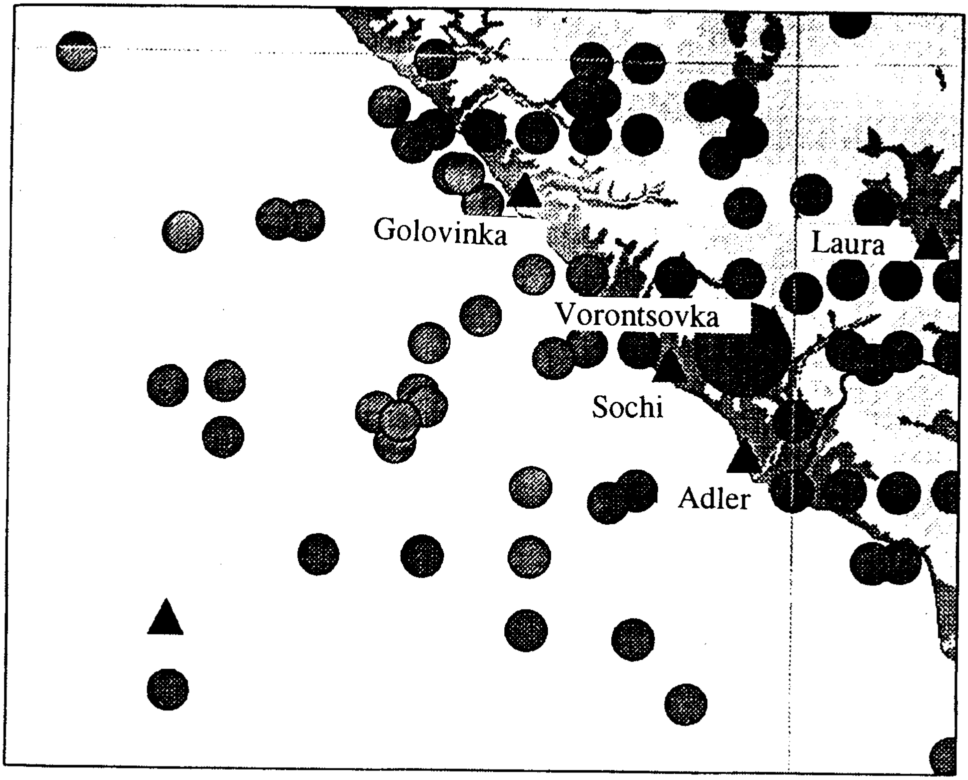

Figure 1 Map of Greater Sochi: 1 – station location; 2 – earthquake epicenters prior to 1991.

The bulk of earthquakes in western Caucasus occur along the Black Sea coast between the cities of Sochi and Anapa; they are related to a fault between the subsiding Black Sea bottom and the (relatively) rising western Caucasus. According to L. A. Vardanyants [5], there are several seismic source zones along the Caucasian Black Sea coast, including the Sochi zone. These source zones generated the following earthquakes:

(1) 1870, 1909 and 1955, all three events had about the same magnitude and epicentral intensity, occurred in the same area, and having followed one another with intervals of 39 and 46 years. The 1870 earthquake produced the strongest shaking at the village of Lesnoe (intensity VII); the highest effects of the 1909 and 1955 events were felt in Krasnaya Polyana;

(2) 1912, the highest intensity of shaking (VI) was felt in the Shakhe River area (Golovinka Village); the aftershocks continued from October 9 to November 6, 1912;

(3) 1849, 1889, and 1913, the highest intensity was recorded in Sochi City and in the neighboring Dagomys Village (V–VI);

(4) 1930–1931 around Matsesta (max. intensity V).

A permanent seismograph station was installed in Sochi in 1932. More than 100 small local shocks were recorded in the Sochi area within 50 km during 1932–1955. Large earthquakes occurred in Krasnaya Polyana in December 1955. The first shock of intensity VII was recorded at 22 h 54 min 52 s LT on December 21, 1955. This shock was followed by another at 18 h 43 min on December 27 with intensity VIII. The earthquakes damaged dwelling-houses near the Krasnaya Polyana hydroelectric power plant.

A swarm of earthquakes occurred in the Sochi area during 1969–1971. The swarm process developed very slowly, the first shocks occurring in July 1969 and the last in March 1971. The main shock of intensity 7.5 was recorded near Loo on December 4, 1970.

Some increase in the rate of near earthquakes was recorded by the Sochi station in late April 1993. An intensity 3.5 earthquake was felt in Sochi on May 2, 1993.

Apart from the earthquakes generated by the local and the Krasnaya Polyana source area, Sochi felt shaking of intensity IV–V due to the Black Sea sources and of III–IV from earthquakes that occurred in the trans-Caucasian region.

A peculiarity of the Greater Sochi earthquakes consists in the fact that they are followed by few aftershocks. This suggests that the stress buildup in the Greater Sochi area is released by large earthquakes rapidly throughout the entire rock volume involved. An example is provided by the intensity IV earthquake which occurred in Krasnaya Polyana at 2 h 28 min on September 12, 1956, and was not followed by aftershocks.

INSTRUMENTAL OBSERVATIONS

The field seismological observations in the Greater Sochi area were conducted using self-contained seismic stations (SCSS) developed at the UIPE RAS. A station consists of a unit of seismic sensors (seismographs) and a recorder which records seismic signals in analog form on magnetic tape. The station can be operated in self-contained mode during 25.5 days.

The unit of seismic sensors is based on SM-3 seismographs and is an orthogonal system that is symmetrical about the vertical axis and can be set in the vertical plane by remote control. This last circumstance permits installation of sensors in barely accessible locations of rough topography.

The replay instrumentation consists of replay stations and a 12-bit 16-channel analog-to-digital converter plate connected to an AT personal computer.

Five seismic stations were first installed to record local seismicity. The siting was generally determined by four main factors. The first and foremost of these was the requirement that the network geometry should be optimal. The second factor, which is not less important, was that microseisms at a site should be as low as possible, the third was to prevent the stations from being meddled with, the fourth was the presence of passable roads, and the fifth (not obligatory in our case) was the presence of power supply.

Our siting was mainly governed by considerations of passable roads and the preservation from unauthorized meddling, so that the recording conditions as to the network geometry and microseism amplitude were not always favorable. The SCSS sites are shown in Fig. 1.

The Sochi station was installed in the Khosta district of Sochi, on Mt. Bytkha composed of Upper Paleogene alternating sandstones and mudstones. The bedrock is overlain there by Quaternary rubble-clay eluvial-diluvial sediments whose thickness does not exceed 1 m (the station stood on bedrock). There is seasonal temporary perched groundwater.

The Golovinka station was located in Golovinka Village at the absolute height above sea level of about 15 m, on the left bank of the Shakhe River within the first terrace above the flood plain some 1.5 km from the mouth of the river. The terrace is composed of Upper Quaternary sand-gravel-pebble deposits containing boulders (15-20%). The rocks are mostly of sedimentary, effusive, and metamorphic origin. The terrace was supposed to be 5-7 m thick. The bedrock is Lower Paleogene clastic flysch consisting of alternating mudstones, sandstones, and siltstones. The groundwater is at 2-2.5 m depth from the ground surface and is mostly replenished from the water under the Shakhe riverbed.

The Vorontsovka station was installed in a tourist camp area at the absolute height above sea level of about 400 m, on the gentle right bank of the upper Kudepsta River in an immediate vicinity of the Upper Cretaceous Vorontsovka cave system. The site is composed of Lower Paleogene clastic subflysch consisting of alternating sandstones, siltstones, and marls. The bedrock is overlain by Quaternary diluvial-proluvial rubble-clay sediments and by man-made ground at the site itself. The Quaternary deposits have a total thickness of 4-5 m. Groundwater sporadically appears at 2-3 m depths or deeper. It is mostly replenished by karst water.

The Laura station was located at the Laura border of the Caucasus State Biosphere Park some 3 km above the mouth of the Achipse River (Mzymta river basin). The absolute height above sea level was about 580 m. The site was on the right bank of the river within its first terrace above the flood plain composed of Upper Quaternary sand-gravel-pebble deposits containing boulders (max. 30%) that consist of various rocks dominated by metamorphic ones. The terrace is supposedly 4-5 m thick. The bedrock is a Jurassic volcanogenic-sedimentary sequence. The groundwater is at 1.5-2.5 m depths and is replenished by precipitation and by water from the Achipse River.

The Adler station was in the Adler region in the town of Sochi in the Yuzhnye Kultury collective farm, between the Mzymta and Psou rivers. The absolute height was about 5 m. The area is a marine accumulation plain of Quaternary age consisting of delta deposits of the Paleomzymta River, sand-gravel-pebble and clay soil, and occasional peat. The

Quaternary sequence is up to 50 m thick. The groundwater occurs at depths of 2-4 m and is replenished by the Mzymta River water and groundwater flowing from the coastal hills.

These stations operated during different intervals of time owing to a variety of causes. Laura was active 80 days, the respective figures being 11 for Vorontsovka, 70 for Golovinka, 80 for Sochi, and 40 for Adler.

RESULTS

Microseism (seismic noise) conditions at recording sites. Amplitude spectra of seismic noise were computed to estimate noise levels at the sites. Figure 2 shows noise spectra at Laura during nighttime (when noise was lowest) in the range 1-20 Hz. The spectra for all three components are plotted on the same log scale. The vertical axis has millimeters marked on it for convenience in estimating the recording conditions at the sites.

Laura was the most favorable site for earthquake recording. The highest microseism level was at lower frequencies, its intensity rapidly falling off with increasing frequency from 10^{-6} mm at 0.5 Hz to 10^{-7} mm at 2 Hz. Further fall-off was lower: 3×10^{-8} mm at 12 Hz and 7×10^{-9} mm at 20 Hz. The second best site as to recording conditions was Vorontsovka. The noise level was little different from that of Laura, except for the frequency range 1 to 2 Hz where noise intensity was somewhat higher. The microseism spectra at Golovinka were nearly an order of magnitude higher from 2 Hz upward compared with the preceding sites. A higher level of seismic noise was at Sochi from 1 Hz upward. The Adler noise level was still higher by a significant amount, the contributing factors being apparently the proximity of the sea and soil conditions.

To assess the cutoff energy of complete reporting for the local seismicity recorded by the SCSS network we used an amplitude nomogram given in [9] for Caucasian earthquakes. According to this nomogram (Fig. 3), an energy class 5 earthquake would produce a ground motion amplitude of 10^{-5} mm at a distance of 20 km. Taking into account the recording conditions, i.e., the highest noise level at the stations and the maximum interstation distance, 24 km, we arrived at the conclusion that the network must record all earthquakes of energy class 5 and above occurring within its range. All stations in the network must simultaneously record earthquakes of at least energy class 8-9 during the most favorable time (night), corresponding to magnitude 2.2-2.8. Earthquakes that were recorded by all stations during daytime might be of a much higher energy class.

Seismicity of the Greater Sochi from October 1995 to February 1996. In all, about 305 earthquakes were recorded during this period. Figure 4 presents histograms showing the number of events recorded by the seismic stations as a function of a difference between shear (S) and compressional (P) travel times. The time $t_S - t_P$ is a measure of a distance between the hypocenter of an earthquake and a recording station. This distance

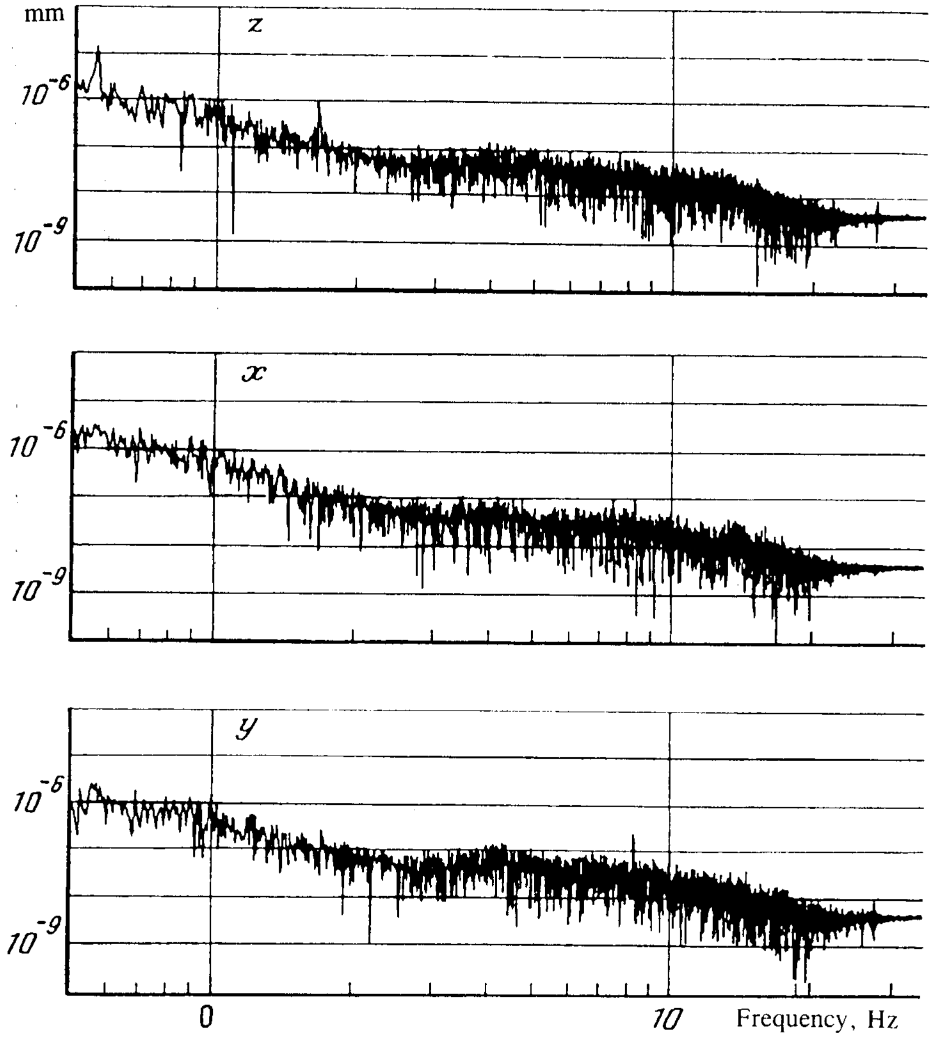

Figure 2 Amplitude spectra of noise recorded at the Laura station.

can be found by multiplying the travel time difference between S and P or the travel time of a so-called fictitious wave t_{S-P} by its velocity of propagation V_{S-P}. For near earthquakes $V_{S-P} \sim 8$ km/s. It goes without saying that, all other things being equal, the number of earthquakes recorded by a station is a function of a recording duration and conditions at the site.

The Laura station in Krasnaya Polyana recorded the greatest number of earthquakes, 113 in all. This was apparently caused by the following three factors. First, this site had the best recording conditions; secondly, the period of operation was long enough; and thirdly, the area in question had higher seismicity rate compared with the other areas of the Greater Sochi. It can be seen from Fig. 4 that most of the events recorded at the station had t_{S-P} between 5 and 15 s, corresponding to distances of 25 to 120 km.

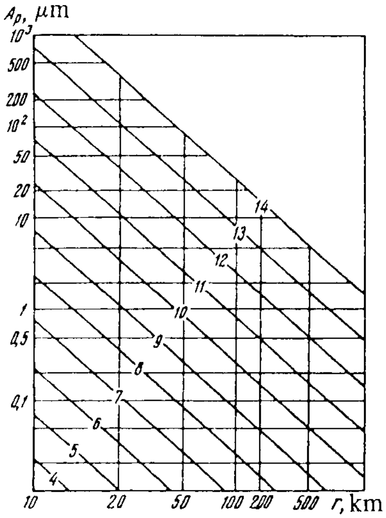

Figure 3 Amplitude nomogram of *P* waves for the Caucasus [9].

The Vorontsovka station recorded 45 earthquakes. This is fairly much, considering that the total time of its operation was 11 days only. Most of the earthquakes recorded at the station (Fig. 4) had t_{S-P} between 0 and 5.0 s, corresponding to distances between 0 and 30 km. This means that there was an active seismic source zone very close to the Vorontsovka caves, so that the caves themselves are not seismically safe.

The Golovinka station recorded 109 earthquakes during 57 days of operation. Most of the earthquakes were in the range t_{S-P} = 5–15 s (Fig. 4). It follows that the station mostly recorded small local earthquakes. It is not unlikely that some of them occurred in the sea.

The Sochi station recorded 52 events only, in spite of a long period of operation (70 days). This was largely due to the high microseism level, i.e., rather poor recording conditions. Nevertheless, the SCSS recorded events within a wide range of epicentral distances, most of them having t_{S-P} between 10 and 15 s (Fig. 4).

The Adler SCSS recorded 19 earthquakes during 43 days of operation. This low number of recorded events was because of the high level of microseisms at the site. Most earthquakes had t_{S-P} = 10–15 s (Fig. 4).

The recording conditions around the Orekhovo waterfall were much better than at the other sites. The magnification could be as high as 100 000 or greater, which considerably exceeds that available in the unified Sochi observation system, a mere 10 000.

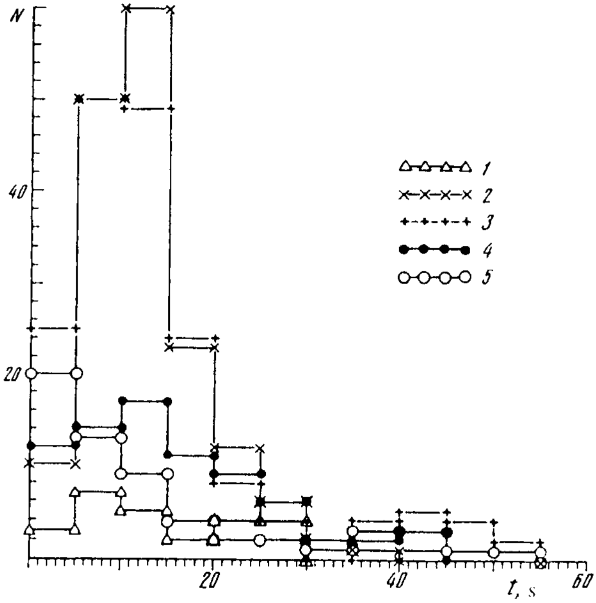

Figure 4 Histograms showing the number of recorded earthquakes as a function of *S–P* travel time differences at SCSS: *1* - Adler; *2* - Golovinka; *3* - Laura; *4* - Sochi; *5* - Vorontsovka.

Recurrence curve for the Greater Sochi seismicity. The straight-line Gutenberg-Richter frequency-magnitude relation for energy class is [22]

$$\log N_j = \log A - \gamma \Delta \mathrm{K}_j, \quad j = r, r+1, \ldots, r+n,$$

where N_j is the mean number of earthquakes with energy in the range $\{10^{\mathrm{K_0}+\Delta\mathrm{K}(j-1/2)}, 10^{\mathrm{K_0}+\Delta\mathrm{K}(j+1/2)}\}$ Joules, normalized for a unit time interval (1 year) and area S = 1000 km^2; ΔK is the spacing between consecutive values of earthquake energy class K_0; A, γ are the parameters of recurrence ($\gamma > 0$); K_0 is a given central energy class regarded as the origin. We used $\mathrm{K}_0 = 5$ and $\Delta\mathrm{K} = 1$.

Because the SCSS operation time was not long, the yearly rate of earthquakes for a station could be found from the number of days in one year divided by the number of operation days.

The normalization for unit area was done by, first, finding the radius R_p within which earthquakes of the energy class of interest had been recorded based on the actual instrument magnification and then dividing 1000 km^2 by $\pi R_p{}^2$, i.e., by the area of the relevant circle.

Figure 5 presents a frequency-magnitude relation based on the normalized SCSS data plus data from [16]. The data points were fitted by a straight line as shown in this figure:

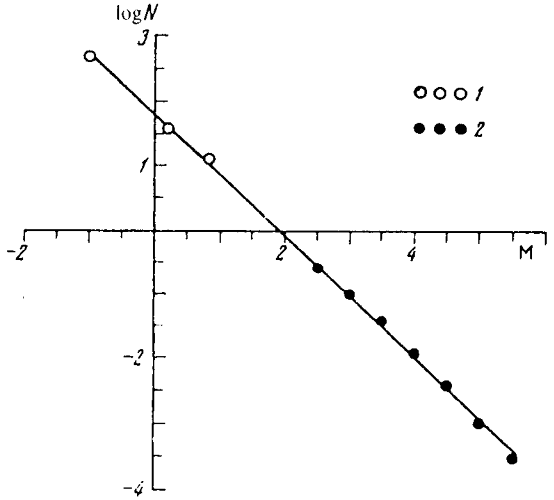

Figure 5 Frequency-magnitude relation for the Greater Sochi seismicity: *1* – data points obtained from SCSS observations; *2* – data points from [16].

log N = 1.82–0.95 M. Energy class K was converted to magnitude M using the relation M = 0.63K−2.83 [16]. The lowest completely reported magnitude for the SCSS network was −1. It should be noted that the slope of the recurrence curve for earthquakes recorded within 75 km was estimated in [16] as 0.92±0.25, which is very close to the value based on the combined data from [16] and the SCSS observations.

CONCLUSIONS

A review of the literature on the seismicity of the northwestern Caucasus shows that this region is prone to earthquake hazard and that, very obviously, continuous seismological observations are needed there. The three short seismological experiments carried out in the Sochi area during the entire period of instrumental observations are clearly inadequate for the study of earthquake generation patterns and a detailed seismic zonation of the area. The regional Caucasian earthquake catalog cannot well be used for the Greater Sochi area for purposes of detailed seismicity analysis because of the large location uncertainty (0.1 degrees).

The observations conducted in the Greater Sochi area by the Seismological Team, UIPE RAS, from October 1995 to February 1996 revealed high seismicity in the area. Although the seismicity consisted of small earthquakes (K ≤ 6) during the period of observation, the rate was high enough (305 events for 105 days of continuous observation), and most of this seismicity occurred in the Greater Sochi. It is a well-known fact in seismological practice that such areas can generate large enough and damaging enough earthquakes. Examples include the 1955 Krasnaya Polyana and the 1995 Neftegorsk earthquakes.

Preparedness for such events calls for continuous seismological observations using a local seismograph network. A telemetric network seems to be more suitable for such observations, because it allows a real-time location of events recorded by the network. Such a local network can be used to identify possible sites of future earthquakes and to study possible seismicity precursors of the earthquakes in order to predict them.

Apart from the damaging effects of large earthquakes, one has to consider shaking of structures due to long-continued exposure to the ground motion caused by large distant and small near earthquakes, which can destroy structures and cause landsliding. A local network is useful for quantitative assessment of seismic excitation due to distant and near earthquakes and for correcting the seismic zonation map of the Greater Sochi.

I wish to thank V. I. Ulomov who took the initiative to conduct seismological observations in the Greater Sochi area.

REFERENCES

1. I. V. Ananyin, in: *Voprosy seismicheskogo raionirovaniya territorii Severnogo Kavkaza* (Problems in the Seismic Zonation of the Northern Caucasus)(Moscow: IFZ AN SSSR, 1963).
2. I. V. Ananyin, *Seismichnost Severnogo Kavkaza* (Seismicity of the Northern Caucasus) (Moscow: Nauka, 1977).
3. *Atlas zemletryasenii SSSR. Rezultaty nablyudenii seti seismicheskikh stantsii SSSR 1911-1957 gg.* (Atlas of USSR Earthquakes. Results from Observations by the USSR Seismic Network in 1911-1957)(Moscow: Izd-vo AN SSSR, 1962).
4. E. I. Byus, *Seismicheskie usloviya Zakavkaziya* (Seismic Conditions of the Trans-Caucasian Region). Part 2 (Tbilisi: Izd-vo AN GruzSSR, 1952).
5. L. A. Vardanyants, *Seismotektonika Kavkaza* (Seismotectonics of the Caucasus). Tr. Seismol. In-ta **64** (1935).
6. N. A. Vvedenskaya and V. A. Rastvorova, *Verkhnyaya Mantiya* N13: 6–19 (1974).
7. G. P. Gorshkov, *Regionalnaya seismotektonika territorii yuga SSSR. Alpiiskii poyas* (Regional Seismotectonics of the Southern USSR. The Alpine Belt)(Moscow: Nauka, 1984).
8. Sh. A. Dzhabua, A. Z. Kats, A. N. Safaryan, *et al.*, *Byul. Soveta po Seismologii* N5: 3–34 (1958).
9. E. A. Dzhibladze, L. K. Darakhvelidze, and Ts. A. Tabutsadze, in: *Magnituda i energeticheskaya klassifikatsiya zemletryasenii* (Magnitude and Energy Classification of Earthquakes). Vol. 2 (Moscow: 1974): 125-132.
10. N. V. Didenko, *Blagoustroistvo Vorontsovskoi peshchery Sochinskogo gosudarstvennogo natsionalnogo parka. Otchet ob inzhenerno-geologicheskikh izyskaniyakh* (Improvement of the

Vorontsovo Cave in the Sochi State National Park. Report on Engineering-Geological Work) (Sochi: Fondy Sochinskogo Otdela Geograficheskogo Obshchestva RAN, 1989).

11. A. V. Dobrychenko, M. P. Zaraiskii, N. V. Vandysheva, and N. V. Shebalin, in: *Zemletryaseniya v SSSR v 1971 g.* (Earthquakes in the USSR for the Year 1971)(Moscow: Nauka, 1975): 36–45.
12. *Katalog zemletryasenii na territorii SSSR. Kavkaz i Srednyaya Aziya* (Earthquake Catalog for the USSR. Caucasus and Soviet Central Asia). Tr. Seismol. In-ta **3**, N95 (1941).
13. A. Z. Kats, *Byul. Soveta po Seismologii* N5: 35–54 (1958).
14. A. Z. Kats, *Tr. IFZ AN SSSR* N10: 27–31 (1960).
15. A. Z. Kats and D. N. Rustanovich, in: *Zemletryaseniya v SSSR* (Earthquakes in the USSR) (Moscow: Nauka, 1961): 235–239.
16. A. I. Lutikov and E. V. Chebkasova, in: *Materialy po seismicheskomu raionirovaniyu Severo-Zapadnogo Kavkaza* (Materials for Seismic Zonation of Northwestern Caucasus)(Moscow: Nauka, 1991): 81–98.
17. E. E. Milanovskii, *Noveishaya tektonika Kavkaza* (Neotectonics of the Caucasus)(Moscow: Nedra, 1968).
18. I. V. Mushketov and A. P. Orlov, *Katalog zemletryasenii Rossiiskoi imperii* (Catalog of Earthquakes in the Russian Empire). Zap. Rossiisk. Geogr. O-va **26** (1893).
19. S. A. Nesmeyanov, *Neostrukturnoe raionirovanie Severo-zapadnogo Kavkaza (operezhayushchie issledovaniya dlya inzhenernykh izyskanii)* (Neostructural Zonation of Northwestern Caucasus: Advance Studies for Engineering Investigations)(Moscow: Nedra, 1992).
20. A. A. Nikonov, in: *Tez. dokl. seminara "Seismicheskaya bezopasnost Severnogo Kavkaza"* (Abst. Seminar "Seismic Safety of Northern Caucasus")(Sochi: 1995): 7.
21. N. V. Kondorskaya and N. V. Shebalin, eds., *Novyi katalog silnykh zemletryasenii na territorii SSSR s drevneishikh vremen do 1975 g.* (New Catalog of Large Earthquakes in the USSR Area since Old Times to 1975)(Moscow: Nauka, 1977).
22. V. F. Pisarenko, in: *Diskretnye svoistva geofizicheskoi sredy* (Discrete Properties of the Geophysical Medium)(Moscow: Nauka, 1989): 47–69.
23. S. I. Poltavtsev, in: *Tez. dokl. seminara "Seismicheskaya bezopasnost Severnogo Kavkaza"* (Abstr. Seminar "Seismic Safety of Northern Caucasus")(Sochi: 1995): 3-4.
24. V. A. Rastvorova, *Byul. MOIP. Otd. Geol.* **36**, N3: 32-37 (1961).
25. V. A. Rastvorova and D. N. Rustanovich, *Byul. Soveta po Seismologii* N8: 110–115 (1960).
26. V. N. Robinson, *Izv. VGRO* **51**, N73: 1079–1091 (1932).
27. D. N. Rustanovich, *Tr. IFZ AN SSSR* N10: 90–98 (1960).
28. D. N. Rustanovich, *Byul. Soveta po Seismologii* N5: 55–62 (1958).
29. *Seismologicheskii byulleten Kavkaza 1974–1986* (Seismological Bulletin of the Caucasus 1974–1986)(Tbilisi: Metsniereba, 1976–1990).
30. V. N. Strakhov, V. N. Krestnikov, A. A. Nikonov, *et al.*, in: *Tez. dokl. seminara "Seismicheskaya bezopasnost Severnogo Kavkaza"* (Abstr. Seminar "Seismic Safety of Northern Caucasus")(Sochi: 1995): 5-6.
31. A. N. Shardanov, in: *Voprosy tektoniki neftegazonosnykh oblastei* (Tectonics of Petroliferous Areas)(Moscow: Izd-vo AN SSSR, 1962): 149–156.